



## Mindful walking and cognition in older adults: A proof of concept study using in-lab and ambulatory cognitive measures

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### ABSTRACT

Mindfulness practice and walking have been linked individually to sustain cognition in older adults. This early-phase study aimed to establish proof-of-concept by evaluating whether an intervention that integrates light-intensity walking with mindfulness practices shows promising signs of improving cognition in older adults. Participants ( $N = 25$ ,  $M_{\text{age}} = 72.4 \pm 6.45$ ) were community-dwelling older adults who engaged in a supervised mindful walking program over one month (8 sessions total, 2 sessions per week, 30-minute slow walking containing mindfulness skills). They completed performance-based and subjective ratings of cognitive measures in field before and after two mindful walking bouts using a smartphone app. They also completed in-lab performance-based and self-report cognitive measures at baseline and after the entire program. Controlling for demographics, potential covariates, and time trends, short-term improvements in perceived cognition and processing speed were observed from pre- to post-mindful walking sessions (i.e., 30 min) across multiple ambulatory cognitive measures (Cohen's  $d$ s range = 0.46–0.66). Longer-term improvements in processing speed and executive function were observed between baseline and end of the program (i.e., one month) across various performance-based cognitive measures ( $d$ s range = 0.43–1.28). No significant changes were observed for other cognitive domains. This early-phase study (Phase IIa) provides preliminary support that mindful walking activity is promising for sustaining cognition in older adults. Our promising findings form the building blocks of evidence needed to advance this intervention to a fully powered randomized controlled trial that examines program efficacy with a comparator. Favorable outcomes will inform the development of this lifestyle behavioral strategy for promoting healthy brain aging in late adulthood.

### 1. Introduction

Human aging is associated with normative alterations in cognition and increased risks for neurodegenerative disease in late life. These diseases are the most expensive US annual health expenditure and place a tremendous economic burden on society and families (Alzheimer's Association, 2020). Cognitive impairments caused by these diseases also exact a toll on the overall health, well-being, and quality of life among older adults. Preventive interventions are needed to help older adults reduce risks for these diseases and preserve functioning into late

adulthood. Two promising strategies for these purposes include physical activity and mindfulness practices (Erickson et al., 2019; Gard et al., 2014 Jan; Malinowski and Shalamanova, 2017; Sofi et al., 2011). It is viable to integrate mindfulness practice with walking as an intervention strategy (i.e., mindful walking) (Kabat-Zinn, 2017). This "active form" of mindfulness practice has been implemented as part of the standard mindfulness-based programs (i.e., Mindfulness-Based Stress Reduction program) to enhance psychological well-being (Gotink et al., 2016; Teut et al., 2013). However, mindful walking has not been used as a major strategy to study cognitive outcomes.

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Walking and mindfulness programs may individually contribute to short- (e.g., after brief practice) and longer-term (e.g., after completing the entire program) cognitive improvements in older adults, albeit variability of intervention design exists among available studies (Scherder et al., 2014; Venturelli et al., 2011; Berk et al., 2017; Chiesa et al., 2011). It is plausible that an integrated mindful walking program may likewise be associated with both short- and longer-term cognitive benefits in older adults. This early phase proof-of-concept study (Phase IIa) evaluated whether a multi-session mindful walking program provided signals consistent with short- and longer-term cognitive improvements in older adults (Czajkowski et al., 2015 Oct).

Walking is the most prevalent type of physical activity among older adults and the most preferred physical activity among cognitively-impaired older adults (Williams et al., 2008; Dai et al., 2015). Current evidence indicates that accruing physical activity at a lower and more achievable intensity (i.e., walking) improves cognitive health in both active and inactive older adults, as well as older adults with cognitive impairments (Prohaska et al., 2009; Spartano et al., 2019; Wang et al., 2012). Mindfulness practice trains individuals to elevate their attention and awareness in every present moment, and engage their present experience in a non-judgmental manner (Kabat-Zinn, 1994; Kabat-Zinn, 2012). Practicing mindfulness is appealing to older adults, as evidenced by the high compliance rates, and initial evidence suggesting that daily mindfulness practice may improve their cognitive health (Gard et al., 2014 Jan; Wong et al., 2017). Previous work suggests that short bouts of mindful-walking sessions are feasible to implement in older adults living in the community (Yang and Conroy, 2019). No study to date has evaluated whether short bouts of mindful-walking practices produce cognitive benefits in older adults.

This study applied both performance-based and subjective ratings of cognition both in the lab and at the walking site to broadly assess cognition in response to the mindful walking activity. To assess longer-term outcomes, conventional methods including performance-based neuropsychological assessments, computerized experimental assessments, and questionnaires were applied at baseline and at post mindful walking program across one month. These lab-based measures are relatively time-consuming, and they are not suitable for administration in the field (e.g., outdoor environments) to capture any acute changes experienced following walking activity (Ladouce et al., 2017). To assess short-term outcomes, this study applied recently validated, ultra-brief, ambulatory cognitive assessments on smartphones to evaluate short-term subjective and performance-based cognitive changes associated with brief 30-min mindful walking bouts (Sliwinski et al., 2018).

The purpose of this study was to establish proof-of-concept for using this mindful walking program to improve short- and longer-term cognition among community-dwelling older adults. Proof-of-concept study represents an early phase of intervention development in the Obesity-Related Behavioral Intervention Trials (ORBIT) framework. We defined the meaningful change in cognitive outcomes as 0.20 standard deviation, which is equivalent to 10 years of normative cognitive aging documented in previous reviews (Salthouse, 1996 Jul; Salthouse, 2000). Available reviews on physical activity interventions on cognition also reported small-to-moderate effect sizes (range = 0.20–0.48) among cognitively normal older adults (Erickson et al., 2019; Mj, et al., 2016). Evidence from a proof-of-concept study is not sufficient to draw conclusions about efficacy, but it is essential for determining whether this intervention warrants investment in a rigorous trial to evaluate effects in relation to a comparator (Czajkowski et al., 2015 Oct; Freedland, 2020).

## 2. Methods

### 2.1. Participants

Participants were community-dwelling older adults who participated in an 8-session slow walking program at a local arboretum. Eligible older adults were at least 65 years old, could walk without other's assistance,

could read and spoke English fluently, and without allergy to plants and flowers. A subset of older adults (N = 25, Mean age = 72.4 ± 6.45, age range = 66–89, 84% female, 84% White) opted to participate in the cognitive assessments designed in this proof-of-concept study. A more detailed description of recruitment with a CONSORT diagram is reported previously (Yang and Conroy, 2019). The primary goal of the proof-of-concept study is to “determine if a treatment package can achieve benefit on a clinically significant target in a small, select sample” (Czajkowski et al., 2015). In this context, “within-subjects designs where subjects act as their own controls in a pre-post comparison are ideal... [and] the sample can be selected from acceptable subjects, rather than representative, because this initial test will determine only whether the treatment merits more rigorous testing” (p. 977). The present sample size is comparable to proof-of-concept studies evaluating the potential benefits of behavioral and technology-based health interventions (Conroy and Heartphone, 2020; Liu-Ambrose and Eng, 2015; Månsson et al., 2013; Conroy et al., 2020).

At baseline, participants were not sufficiently active (based on the Physical Activity Guidelines for Americans) and 16% (n = 4) of them were overweight/obese. They reported no formal mindfulness training experiences, cognitive/memory complaints, or diagnosis of neuropsychological diseases. The majority of the walking sessions were completed on weekdays (n = 160, 80%) and before noon (n = 152, 76%) in October and December. Participants who completed all walking sessions and assessments were eligible to win one of nine \$25 gift cards in a raffle. All procedures followed were in accordance with the ethical standards of the responsible committee on human subject research and with the Helsinki Declaration. Written informed consent was obtained from all participants. The Institutional Review Board approved all study protocols.

### 2.2. Procedure

Participants first completed an initial lab visit and completed baseline cognitive assessments. These assessments included a computerized Stroop task, two sets of neuropsychological tests using paper-pencil format (see “Measures” below), and a survey of perceived cognition. Participants then scheduled eight sessions of outdoor mindful walking within the following month, with a maximum of scheduling two sessions per week. After completing the mindful walking sessions, participants returned to the lab for post-program cognitive assessments that were identical to the formats used in the initial lab visit.

Each walking session consisted of a 30-minute individual slow walking along a flat, designated route in an arboretum. Participants were instructed to walk at a slower pace of approximately one step per second (i.e., light-intensity activity). Walking at a slower speed helped participants elicit the state of mindfulness and elevate their awareness to the present moment experiences (Kabat-Zinn, 2017). The research staff met with participants on the walking site to provide instructions on mindfulness skills and conducted pre-and post- walking assessments. Three fundamental mindfulness skills were introduced and incorporated progressively in sequence starting from the second session to help participants build up mindful walking skills. These fundamental skills involve being attentive to the rhythm of their breathing (i.e., each inhale and exhale), being attentive to the movement of their every step, and mentally scanning the body to identify and accept sensations/feelings that arise in every present moment (Kabat-Zinn, 1994). In the last two mindful walking sessions (7th and 8th), participants practiced all three mindfulness skills in sequence throughout their 30-minute walk. Immediately before and after the 7th and 8th sessions, participants completed subjective ratings of cognition and a short battery of smartphone-based ambulatory cognitive assessments (see “Measures” below). Participants overall reported increased state mindfulness ( $p < .001$ ,  $d = 0.84$ ) using items from the State Mindfulness Scale across all mindful walking sessions (Tanay and Bernstein, 2013).

## 2.3. Measures

### 2.3.1. Demographics (lab-based)

Participants' basic demographic variables, including gender, age, race/ethnicity, socioeconomic status, and educational level, were collected by self-report surveys during the initial lab visit.

### 2.3.2. Neuropsychological tests (lab-based)

The paper-and-pencil format of Trail Making Tests (forms A and B) and Porteus Maze Tests (forms Adult-I and Adult-II) were used to assess older adults' various domains of cognition during the two lab visits before and after the entire program (Reitan, 1986; Porteus and Peters, 1947). The outcome variables in these in-lab tests include the task completion time and the number of errors. Each participant followed the instruction by trained staff to complete the tests individually during the two lab visits.

### 2.3.3. Perceived cognition (lab-based)

Four subscales were selected and slightly modified from the Everyday Cognition Scale to assess subjective ratings of cognition: everyday memory (8 items), everyday planning (5 items), everyday organization (6 items), and everyday divided attention (4 items) (Farias et al., 2008). Participants reported each question on a 6-point Likert scale ranging from 1 (almost always) to 6 (almost never). The average score in each subscale was calculated to represent the general level in the specific cognitive domain of everyday life, with a higher score indicating better cognition (Marshall et al., 2014).

### 2.3.4. Stroop task (lab-based)

Procedures for the computerized Stroop task are described in greater detail elsewhere (Kim et al., 2014). In brief, participants were instructed to, as quickly and as accurately as possible, select the response option from the bottom of the screen (color words written in white font) that matched the font color of the target stimulus presented centrally on a black background. The meaning and font color of the target stimulus either matched ("congruent") or mismatched ("incongruent") with a 50% probability across all trials. During congruent trials, the incorrect response option was selected randomly from the remaining five color word options. During incongruent trials, the incorrect response matched the orthography of the target stimulus. Participants completed 80 total trials (40 trials per condition: congruent/incongruent). Primary outcomes for the Stroop task included mean accuracy and response time during each condition.

### 2.3.5. Ambulatory cognitive tests (in field)

Three ultra-brief ambulatory cognitive tasks described in detail in Sliwinski et al. (2018) were used to assess processing speed, working memory, and executive function: Symbol Search, Dot Memory, and N-Back. These tasks were administered using a custom java-based mobile application loaded onto Samsung Galaxy S5 Android smartphones. These three cognitive tasks were performed during the 7th and 8th walking sessions where participants carried out mindful walking skills throughout the 30-minute walk, with two pre-walk tests and two post-walk tests. Outcome variables included mean response time (Symbol Search/N-Back/Dot Memory) and mean accuracy (mean of trial-level binary correct/incorrect for Symbol Search/N-Back; mean distance of dot locations between actual and recall arrays for Dot Memory).

### 2.3.6. Momentary rating of cognition (in field)

One item adapted from the PROMIS Applied Cognitive Abilities Short Form (v1.0) was used to assess perceived cognition immediately before and after the walking session (Fries et al., 2005). Participants responded to the question - "My mind is sharper than usual now" - on a 1 (Strongly Disagree) to 7 scale (Strongly Agree).

### 2.3.7. Perceived sleep quality (in field)

One item was used to assess participants' overall sleep quality in the previous night at the beginning of each walking session. Participants answer one question, "What was your overall quality of sleep last night?" on a 7-point scale ranging from 1 (*very bad*) to 7 (*very good*). This item was included to account for the impact of the previous day sleep quality on cognition on the next day (Nebes et al., 2009).

## 2.4. Data analysis

For lab-based cognitive tests, paired t-tests and within-subjects effect sizes were used to examine the preliminary magnitude of change between baseline and post-program measures. The standard  $2 \times 2$  repeated measures ANOVA was used for Stroop Task to test the main effects and the occasion by condition interaction (Bugg et al., 2008). For ambulatory cognitive assessments, the mixed-effects linear models were used to test within-person differences between their paired pre- and post-walk scores from the 7th and the 8th walking sessions. The four cognitive measures were coded (0 = pre-walks, 1 = post-walks) to test whether post-walking cognitive scores significantly differed from pre-walk scores after controlling for covariates. These models adjusted for demographics (age, sex) and time-varying temporal and contextual factors that may impact the outcomes. Temporal factors included day of the week, time of day (to adjust for diurnal influences), and number of walking session to account for any session-to-session trends associated with retest improvements that account for main sources of practice effect. Contextual factors included previous night sleep quality and mean daytime temperature. Separate models were tested for each outcome variable. Cohen's *d* was calculated using the Satterthwaite approximations to calculate the degrees of freedom to estimate the effect sizes fixed effects in each model (Valliant and Rust, 2010).

## 3. Results

All participants completed the baseline and the post-program in-lab cognitive assessments.

### 3.1. Longer-term cognitive change (in-lab)

Table 1 summarizes descriptive statistics and the paired t-test results for the laboratory-based cognitive assessments. At baseline, relatively high levels of everyday cognition on all four domains of the Everyday Cognition Scale, including Memory, Planning, Organization, and Divided Attention (mean scores  $\geq 4.83$  on a 1–6 scale). There were no differences in scores on any domain of the Everyday Cognition Scale after exposure to the mindful walking program.

Results of paired t-test revealed that mean completion times on the Trail Making Test were faster post-program compared to baseline (forms A and B,  $ps < 0.05$ ,  $ds = 0.44$  and  $0.43$ ). No change in difference scores for forms B-A was observed. Similarly, the completion time for both test forms on the Porteus Maze Test was faster post-program compared to baseline ( $ps < 0.05$ ,  $ds = 0.49$  and  $0.45$ ). No changes in error rate on the Trail Making Test and Porteus Maze Test were observed between occasions.

Results of a 2 (occasion: baseline/post-program)  $\times$  2 (condition: congruent/incongruent) repeated measures ANOVA on Stroop Task response times revealed significant main effects of measurement occasion ( $F_{(1,23)} = 9.65$ ,  $MSE = 14521.95$ ,  $p < .01$ ) and condition ( $F_{(1,23)} = 101.11$ ,  $MSE = 6365.74$ ,  $p < .001$ ). No significant condition  $\times$  occasion interaction was observed ( $p = .88$ ). Post-hoc analyses revealed that overall response times were faster post-program compared with baseline ( $d = 1.28$ ,  $p < .01$ ) and during congruent trials compared with incongruent trials ( $d = 3.88$ ,  $p < .001$ ).

Results of a  $2 \times 2$  repeated measures ANOVA on Stroop Task accuracy rate revealed significant main effects of measurement occasion ( $F_{(1,23)} = 10.86$ ,  $MSE = 0.11$ ,  $p < .01$ ) and condition ( $F_{(1,23)} = 46.16$ ,

**Table 1**

Descriptives of in-lab cognitive assessments and the within-group differences between baseline and post mindful walking program.

Variable	Baseline mean(SD)	Post-program mean(SD)	Mean difference(SD)	95%CI of mean difference	t	Pre-post Correlation
<b>Everyday Cognition Scale<sup>a</sup></b>						
Memory	4.83 (0.39)	4.80 (0.56)	0.03 (0.57)	[-0.20, 0.25]	0.21	0.31
Planning	5.54 (0.44)	5.61 (0.47)	-0.07 (0.51)	[-0.27, 0.13]	-0.69	0.38
Organization	4.92 (0.85)	5.05 (0.76)	-0.13 (0.55)	[-0.34, 0.09]	-1.17	0.77***
Divided attention	4.96 (0.79)	4.83 (0.80)	0.13 (0.72)	[-0.15, 0.41]	0.94	0.60**
<b>Trail Making Test<sup>a</sup></b>						
Trail A completion time (sec)	26.62 (7.50)	24.50 (7.10)	2.12 (4.90)	[0.14, 4.10]	2.20*	0.78***
Trail B completion time (sec)	59.11 (20.88)	51.08 (19.14)	8.03 (18.75)	[0.46, 15.60]	2.18*	0.56**
Trail B-A time difference (sec)	32.49 (18.45)	26.58 (16.31)	5.91 (19.80)	[-2.08, 13.91]	1.52	0.36
Trail A Errors	0.26 (0.66)	0.37 (0.63)	-0.11 (0.80)	[-0.43, 0.21]	-0.72	0.22
Trail B Errors	1.19 (1.62)	0.59 (0.89)	0.59 (1.80)	[-0.12, 1.31]	1.71	0.06
<b>Porteus Maze Test<sup>a</sup></b>						
Maze I completion time (sec)	60.81 (34.96)	44.45 (28.72)	16.35 (33.65)	[2.76, 29.94]	2.48*	0.46*
Maze II completion time (sec)	103.72 (72.02)	72.49 (41.17)	31.23 (69.19)	[2.67, 59.79]	2.26*	0.35
Maze I Errors	2.85 (1.98)	2.04 (2.26)	0.82 (2.42)	[-0.14, 1.78]	1.75	0.35
Maze II Errors	2.70 (1.88)	2.30 (1.44)	0.41 (2.12)	[-0.43, 1.25]	1.00	0.21
<b>Stroop Test<sup>b</sup></b>						
Congruence reaction time (ms)	1120.26 (141.83)	1047.46 (125.23)	-72.80 (132.47)	[-127.48, -18.11]	-2.75*	0.51**
Incongruence reaction time (ms)	1282.78 (136.85)	1205.85 (139.95)	-76.93 (141.35)	[-135.27, -18.58]	-2.72*	0.48*
Congruence accuracy rate (%)	96.30 (7.94)	98.80 (3.16)	2.50 (7.97)	[-0.79, 5.79]	1.57	0.19
Incongruence accuracy rate (%)	80.62 (17.10)	91.56 (6.79)	10.94 (13.29)	[5.33, 16.55]	4.03**	0.70***

Note: Number of participants = 25; <sup>a</sup> paper-and-pencil format; <sup>b</sup> computer-based test; sec = second, ms = millisecond.

\* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$ .

MSE = 0.32,  $p < .001$ ). Post-hoc analyses revealed that overall accuracy rate was higher post-program compared with baseline ( $d = 1.37$ ,  $p < .01$ ) and during congruent trials compared with incongruent trials ( $d = 2.78$ ,  $p < .001$ ). Additionally, there was a condition  $\times$  occasion interaction in predicting overall accuracy rate ( $F_{(1,23)} = 22.57$ , MSE = 0.01,  $p < .001$ ). During incongruent trials, participants significantly increased overall accuracy rate post-program compared with baseline ( $d = 1.96$ ,  $p < .001$ ). There was no difference in accuracy rate during congruent trials between baseline and post-program measures.

### 3.2. Short-term cognitive change (in field)

Table 2 summarizes the mixed-effects model results for the perceived and objective ambulatory cognitive assessments from the mobile cognitive assessment protocol. Four participants had missing records in their 7th walking session due to malfunction identified in one of the study smartphones, resulting in a total of 92 measurement occasions. Controlling for contextual and time-based factors (main sources of practice effect), subjective ratings of cognition were better at post-walking session compared to pre-walking session ( $d = 1.15$ ,  $p < .001$ ). Further, participants' response time was generally faster post- compared to pre-walking sessions across objective ambulatory cognitive assessments. Significant faster post-walking response time was observed during two of the three ambulatory cognitive tasks, including Symbol Search ( $d = 0.46$ ,  $p < .05$ ) and the N-Back task ( $d = 0.66$ ,  $p < .01$ ). The mean reduction in response time observed in the Dot Memory task was not significant ( $p = .61$ ). No significant changes in mean accuracy were observed from pre- to post-walking sessions among cognitive tasks.

## 4. Discussion

Overall, the observed within-person changes of cognitive outcomes in both short- and longer-term exceeded the meaningful benchmarks that were given (i.e.,  $d \geq 0.20$ ) for concluding that there was a favorable signal on sustaining cognition from mindful walking. These results indicate that mindful walking warrants progression in the intervention development pipeline (Phase IIb/III) described in the ORBIT model. The benefits of both acute (from 30-min bout) and accumulated practice (from multiple sessions) of mindful walking appear to be conferred to information processing speed, which holds implications for a wide range of cognitive processes affected by cognitive aging (Kail and Salthouse,

1994; Salthouse, 1996 Jul; Salthouse, 2000). Previous studies of mindful walking have focused on mental health (Mj, et al., 2016; Peavy et al., 2012). This study extended the literature by modifying key domains of cognition in response to a multi-session mindful walking program for older adults.

The current study identified longer-term within-person improvements in processing speed and executive function across paper-pencil and computerized assessments. Performance improvements on the Stroop task appeared to be specifically associated with incongruent condition accuracy. This finding may imply improvements in inhibitory control, selective attention, and overall executive function (Scarpina, 2017). However, we caution that accuracy during the congruent condition was overall very high at baseline, and thus, the observed interaction effect may be driven by either the changes in executive function (incongruent condition-only) or general task performance improvements (in both conditions) that were masked by baseline ceiling performance in the congruent condition. A potential ceiling effect may also explain the no difference in subjective measures of everyday cognition. Participants in this study were not cognitively impaired; their ability to carry out daily cognitive tasks should be similar before and after the program.

Mirroring the longer-term cognitive improvements, short-term improvements in processing speed were observed during performance of a task with instructions that stressed speeded performance (Symbol Match) and another that stressed accuracy (N-Back), indicated that a general impact on cognition may exist from practicing mindful walking. It is possible that these short-term changes of mindful walking on processing speed are the mechanisms by which longer-term advantages are conferred (e.g., improvements are immediate and incremental). Processing speed is a central marker of neurocognitive function that changes with age, and is altered significantly by the presence of neurodegenerative disease (Salthouse, 2000; Finkel et al., 2007). Slower processing speed can have a widespread influence on other higher-order cognitive processes that unfold over time and require coordination of lower-level processes (e.g., working memory) (Kail, 2000). This proof-of-concept study controlled for potential practice effect, but an efficacy trial is needed to evaluate if mindful walking practice contributes to improvements of processing speed (Duff et al., 2007). Further, a short-term improvement in subjective cognition from pre- to post-walking session was observed using a single self-report item. This single item is a global measure of cognition that does not represent a specific cognitive

**Table 2**  
Results of the within-person changes in mobile-based cognitive outcomes from pre to post mindful walking session.

Model	Symbol searchmeanRT	Symbol searchpropaccuracy	2-BackmeanRT	2-Backpropaccuracy	DotmemorymeanRT	Dotmemorymean error dis.	Perceivedcognitivefunction
Mean(SD)	3746.60(1131.09)	0.96(0.77)	2005.21(719.11)	0.77(0.13)	8138.66(4704.54)	2.15(1.44)	5.05(1.12)
<b>Fixed Effect</b>							
(Intercept)	3032.62*	0.85***	1230.69	1.05***	3671.83	1.36	5.92***
Post walking session (=1)	-266.88*	0.01	-266.43**	0.02	-321.21	0.11	0.74***
Walking session number	-61.07	-0.03	187.85	<-0.01	210.63	0.10	-1.52***
Age (centered)	80.64*	<-0.01	50.39*	-0.01	394.02**	0.03	0.02
Sex (male = 1)	280.00	-0.04	180.61	<-0.01	13.11	-0.38	-0.65
Day of the week (Mon = 0)	17.38	0.01	23.72	-0.02	114.22	-0.08	-0.02
Mean temperature (centered)	-17.06	<-0.01	-10.36	<-0.01	14.46	0.01	0.02
Time of the day (hour)	13.04	0.01	63.03	-0.02	375.86	0.09	-0.10
Perceived sleep quality	157.11*	<-0.01	35.32	-0.01	130.65	-0.01	0.07
<b>Random Effect</b>							
Intercept (SD)	765.7	0.05	444.6	0.08	2788	0.89	0.85
Residual (SD)	695.3	0.06	496.7	0.10	3581	1.18	0.79

Note: 1. Number of measurement occasions = 92; number of participants = 25; RT = response time.

2. Analyses were based on the 7th and the 8th walking sessions in which 30 min of mindfulness practice was incorporated.

3. Perceived cognitive function was measured using self-report; all other cognitive outcomes were measured objectively.

4. \* $p < .05$ ; \*\*  $p < .01$ ; \*\*\*  $p < .001$ .

domain. Thus, finding from this self-report may be different from those measured by Everyday Cognition Scale in which daily cognitive aspects were targeted.

The mindfulness skills practiced in this study emphasized cultivating heightened awareness and attention to every present moment and movement. These basic skills may enhance older adults' ability to focus on timed or speeded tasks that lead to the observed improvement in processing speed. A review on mindfulness trainings suggested that the development of focused attention is linked to improved executive function and selective attention (Chiesa et al., 2011). The simultaneous rhythmic walking activity carried out in this program may also evoke the mindfulness state that facilitates attention and cognition (Spartano et al., 2019; Christie et al., 2017). Light-intensity physical activity also influences lipid and glucose metabolism, and both markers may regulate risks for neurodegenerative diseases in older adults (Sato and Morishita, 2015; Füzeki et al., 2017). Future trials can collect blood drops to understand whether those bio-physiological markers change as a function of mindful walking practice, and, in turn, explain cognitive improvements. The null findings in the memory aspect did not support previous findings from moderate-to-vigorous physical activity engagement (Erickson et al., 2019). One possible explanation may be that brain region governing memory capacities (i.e., amygdala, hippocampus, cerebellum, prefrontal cortex) are less likely to be engaged by light-intensity movement targeted in the current program (Tulving and Markowitsch, 1997). This hypothesis warrants future intervention studies using neuroimaging measures to detect brain structural differences in those areas.

This proof-of-concept study combines objective and subjective cognitive measures administered both in-lab and in the field to broadly access key domains of cognition in response to a mindful walking program. It demonstrates readiness for developing a well-powered randomized controlled trial to draw causal inferences by ruling out other confounders with a comparator. We suggest that future efficacy trials should establish criteria to determine meaningful magnitude of the within-person cognitive changes using ambulatory assessments. Device-based activity measures, such as accelerometers, should be applied during the intervention to control for potential extra practices. Multiple occasions of post-program measures could be applied in future studies to reveal the timing and duration of cognitive improvements in response to the intervention. Given recent evidence that exposure to nature may enhance short-term cognition (Berman et al., 2008; Bratman et al., 2015 Jun), future trials should also consider different mindful walking contexts (e.g., indoor track, treadmill) to examine whether cognitive improvements are consistent across settings.

The walking and mindfulness training were delivered as an integrated intervention package in this study. A multi-arm randomized controlled trial can be conducted to understand the relative cognitive effect between walking, mindful practice, and the integrated mindful walking conditions. Lastly, it will be valuable to investigate if older adults who already have lower neurocognitive performance or with mild cognitive impairment may also benefit from practicing mindful walking. Validating the immediate and longer-term efficacy of brief mindful walking activity in future efficacy trials can contribute to designing scalable and sustainable behavioral interventions to promote healthy aging in everyday life. Favorable results in future efficacy trials may warrant the dissemination of mindful walking as part of a lifestyle strategy to sustaining healthy cognitive aging in late adulthood.

**CRedit authorship contribution statement**

**Chih-Hsiang Yang:** Conceptualization, Methodology, Investigation, Writing - original draft. **Jonathan G. Hakun:** Software, Visualization, Writing - review & editing. **Nelson Roque:** Data curation, Writing - review & editing. **Martin J. Sliwinski:** Resources, Writing - review & editing. **David E. Conroy:** Supervision, Conceptualization, Writing - review & editing.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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