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Improvements in Cognitive Performance With Computerized Training in Older People With and Without Cognitive Impairment: Synergistic Effects of Skills-Focused and Cognitive-Focused Strategies

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ABSTRACT

Objectives: *Both cognitively impaired (CI) and nonimpaired (NC) older people have challenges in performing everyday tasks. Previous skills training efforts in NC individuals have led to improvements in both functional skills and cognitive functioning. We evaluated the cognitive benefits of combining computerized cognitive training (CCT) with a computer-based functional skills assessment and training (CFSAT) program in a sample of CI and NC older adults.* ***Design:*** *Randomized parallel clinical trial with two treatment conditions: up to 24 sessions of CFSAT training alone or CFSAT plus speed focused CCT.* ***Participants:*** *NC (n = 62) and CI (n = 55) older adults, ranging in age from 60−86 years (M = 73.12), primarily female (90%), and ethnically diverse (21% Hispanic, 52% African American). Participants were divided based on Montreal Cognitive Assessment scores and cognitive complaints.* ***Setting:*** *Three different community centers in Miami, FL.* ***Measurements:*** *The Brief Assessment of Cognition, app version, was used to measure cognitive performance across six different cognitive domains before and after training.* ***Results:*** *All six cognitive domains improved from baseline. Multivariate analyses found the effects of the combined CFSAT and CCT to be superior. The interaction of training condition and cognitive status was not statistically significant, indicating no global impact of cognitive status on improvements in cognition across*

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training conditions. ***Conclusions:*** *CFSAT training was associated with cognitive benefits, particularly in CI participants. The combined intervention led to greater improvements. Consistent with results of previous studies, there is considerable evidence of cognitive plasticity in older adults, including those with CI.* (Am J Geriatr Psychiatry 2021; ■■:■■−■■)

Highlights

- **What is the primary question addressed by this study?—**This study addressed the question of whether computerized functional skills training improved cognition in older people with normal cognition or cognitive impairments.
- **What is the main finding of this study?—**Computerized functional skills training alone was associated with improvements in four of six cognitive domains assessed in participants with cognitive impairments. Overall, combined computerized cognitive and functional skills training led to greater improvements in all six domains of cognition across the two participant groups.
- **What is the meaning of the finding?—**These data suggest that both older people with cognitive impairments and normal cognition show evidence of plasticity in their cognitive functioning and that combining functional skills and cognitive training leads to wide-ranging cognitive improvements.

OBJECTIVES

With a predicted increase in the prevalence of Alzheimer's Disease (AD) of 75% in the next 25 years, aging-related cognitive challenges are a global concern.[1] Mild Cognitive Impairment (MCI) is defined by cognitive functioning between normal and dementia, reflecting a decline in performance from a previous level. Amnestic MCI (a-MCI;[2]) has been found to predict increased risk for developing AD.[3]

Although there are multi-domain forms of MCI,[4] the classic definitions of MCI excluded functional impairments.[5] However, the evidence indicates that participants with even mild MCI demonstrate impaired performance on paper and pencil tasks of everyday functional skills (e.g.,[6]). Individuals with MCI performed worse than nonimpaired (NC) older adults but outperformed those with AD.[7−8] Research has found similar effects with computer-based functional assessments, wherein younger participants outperformed older participants and functional performance was correlated with cognition in both groups.[9] Other research found functional performance deficits in older adults with memory complaints[10] compared to same-aged participants without complaints. Our research has shown that older adults with NC and CI have initial challenges in performing simulations of technology-based tasks such ATM and internet banking, and internet shopping,[11] with greater challenges in CI. Considering the importance of technology for functioning, these challenges place older individuals at a disadvantage in terms of being able to live independently in the increasingly digital world.[12]

Despite age-related changes in cognitive and functional tasks, considerable evidence suggests that older individuals retain cognitive plasticity and can benefit from computerized cognitive training (CCT). Reviews found significant benefits of CCT in those with subjective cognitive decline[13] and with MCI.[14] A recent meta-analysis found that CCT was associated with significant improvements in processing speed, episodic memory, executive functioning, and working memory as well as overall performance.[15]

CCT has also been used to train cognition among nonimpaired aging adults. For example, the ACTIVE trial found benefits of speed training on cognition among a sample of NC participants, aged 65 and over.[16] The cognitive benefits of speed training were specific,[17] were persistent for a decade,[18] and associated with decreased risks of dementia compared to other interventions.[19] These results have been replicated in two similar large-scale studies,[20−21] leading to our choice of speed training as the CCT intervention.

Given the importance of functional skills to independent living, evidence regarding the direct benefits of CCT on real world functioning is crucial. There is minimal evidence that skills never performed previously will spontaneously appear after CCT. In the ACTIVE trial, participants showed improvements in driving performance, a pre-existing skill, after speed training.[22] However, performance improvements did not generalize to functional skills not acquired at younger ages.[23] Other studies have shown that participants with severe mental illness (SMI) who received CCT manifested cognitive gains but did not improve in everyday functioning.[24] Further, in SMI populations outcomes such as competitively obtained employment improved only with the combination of skills training and CCT.[25]

In this paper, we examine the cognitive benefits of combining computerized speed training with a previously developed computerized functional skills training (CFSAT) program in older adults. The analyses are based on a previous randomized controlled trial[26] that examined the impact of training with the CFSAT program. In that study, NC and CI older adults received CFSAT training, targeting technology-based functional skills, with half of the participants randomized to computerized speed training. The speed training was the Brain HQ Double Decision program, selected because it was derived from the speed training interventions in ACTIVE. Six domains of functioning were trained, with a composite cognitive score examined. We found that the CFSAT training led to statistically significant performance improvements in all six domains in both NC and CI participants and that performance on the composite cognitive measure also improved significantly in both training groups, with significantly larger gains with combined training.

In a finding relevant to the potential synergy of speed and skills training, participants who received combined training or CFSAT alone manifested equivalent training-related improvements on all functional skills, although combined participants received half the dose of skills training. Thus, these analyses demonstrated functional skills gains in participants with CI and NC, as well as improvement on a global index of cognition in both groups.

Since we found a small, but statistically significant, improvement in global cognitive performance in participants who received CFSAT alone, we became interested in whether there were global versus specific benefits across cognitive ability domains associated with CFSAT training. In previous studies of skills training in participants with NC, training new functional skills has been shown to lead to improvements in cognition, even in the absence of cognitive training. Chan et al.[27] found that older adults who learned how to use a computer to perform adaptive tasks manifested cognitive gains without cognitive training. Park et al.[28] showed that learning new skills through in-person training led to improved cognitive performance, with minimal differences between technological skills (digital photography and photo editing) or nontechnical skills such as quilting. Leanos et al.[29] found that learning multiple novel skills was feasible for older adults with NC and learning new skills resulted in improvements in cognitive performance. Since these studies examined individuals without cognitive impairments (MMSE/Montreal Cognitive Assessment [MOCA] >26), our study expands those findings by comparing the cognitive outcomes of skills training for both CI and NC individuals.

As the CCT intervention focused on speed training, we hypothesized that combined CCT + CFSAT training would have a greater impact on the cognitive domains of processing speed, working memory, and motor speed compared to CFSAT alone. We further hypothesized that participants, across cognitive status, who only received CFSAT training would demonstrate improvements in executive functioning, as shown in the studies cited above, because the CFSAT training involved understanding new concepts (e.g., using ticket kiosk) and solving new problems (e.g., identifying the type of ticket to purchase).

METHODS

Study Design

As described before[26] the study was conducted at three South Florida community centers: Coral Gables Adult Activity Center, Key Biscayne Community Center, and Charles Hadley Community Center.

Following eligibility and baseline assessments, participants were randomized to CFSAT alone or combined training. Randomization was stratified by cognitive status at each site. The Institutional Review Board at the University of Miami approved the study. All participants signed an informed consent form. Participants unable to comprehend the written consent form were not enrolled.

Participants

The sample consisted of English-speaking adults, aged 60 or older, living independently, who had at least 20/60 vision, could read a computer screen and use a computer keyboard and mouse. Cognitive status was assessed using the MOCA.[30] For the NC participants the MOCA cut-off was ≥26 (adjusted for education to a cut-off of 24 for participants with low education[31] and no history of memory impairments. Those in the CI group had a MOCA ≥16 and ≤23−25 and reported a subjective history of memory complaints. Participants were compensated $30.00 per assessment and $15.00 per training session.

Participant Flow

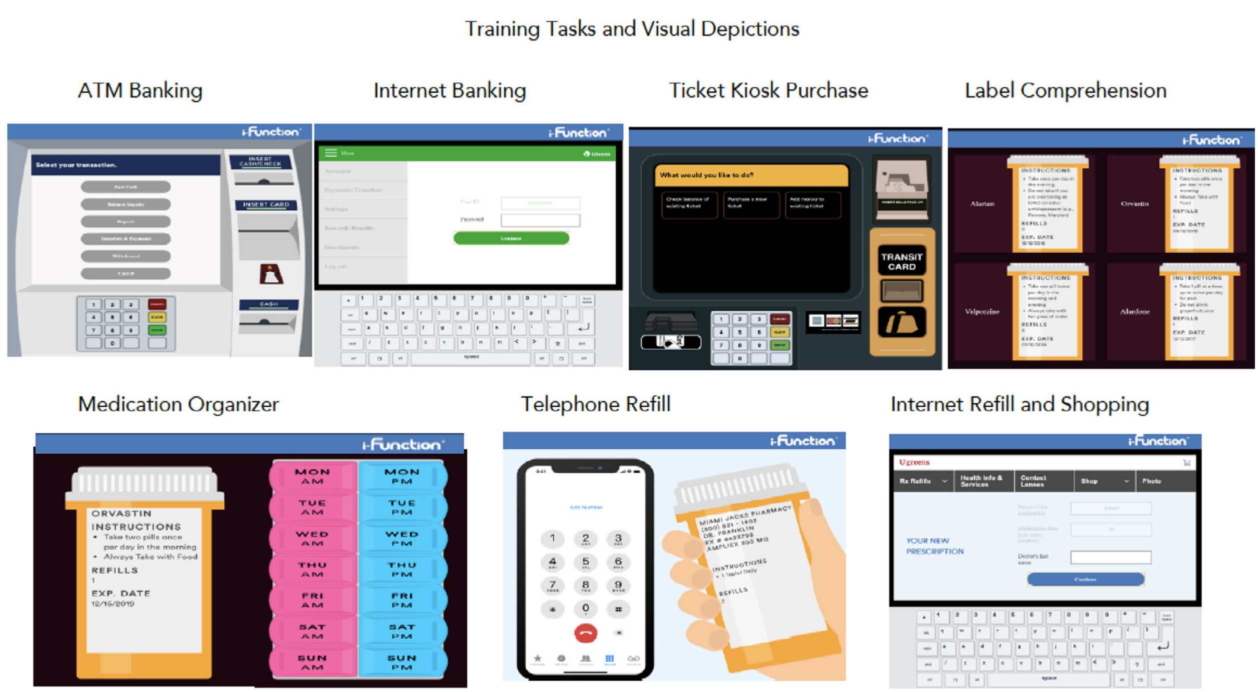
A total of 154 individuals were screened (supplemental Fig. 1). Of these, 20 were ineligible and 13 withdrew from participation before baseline assessment. A total of 121 participants were enrolled and 21 dropped out before completion (7 CFSAT participants (6%) and 14 combined participants (12%). Due to the COVID-19 pandemic, an additional 6 (3 per condition) were unable to complete training. Thus, we present complete data for 94 participants.

PROCEDURE

CFSAT Training

The tasks included in the CFSAT program included: using an ATM; using a ticket kiosk; internet banking; using a pharmacy Website for online shopping and prescription refill; using a telephone voice menu; and comprehending medication labels and organizing medications with a planner; (Fig. 1). The tasks are presented in a multimedia format with

FIGURE 1. Training tasks and visual depictions.



graphic representations, text, and voice, and each task consists of multiple subtasks with sequentially more challenging demands. The CFSAT program was delivered in a PC environment with a mouse.

The training component of CFSAT is an adaptive protocol. Immediate feedback and graduated instruction, with increasing detailed corrective information, is provided following errors, followed by repetition of the instructions for the failed item. After four consecutive errors on an item, the program automatically proceeded to the next (see[26] for details). Successful mastery of a task was defined as performing all the subtasks in a task twice consecutively without errors. Participants participated in up to 24 one-hour training sessions, unless they achieved mastery on all six tasks prior to 24 sessions at which time training ended.

Computerized Cognitive Training

The CCT procedure was Brain HQ Double Decision, derived from the Speed training intervention in ACTIVE. This is a speeded multitasking training program where participants perform two concurrent tasks: discriminating between two centrally presented items: Car versus Truck and identifying the location of a concurrently presented stimulus that differs from seven others in a semicircular array (Route 66). The training sequence presents the concurrent stimuli at successively shorter latencies following correct responses, with reductions in latency for correct discrimination of both central and peripheral stimuli as the training outcome.

COGNITIVE ASSESSMENT

Brief Assessment of Cognition: App Version

The Brief assessment of Cognition (BAC;[32,33]) measures critical domains of cognition related to everyday functioning. The BAC App[34] is a tablet (i-Pad) form of the BAC, which delivers the same assessments. The BAC-app has been normed in samples of healthy participants up to age 85 (n = 496) and acceptability and performance characteristics are well understood.[9]

All tests administered within the BAC App are completed with an in-person trained assessor. A female narrator operated by the App presents instructions and the assessor can initiate repetition of instructions. The BAC has multiple forms. We administered form 1 at baseline and form 2 at the end of training to minimize practice effects.

The cognitive domains assessed in the BAC app include:

Episodic Memory/List Learning: Subjects hear a list of 15 words to remember. Words are presented at a standard rate, eliminating the effects of rater variability. A total of five learning trials are presented.

Working Memory/Digit Sequencing: Subjects are presented with randomly ordered auditory clusters of numbers (e.g., 936), which increase in length across trials from 2 digits to 8. Participants report the numbers in order, from lowest to highest, with three trials per length. The task terminates when all trials at a specific length are failed.

Psychomotor Speed/Token Motor Task: Subjects are presented with a virtual bowl and a supply of virtual tokens and swipe a token from each side of the tablet with both hands simultaneously and release them into a center container for 60 seconds.

Verbal Fluency. Subjects are given 60 seconds to generate as many words as possible within the category "animals." During Letter Fluency, subjects are asked to generate as many words as possible beginning with the letters F and S for 60 seconds each.

Processing Speed/ Symbol Coding: Subjects match numbers to nonmeaningful symbols based on a key. Numbers are entered on the digital keypad and appear in the location below the corresponding symbol. Following instructions and practice, subjects complete as many items as possible in 90 seconds.

Executive Functioning/Tower of London: Subjects are shown two images presented on opposite sides of the screen. Each image shows a different configuration of three colored balls arranged on three pegs. The subject is required to accurately determine the total number of moves required to make the arrangement of balls identical to that of the opposing picture, while employing the standard rules employed in tower tests (balls are moved one at a time and balls on top of other balls must be moved first).

TRAINING PROCEDURES

Participants were randomized into CFSAT only or the CFSAT + CCT training conditions, stratified by cognitive status and site. Those receiving CFSAT only trained for 60 minutes per session on the CFSAT, two tasks per day, training each task twice per session, before attempting the next task. The tasks were trained in the same order as the baseline assessment. Training progress was tracked by the application so at the next session the participant would begin with the next uncompleted task. As participants progressed through training, they trained only on tasks not previously mastered. Those in the CFSAT + CCT condition trained for 30 minutes on the Brain HQ Double Decision task each session before CFSAT training for 30 minutes. Thus, participants in this condition trained only 50% of the time on the CFSAT tasks.

The scheduled training protocol was two sessions per week over a period of 12 weeks. As reported before,[26] most participants (94%) graduated or completed 24 sessions of training in 20 or fewer weeks, with 90% finishing in 16 or fewer weeks and 71% finishing in 12 weeks.

DATA ANALYSES

One of our interests was in examining if CFSAT training alone improved cognitive performance and if so in which domains and participant groups. We were also interested in examining if cognitive improvements were found in both NC and CI participants, and if so, the relative effect sizes. We first examined overall changes in the six cognitive domains with paired *t*-tests in the entire group to substantiate overall changes from baseline. We present the within-sample effect sizes for changes in each of the six domains by group and condition, thus using baseline standard deviations as the index of effect size. Next, we examined change scores from baseline to endpoint in the six cognitive domains using a Condition (CFSAT Only, Combined CFSAT + CCT) x Group (NC, CI) multivariate analysis of variance. Using a multivariate analysis of variance allowed us to examine benefits simultaneously across training conditions and all cognitive domains. This analysis also identified any individual cognitive domains that differed in treatment response. Training Condition, Cognitive Status and their interaction were entered as the primary factors. All multivariate comparisons were performed with 6 and 85 degrees of freedom and the test statistic was Wilks' lambda, with Pillais approximate F used for significance. The multivariate corrected changes across the individual tasks were also examined for statistical significance. All analyses were performed with the SPSS version 28[35] software.

RESULTS

The CONSORT diagram is presented in supplemental Figure 1, as it was previously published. The sample was primarily female (90%), aged from 60−86 years (*M* = 73.12; *SD* = 6.06), and ethnically diverse (23% Hispanic, 51% African American, 4% Asian; Supplementary Table 1). There were no differences in baseline characteristics among participants by treatment condition based on *t*-tests or X^2 analyses. The CI participants had lower baseline composite scores on the BAC App, as well as lower education and MOCA scores.

Table 1 presents the scores on the BAC app domains, by baseline cognitive status and training condition. All six domains improved significantly from baseline to endpoint for the group as a whole, all t(94) >2.04, all p <0.05. All domains except for verbal fluency had significant changes from baseline at p <0.001. Within subgroup effect sizes (calculated as described above) ranged from d = 0.01−0.54 in the CFSAT condition and from 0.18−0.85 in the combined training condition.

There was a statistically significant multivariate effect of Cognitive status, Wilks's lambda = 0.851, Pillais Approx. F (6, 85) = 2.50, p = 0.039, on changes in the six domains. There was also a statistically significant multivariate effect of Training Condition, Wilks's lambda = 0.715, Pillais Approx F (6, 85) = 5.66, p <0.001, on changes in the six domains. The multivariate interaction of Cognitive Status x Training Condition was not significant, Wilks's lambda = 0.928, Pillais Approx F (6, 85) = 1.11, p =0.365, indicating that the CI participants improved proportionately as much as the NC participants across cognitive domains and training conditions. The multivariate corrected main effect of Training Condition was significant in all six domains, all F(1,94) >4.04, all p <0.045 (Table 1). There was only one significant multivariate corrected effect of Cognitive Status, wherein the CI subgroup unexpectedly improved more on verbal learning than the NC group.

TABLE 1. Performance on Six Different Cognitive Tests at Baseline and Endpoint; Separated by Cognitive Status

	Skills Only					Combined Training					Multivariate Corrected F Test (1,94)	
	Baseline		Post Test			Baseline		Post Test			Cognitive Training	
BAC APP Domain	M	SD	M	SD	d	M	SD	M	SD	d	Status	Condition
Verbal Learning												
Normal	40.18	10.58	40.29	9.40	0.01	39.00	8.97	42.68	9.40	0.41	11.32	7.10
Impaired	26.09	7.10	30.70	9.83	0.54	25.83	7.32	33.94	9.73	0.95	p <0.001	p = 0.009
Digit Sequencing												
Normal	18.68	4.82	19.32	4.85	0.13	18.68	4.38	19.32	4.85	0.14	1.36	6.37
Impaired	12.35	4.47	14.26	4.19	0.44	13.22	3.70	16.17	3.31	0.85	p = 0.25	p = 0.013
Token Motor												
Normal	55.96	26.65	61.57	25.37	0.22	48.04	19.18	57.44	19.78	0.48	2.24	8.23
Impaired	35.83	20.26	37.57	24.32	0.08	33.67	16.06	42.89	18.30	0.54	p = 0.14	p = 0.005
Verbal Fluency												
Normal	55.54	15.67	55.96	12.92	0.03	47.92	12.82	53.04	12.67	0.40	2.05	13.69
Impaired	33.26	9.80	34.35	8.76	0.01	32.11	10.00	37.67	8.51	0.60	p = 0.16	p <0.001
Symbol Coding												
Normal	25.86	6.73	28.54	9.10	0.05	25.84	9.69	28.54	9.10	0.28	0.68	5.06
Impaired	19.43	8.88	22.78	8.60	0.39	19.39	11.29	23.83	11.32	0.39	p = 0.41	p = 0.027
Tower of London												
Normal	14.39	3.88	14.89	4.07	0.13	13.92	5.11	14.89	4.07	0.23	0.70	4.04
Impaired	9.48	5.25	11.74	4.38	0.46	9.39	5.23	12.00	5.85	0.47	p = 0.40	p = 0.045

Note: d is Cohen's effect size measure for within subgroup improvements.

CONCLUSIONS

Our findings indicated that CCT plus CFSAT training resulted in improvements in six domains of cognitive functioning among older adults with normal and impaired cognition. Four of the six domains also improved in CI group in the CFSAT condition with effect sizes larger than (Cohen's) d = 0.40, including the Tower of London (reasoning and problem solving) as hypothesized. Combined training was significantly superior to the CFSAT alone for improvements across all cognitive domains, based on overall multivariate analyses and follow-up individual domain analyses. This is not surprising as CFSAT + CCT combined training address a wide range of cognitive abilities. These findings replicate other studies cited above that have shown that CCT can improve cognition across a wide array of older populations.[16,18] Importantly, our findings also show that aging adults with cognitive impairments manifest considerable evidence of plasticity and can exhibit wide-ranging cognitive gains, in addition to improvements in functional skills. Although the CI participants performed more poorly overall, the only task on which they differed from the NC sample in training benefits was on verbal learning, where they improved more in both conditions than the NC sample. Although cognitive performance in the CI sample at endpoint was still poorer than NC participants at baseline, effect sizes for improvement across domains in the combined training condition were in the moderate to large range. This level of change exceeds expected practice effects.

There are several strengths in this study. Alternate forms were used at retest, to reduce practice effects. Previous studies of testing-related improvements suggested about 0.1−0.2 SD practice/exposure improvements at retesting of NC and CI individuals on verbal learning and processing speed assessments.[36] The improvements in this study for NC and CI individuals who received combined training, with alternative forms, were larger those practice effects. There were six domains of cognition examined, all of which correlated with performance on the six functional skills tasks in this same sample.[37] The functional skill tasks place demands on a variety of cognitive processes such as executive functioning, memory, and processing speed. Another strength of our study was that the participants were ethnically diverse (23% was Hispanic and 51% were African American) and varied in educational attainment.

Study limitations include the fact that the training groups were not balanced with respect to cognitive status because more participants in the CI group failed to complete training in the combined condition. Skills training tasks were focused on skills and not the potential cognitive abilities required to perform those skills. We also did not include a CCT alone condition; but the benefits of CCT, particularly speed training, on these cognitive domains in both impaired and unimpaired older samples have been demonstrated repeatedly. Anecdotally, some of the CI participants reported frustration with the Double Decision task. However, we do not know if these same participants would have experienced frustrations with the CFSAT alone. Finally, although our sample was diverse there were more females than males. Although this reflects the general demographics of the older population, future studies should include more males. Finally, we did not collect data on the sustainability of the cognitive improvements but are doing so in an on-going study.

Overall, these data provide additional information regarding the benefits of combining computerized cognitive training with skills training. In our prior study[26] we showed that the combined CFSAT + CCT training condition led to equivalent gains in performance on the six functional skills tasks compared to twice as much CFSAT training alone. In total, the combination of CFSAT + CCT training has now been found to be associated with improvements in performance on six different functional skills tasks as well as the six domains of cognitive performance across samples of NC and CI older adults.

These findings are like those found in studies that have combined skills training with computerized cognitive training among people SMI, finding that combined training leads to greater benefits on real-world functional outcomes compared to cognitive or skills training alone. In a study of chronic SMI patients, combining social cognitive training with computerized cognitive training led to greater gains in both social cognition and neurocognition than "monotherapy" training.[38] In another study with participants with SMI, combined cognitive and functional skills training led to the same gains in cognition and functional capacity as single domain training, but real world functioning only improved with combined training.[39] Given the minimal number of previous studies of functional skills training in cognitively impaired aging populations, our results will require replication. However, the overall results of this study suggest that combining CCT and skills training leads to wide ranging gains, even among aging individuals with cognitive impairments. This is an important finding as improvements in functional skills and cognition can enhance potential independence. Aging adults with and without CI demonstrate cognitive plasticity and can learn new things, including technology-based tasks, and improve their cognitive skills. Our upcoming study (NCT04679441) will address persistence of cognitive and functional gains and environmental transfer to activities in the real world, in participants who meet criteria for MCI based on formal assessments, compared to NC older individuals.

AUTHORS' CONTRIBUTIONS

Drs. Harvey and Czaja and Mr. Kallestrup designed the study. Dr. Tiberica and Mr. Zayas-Bayan tested research participants and organized and managed data for the study. Dr. Harvey ran the specific analyses for this paper. All of the authors have edited the paper and contributed to the final version.

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The data has not been previously presented orally or by poster at scientific meetings.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.jagp.2021.11.008.

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