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ORIGINAL RESEARCH

SMARTfit Dual-Task Exercise Improves Cognition and Physical Function in Older Adults With Mild Cognitive Impairment: Results of a Community-Based Pilot Study

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Mild cognitive impairment is an intermediate state between the cognitive decline often experienced in normal aging and dementia that affects 15% of Americans over 65 years of age. Our communities have an opportunity to support the development and adoption of evidence-based programs to help older adults preserve cognition and physical function. In partnership with a local urban YMCA in an underserved, predominantly minority neighborhood, we tested the appeal and therapeutic benefits of SMARTfit training among older adults with mild cognitive impairment. The participants reported a positive training experience. After 12 weeks of dual-task training, Trail-Making Test and Stroop Color–Word Interference Test scores improved, as did scores on the Short Physical Performance Battery. Results of our SMARTfit dual-task training intervention are encouraging. Larger randomized controlled trials must further investigate the development, implementation, and therapeutic impacts of SMARTfit dual-task training on cognitive and physical function in aging.

Keywords: motor function, balance, walking, exergaming

Mild cognitive impairment (MCI) is an intermediate state between the cognitive decline associated with normal aging and more severe dementia that affects 15% of American adults over age 65 years (Anderson, 2019). MCI is also predictive of Alzheimer's disease (AD) with a rate of conversion from MCI to AD of 15% per year in the United States (Petersen et al., 1999). Coping with MCI in aging can be of significant burden as it is associated with increased fall risk, social isolation and anxiety, and poorer quality of life (Conrad et al., 2015; Hwang et al., 2022; Tyrovolas et al., 2016). With our rapidly aging society and increasing life expectancy, we are facing a public health crisis for which we are not fully prepared. To meet this challenge and help adults maintain their function and quality of life well into older age, we must support our communities with the resources needed to sustain appealing and impactful programs that preserve cognitive and physical function.

The dual-task paradigm is an established methodology for studying cognitive performance under conditions wherein attention must be divided between two simultaneous tasks (Della Sala et al., 1995). Adults with MCI and AD often experience limitations in their ability to complete dual-task challenges (e.g., walking while counting backward; Makizako et al., 2013; Sobol et al., 2016). Furthermore, dual-task ability is essential to maintaining independence in aging. For instance, Brustio et al. (2018) found that among older adults, dual-task performance mediates the association between fear of falling and ability to complete activities of daily living. In addition, Muir-Hunter et al. (2016) found that deterioration in gait quality during dual-task walking compared with single-task walking was associated withincreased fall risk in community-dwelling older adults. The evidence presented by Brustio et al. and Muir-Hunter et al. shows that dual-task ability is important to successfully meeting the challenges of daily life. Further investigation on the impacts of dual-task training (DTT) on cognitive and physical function is still needed to adapt and integrate effective therapies into communities in need.

Increased focus has been placed on leveraging the dual-task paradigm not only to assess function but also to design therapeutic strategies aimed at preserving cognition and physical function for a host of aging-related challenges (Choi et al., 2015; Falbo et al., 2016; Li et al., 2020; Wollesen et al., 2017). This method facilitates cognitive testing and training using tasks that better replicate the complex activities of daily life that often require divided attention. Exergaming is an engaging and immersive method that can be used to deliver DTT (Delbroek et al., 2017; Gallou-Guyot et al., 2020; Ogawa et al., 2015). Exergaming capitalizes on physical movement and subsequently critical thinking and decision making, as a means of accomplishing a task presented in game.

Evidence supports DTT as an effective therapy to help improve cognitive and physical function in older adults with MCI. In a recent systematic review and meta-analysis of the impacts of DTT, Ali et al. (2022) found among 21 studies, small to medium effect sizes (standardized mean differences) ranging from 0.19 to 0.56 for global cognition, memory, executive function, attention, gait speed, dual-task cost, and balance. For instance, Park et al. (2019) examined the impacts of aerobic exercise combined with simultaneous cognitive training (completion of word games, simple numerical calculations, and memory span games), a program the team coined as "Cognicise." In response to once weekly "Cognicise" for 24 weeks, participants demonstrated improved global cognitive function, working memory, and executive function.

In a randomized controlled trial (RCT), Liao et al. (2019) found that 12 weeks of virtual reality-based DTT in older adults with MCI improved performance on the Stroop Color–Word Test (Stroop), motor dual-task gait, cognitive-motor dual-task gait, and dual-task cost. The authors contend that these improvements show that DTT has the potential to enhance executive function in older

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Figure 1 — SMARTfit trainer.

adults with MCI. Overall, the current evidence supports DTT as an effective therapy to assist older adults with MCI maintain or even enhance cognitive and physical function. Furthermore, the nature of DTT interventions that bring people together increases social engagement and social support among participants, in turn, resulting in a higher likelihood of their long-term investment and ongoing participation (Christensen et al., 2006; Chu et al., 2021; Resnick et al., 2002).

While the underlying neurophysiological mechanisms of improved cognition in response to simultaneous exercise and cognitive training have not yet been fully characterized, exercise and cognitive training likely stimulate similar neurobiological processes and pathways which produce a synergistic therapeutic effect (Tait et al., 2017). Cognitive and motor training improve cerebral blood flow in humans (Ide & Secher, 2000; Mozolic et al., 2010), and studies in rats show that they induce angiogenesis (Mu et al., 1999). Furthermore, evidence demonstrates that areas of the brain underlying executive control processes, such as the frontal and hippocampal regions, are malleable and adaptive even in older age (Voelcker-Rehage & Niemann, 2013), responding to both physical exertional training and cognitive stimulation, thus enhancing neuroplasticity (Erickson et al., 2006; Maass et al., 2015) and preserving brain volume (Boyke et al., 2008). Moreover, physical activity and exercise increase release of brain-derived neurotrophic factor (BDNF), a member of the neurotrophin family of growth factors that promotes neuronal survival, neurite outgrowth, and synaptic plasticity in healthy older adults and those AD (Coelho et al., 2013; Coelho et al., 2014; Marinus et al., 2019). BDNF is essential to cognitive performance and adaptations in brain morphology (Cirulli et al., 2004; Mu et al., 1999). The underlying mechanisms by which cognition improves with exercise and cognitive training are complex and multidimensional and concerted efforts must be made to better characterize this model. The objective of our study was to assess the appeal of SMARTfit DTT among key community stakeholders and to detect changes in cognitive and physical function 12 weeks of training in adults with 65 years or older, who screened positive for MCI.

Our team sought to contribute to the DTT evidence base by exploring the participant training experience and therapeutic benefits associated with DTT using the SMARTfit Cognitive-Motor Exercise System (SMARTfit). SMARTfit is an exergaming system that facilitates simultaneous cognitive and motor training using a series of touch-sensitive light-emitting diode (LED) arrays embedded in a high-strength panel that can be wall-mounted or attached to a floor stand. The LED arrays are programmable to deliver cognitive challenges such as memory, numerical calculations, or counting, while simultaneously executing a given physical task such as walking while carrying a medicine ball, stance-switching, or stepping in place. Participants can interact with the device by striking the individual targets using their hands or feet, or by throwing balls or other objects that require manipulation and movement (Figure 1).

To test the appeal and impact of SMARTfit DTT, we partnered with a local YMCA in an underserved, urban neighborhood, with a membership that is predominantly African American. With direct stakeholder input, we have developed and conducted this pilot investigation. This project is important because it sought to address a pressing health issue that can profoundly impact function, independence, and quality of life in a community with a long history of health disparities and inequitable access to health-promoting resources.

Methods

Design

This community-based study was conducted in partnership with a YMCA in the city of Buffalo, NY, and was divided into two phases. The development phase was designed to build the partnership between our university and this local YMCA, involving preliminary appeal and enjoyability testing to characterize the participants' training experience using SMARTfit. Garnering direct input from community members was important to creating a positive training experience. The impact phase focused on conducting a small-scale pilot investigation to detect changes in cognitive and physical functional outcomes in response to 12 weeks of SMARTfit DTT among older adults with MCI.

Participants and Recruitment

For the development phase, adults aged 65 years or older were recruited from local senior centers, libraries, churches, and other community organizations using recruitment flyers posted in high-traffic areas. To enhance enrollment, two informational sessions were hosted at the YMCA. Those interested in participating in a user group to help assess the participant training experience were asked to telephone the research team to set up an appointment to provide written informed consent and screen for safety.

Recruitment procedures for the impact phase were conducted in a manner similar to those of the development phase with recruitment flyers placed prominently in churches, community centers, and senior centers. Potential participants interested in enrolling in the study were asked to telephone the research team to set up a consent and screening appointment. Screening for eligibility included: (a) cognitive assessment via the Montreal Cognitive Assessment (MoCA), score equal to 23–26 points; (b) appropriateness for physical activity via the Physical Activity Readiness Questionnaire for Older Adults; and (c) capacity to consent to research procedures using the University's of California Brief Assessment of Capacity to Consent. All participants were provided with detailed information about the study and written informed consent was obtained. All research procedures in this protocol were approved by the University Institutional Review Board.

Participants were included if they: (a) were $\geq$65 years of age; (b) had MCI, as screened using the MoCA (23–26 points for MCI); (c) had no contraindications to supervised exercise, as guided by the American College of Sports Medicine, specific to older adults; and (d) were able to speak, read, and write proficiently in English.

Exclusion was based upon the following: (a) having any conditions that prevent safe participation in physical activity as screened using the Physical Activity Readiness Questionnaire for Older Adults, (b) severe neurological disease, (c) severe psychiatric illness, (d) likelihood of withdrawal from the study due to the presence of severe illness or a life expectancy < 6 months, (e) having any lower/upper limb amputation, (f) having greater than MCI (MoCA score $<$ 23 points), and (g) having less than MCI (MoCA score > 26 points).

Study Phases

Development and Participant Experience Assessment

The development phase was designed to explore participants' experience using the SMARTfit system and to ascertain the appeal of training activities. A total of eight older adults completed this phase. Two 60-min user group sessions were conducted to introduce community members to the SMARTfit system, allowing small groups of participants to test several cognitively demanding activities (games) paired with physical tasks. A variety of physical tasks were tested including walking, stepping in place in different patterns, striking the SMARTfit targets with medicine balls, tennis balls, or by punching (with boxing gloves on) or kicking (lowest targets only). In addition to these physical tasks, games that required varying durations were tested, ranging from 30 s to 2 min. This phase was critical to reaching a consensus in identifying the dual-task games that were then tested in the impact phase. Training activities identified as least appealing by the participants were not included in the follow-on impact phase. A sample training session used in the development phase is provided in Table 1.

To explore participants' training experience and the appeal and enjoyment associated with the training activities, we developed a 10-item survey that was administered to each participant after completion of their introductory session (Table 2). In addition, in a brief exit interview, participants were asked to identify the most and least appealing training games that they completed. Participants were also asked to briefly discuss the reasons for liking or disliking specific training games. These perspectives directly informed the selection of training activities that were tested during the impact phase.

Impact Assessment

For the impact phase, a small pilot study was conducted to detect changes in cognitive and physical function with 12 weeks of

Table 1 Example Introductory Session for the Development Phase

Time	Intervention component
0–15 min	Warm-up: Light standing stretches, light stepping in place
16–24 min	Game 1 Trials 1–4: “Lights Out” race for speed and accuracy
25–33 min	Game 2 Trials 1–4: “Chase the Letter” with medicine ball carry
34–42 min	Game 3 Trials 1–4: “Memory” with stance alterations (wide, semitandem, tandem, one-leg)
43–51 min	Game 4 Trials 1–4: “Chase the Number” alternating one-leg stances
Postsession	Cooldown: Light standing stretches and focus on breathing

Table 2 Usability Survey Questions

1. How enjoyable was your SMARTfit training session?				
Not at all	A Little	Neutral	Very	Extremely
2. How easy was it to select and set up the different games on SMARTfit?				
Not at all	A Little	Neutral	Very	Extremely
3. How enjoyable was the team-based, social aspect of SMARTfit?				
Not at all	A Little	Neutral	Very	Extremely
4. How easy to follow were the instructions for each SMARTfit game?				
Not at all	A Little	Neutral	Very	Extremely
5. How physically challenging were the SMARTfit games your group selected?				
Not at all	A Little	Neutral	Very	Extremely
6. How appropriate for your age and capabilities were the SMARTfit games?				
Not at all	A Little	Neutral	Very	Extremely
7. How mentally challenging were the SMARTfit games your group selected?				
Not at all	A Little	Neutral	Very	Extremely
8. How willing are you to participate in a weekly SMARTfit training program?				
Not at all	A Little	Neutral	Very	Extremely
9. How likely are you to recommend the SMARTfit program to others?				
Not at all	A Little	Neutral	Very	Extremely
10. How does SMARTfit training compare to other group exercises you have done?				
Much Worse	A Little Worse	The Same	Better	Much Better

SMARTfit DTT. A total of 10 participants received one small-group-based, 60-min DTT session per week (Park et al., 2019) for 12 weeks (Figure 2). Each session was guided by a trained and experienced instructor with personal training certification from the National Strength and Conditioning Association. The DTT program was created by the principal investigator and informed by the results of the preliminary development phase. Importantly, a total of four participants from the development phase took part in the impact phase.

Description of the DTT Intervention

In each 60-min training session, four to six individuals participated as a small group. Our training venue contains two SMARTfit systems, allowing for at least two participants to train simultaneously, thus minimizing the volume of time each participant spent sedentary. Training sessions began with a 3-min group warm-up of walking back and forth (16-foot distance) between the SMARTfit board and a tape line on the floor in front of the board. Next, the group chose the order of training games from a daily menu provided by the instructor (Table 3: example daily menu), and all participants then completed the selected games in the same order for that session. Training games were individual, involving only one participant, or team-based, involving at least two participants working together. Games also map on to specific domains including balance, muscle strengthening, eye–hand coordination, processing speed, memory, and attention. The flexibility of the SMARTfit system allows the cognitive games to be paired with different physical movements, giving the instructor several options for both individual and team-based engagement. An array of physical movements was used to either vary how participants interacted with SMARTfit (e.g., tapping targets with a medicine ball or punching) or to add a simultaneous physical dimension to the cognitive training (e.g., stance changes, chair squats, or dribbling a soccer ball). The specific pairings are shown in Table 3. Each game was 2 min in duration and participants completed a total of three trials of each game in alternating order, for a total of 6 min in each game. The allotted timeframe for each session allowed for six to eight different games to be completed. It was estimated each participant spent a cumulative total of 8–10 min sedentary, while transitioning from one game to another. Each DTT session ended with a 5-min mindfulness session with focus on breathing.

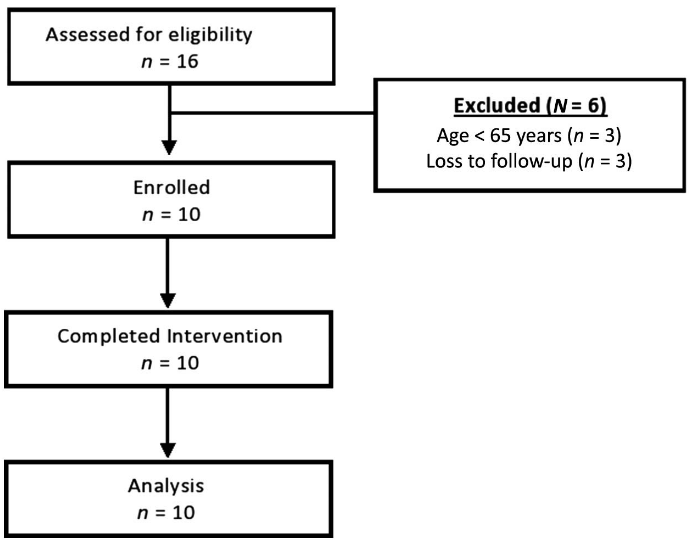

Figure 2 — Participant enrollment.

Participants were instructed to strive for speed while maintaining accuracy when completing the training games. In addition, they were instructed to refrain from helping one another while completing the cognitive portion of each game (e.g., symbol identification, solving addition or subtraction, etc.) If needed, participants could take a brief break during their session at any time. Consistent and frequent encouragement was provided to each participant by the instructor. Participant safety was also monitored continuously.

Impact Assessment

To assess the therapeutic impact of SMARTfit DTT, changes over the 12-week intervention in attention, task-switching, working memory, and interference inhibition were assessed using the Trail-Making Test (TMT; Bowie & Harvey, 2006) and Stroop Color-Word Interference Test (Stroop) at baseline and end point. The Short Physical Performance Battery (SPPB; Cabrero-García et al., 2012) was used to assess physical function before and after the DTT intervention. All assessments were conducted at the YMCA in a private office or aerobics room by the principal investigator.

Table 3 Example Menu of Training Games

Name of game	Focus areas
Chase the symbol with stance changes	Balance, attention
Subtraction with drumstick tap	Processing speed, eye–hand coordination
Pattern replication with medicine ball tap	Working memory, attention, strength
Medicine ball tap (upper targets) with chair squat	Strength, attention, processing speed
Knock-out for speed with punching	Eye–hand coordination, processing speed
Kicking with one-leg stand (assisted or unassisted)	Strength, attention
Left, right, or both hands (alternating)	Attention, processing speed, eye–hand coordination
Addition with side-step (alternating)	Balance, processing speed
Chase the color with ball toss and catch (alternating)	Eye–hand coordination, attention
Counting with medicine ball carry (alternating)	Attention, strength, processing speed
Serial sevens with soccer ball dribble (alternating)	Balance, processing speed
Trail-making with ball bounce pass (alternating)	Eye–hand coordination, attention, processing speed

Trail-Making Test

The TMT is a timed neuropsychological test of visual attention and task-switching. The TMT has two parts: the TMT-A (rote memory) and TMT-B (executive functioning). In each test the participant is asked to draw a line connecting 24 consecutive circles containing numbers and/or letters that are randomly arranged on a page. The TMT-A uses all numbers whereas the TMT-B alternates numbers and letters, requiring the examinee to switch between numbers and letters in consecutive, ascending order. The TMT is scored according to how long it takes to complete each section of the test (Bowie & Harvey, 2006).

For this study, the TMT was administered individually by paper and pencil. For each participant, the TMT was administered once at baseline and once after the 12-week intervention according to standard procedures that included one sample trial (short version) followed by one test trial (Bowie & Harvey, 2006).

Stroop

The Stroop is a neuropsychological test used to assess ability to inhibit cognitive interference. This test requires the examinee to read aloud three different tables, one at a time, as quickly as possible. The first two tables represent the "congruent condition" wherein the participant must read names of colors printed in black ink (word condition) and then name different color blocks (color condition). Conversely, the third condition, named "color–word," otherwise known as the incongruent condition, contains color names printed in an inconsistent color ink (e.g., the word "red" would be printed in "green" ink). In this condition, the examinee must name the color ink rather than reading the word. Scoring for all three conditions is based on the number of correct answers in each condition provided in 45 s (Scarpina & Tagini, 2017).

For this study, the Stroop test was administered individually, with the examinee presented with the three tables, one at a time, by the principal investigator. For each participant the Stroop was administered once at baseline and once after the 12-week intervention that included one sample trial (short version) followed by one test trial.

Short Physical Performance Battery

Change in physical function was assessed at baseline and end point using the SPPB (Cabrero-García et al., 2012). This test battery includes an assessment of balance (side-by-side stand, semitandem stand, and tandem stand), a gait-speed test (3- or 4-m walk), as well as a timed five chair-stand test to assess lower body strength. Scoring is out of a maximum of 12 points for the entire test with lower scores representing lower physical functioning (Treacy & Hassett, 2018).

For this study, the SPPB was administered individually in an aerobics room by the principal investigator. The room was closed to others while testing procedures were conducted. The order of assessments followed the standard procedures as described here: (a) balance test: side-by-side stand, semitandem stand, tandem stand (timed for 10 s each); (b) 4-m gait-speed test: two trials with 2-min rest between trials; and (c) chair-stand test: single chair stand followed by five repeated chair stands. A higher score on each measure and the total score indicates better performance. Participant safety was monitored throughout the test by the principal investigator.

Statistical Methods

Preliminarily, continuous variables were examined using measures of central tendency (mean, median, and mode), while categorical and survey data were explored using frequencies. To assess the participant experience with the SMARTfit DTT games, results per survey item were tabulated and presented as proportions of the total number of possible responses to each individual survey item. Immersion crystallization was used to identify common themes with regard to the individual SMARTfit training activities participants found most and least appealing and enjoyable (McLaughlin et al., 2013).

Due to the small sample size and nonnormal distribution, median and interquartile range were calculated to assess changes between baseline and end-point performance on the TMT, Stroop, and SPPB. To assess these changes median performance on the TMT (A and B), Stroop (word, color, color–word), and SPPB (balance, walking, lower limb strength, and total; Bernabeu-Mora et al., 2017; Uehara et al., 2018) were compared using Wilcoxon signed-rank tests. In addition, for the Stroop test, the predicted color–word (P_{cw}) score was derived from scores on the two congruent conditions, color (C) and word (W) tests. The formula below demonstrates the direct impact of an individual's C and W scores on P_{cw} scores:

$$P_{cw} = \frac{45}{((45 \times W) + (45 \times C))/(W \times C)}.$$

From the P_{cw}, the Stroop interference score (IG) was then calculated by subtracting the P_{cw} value from the actual number of items correctly named in the incongruous condition (color–word: CW; i.e., $IG = CW - P_{cw}$). Thus, a lower IG represents a greater difficulty in inhibiting interference (Ivnik et al., 1996). Pre- to post-intervention change in the IG was then determined using a Wilcoxon signed-rank test.

Finally, we have identified a range of estimated effect sizes for the individual components of the TMT and Stroop tests, and the total SPPB that will inform sample size calculations for future larger RCTs. For change in TMT from baseline to end point, we found a range of effect sizes between 0.62 and 0.63 (medium). For change in Stroop from baseline to end point, our estimated range was 0.57–0.64 (medium). For the total SPPB score, the effect size range was 0.50–0.62 (medium). To achieve a desired statistical power equal to 0.80, we require a total of 60–78 participants per group (intervention vs. attention control).

Results

Sample Characteristics

In all, eight older adults completed the development phase. The sample consisted of six females and two males, with a mean age of 69.00 ± 4.21 years. In addition, all eight participants self-identified as African American. A total of seven participants reported completing high school, and one participant reported having an undergraduate degree. Regarding employment status, six participants reported being retired while the two remaining participants reported being employed part time.

For the impact phase, a total of 16 participants were screened for eligibility with three excluded for not meeting inclusion criteria for age (≥65 years). Among the 13 who were eligible, 10 were enrolled. "Fear of injury," "conflicting home responsibilities," and "lack of interest" were the reasons given for nonparticipation among the three who chose not to enroll. Among those enrolled, there were seven females and three males, and the mean age equaled 73 ± 4.64 years. All 10 participants self-identified as African American. In addition, eight participants reported having completed high school and two participants reported having an undergraduate degree. All participants reported being retired. Upon completion of the intervention, all 10 participants who enrolled completed at least 11 out of 12 (92%) exercise sessions and eight out of 10 participants completed all 12 exercise sessions.

Participant Experience Outcomes

Our survey results indicate that overall the appeal and enjoyment associated with training on the SMARTfit system were very high, with 100% of participants rating their session as at least "very enjoyable," with seven participants indicating their experience was "extremely enjoyable." When asked how enjoyable the group training experience was, 100% of participants reported their experience was "extremely enjoyable." Furthermore, when asked about the ease of use of the SMARTfit system and the ease of participation, again 100% of participants reported that interacting with SMARTfit was at least "very easy," with five participants rating their introductory experience as "extremely easy." In addition, when asked whether the DTT games were appropriate for age, and physically and intellectually challenging, seven participants indicated that the training activities were appropriate for their age, and all participants reported that the activities were both physically and intellectually "very challenging." The one participant who responded negatively when exploring the appropriateness of the training activities stated that "elderly people should not have to exercise" and that "exercise is too dangerous for people over 70 years old." Finally, when we explored individuals' willingness to participate in a future program, how the SMARTfit training compared to other group-based exercises, and whether they would recommend SMARTfit to others, seven participants reported they would participate in a future program, rating SMARTfit as "much better" than other group exercise experiences. These included "Zumba," low-impact aerobics, and other dance-based activities. These participants also reported they would recommend the SMARTfit class to others.

Key themes emerged that informed delivery of the impact study in selecting specific training games. All participants reported that their least favorite game was "Memory." This game involves identifying and matching pairs of common symbols within each LED array of the SMARTfit system (similar to the card game that young children often play), while altering stance (two feet, semi-tandem, tandem, one foot) for a duration of 1 min. The memory component of the game proved "very frustrating and too slow" for several participants. In contrast, the favorite game identified was "Knock-out and Chase three Targets with hand-switching" for a duration of 2 min. This game involves standing in front of the SMARTfit board with all LED targets illuminated. Participants then must knock out all the targets as quickly as possible and then chase three targets all over the board, while following constant hand-switching cues randomly called out by the instructor (left hand, right hand, or both hands). Participants reported that they enjoyed the "fast-paced, unpredictable" nature of this game. In addition, they reported that having to follow constant instructions made them feel "connected" to the instructor and more motivated. Participants also indicated that they appreciated games that involved walking or stepping in place. For example, when the "Chase the Letter of the Alphabet Game (with simultaneous animal naming)" was combined with walking to and from the SMARTfit board while carrying a 4 lb. medicine ball (16-ft distance), five participants indicated that it was "very challenging," but they felt "stronger and more capable" after the game ended. Furthermore, several participants perceived that training on that game would be beneficial to their "balance, walking, and heart health." Finally, we learned that duration of each training game was an important factor to address. Overall, participants preferred 2-min over shorter duration games. All participants reported that they felt 30-s games did not give them sufficient time to adjust to the game, before it ended, despite having time to practice. Three participants stated that they felt "rushed" by the 30-s timer and were not satisfied with their performance because they felt "anxious" during the game.

Performance Outcomes

Cognition

For baseline screening, the MoCA was administered before the intervention. For both the TMT and Stroop cognitive outcomes, scores are reported as median (interquartile range). When we compared scores on the TMT-A, we found median time to complete TMT-A improved from 45 (4.00) to 40.00 (4.00) s, $p = .005$ (Table 4). Similarly, performance on the TMT-B improved from a median of 140.00 (7.00) to 135.00 (2.00) s, $p = .004$ (Table 4).

When we examined change in performance on the Stroop test, we found that with 12 weeks of SMARTfit DTT, scores on the "color" and "color–word" conditions improved. The median baseline score on the "color" condition equaled 72.00 (4.00) correct responses, and the end-point score equaled 74.00 (2.00) correct responses, $p = .035$ (Table 4). The score on the "color–word" condition also improved from a median of 34.00 (3.00) to 36.00 (2.00) correct responses, $p = .001$ (Table 4). In addition, the Stroop interference score improved significantly from baseline to end point with training. The median baseline interference score equaled −3.24 (1.50), and the end-point score was −1.25 (2.50), $p = .007$.

Physical Function

Performance on the SPPB was assessed at baseline and end point to explore changes in balance, walking ability, and lower limb strength (Table 4). Results are presented as median (interquartile range) for all the SPPB domains and total. The balance subscore of the SPPB improved with training, with a median baseline of 3.50 (1.00) points versus an end-point score of 4.00 (1.00) points, $p = .025$. In addition, lower limb strength as measured by the chair-stand test improved after DTT. The median baseline chair-stand (strength) score was 3.00 (1.00) versus 4.00 (1.00) points, $p = .004$ after DTT. In addition, the overall score on the SPPB improved from a median of 10.00 (2.00) versus 12.00 (1.00) points after training, $p = .004$ (Table 4). Results also indicate that walking ability did not change as assessed using the 4-m walk test component of the SPPB. The median value of 4.00 did not change baseline to end point, $p = .126$.

Discussion

Participant Experience Outcomes

Our novel SMARTfit intervention has demonstrated that a small community–university partnership can develop an appealing and enjoyable community-based, group DTT program using the SMARTfit Cognitive-Motor Exercise System. The development process allowed us to structure the impact phase around participants' feedback and preferences regarding which training activities they found most appealing. This is an important and novel component of our impact assessment and will inform development of larger RCTs to follow. We found that participants who attended

Table 4 Changes From Baseline to End Point in Cognitive and Physical Functional Outcomes

Outcome	Median score (IQR)	Wilcoxon *W*	*z* score	*p*	Effect size (*r*)
Trail-Making Test A*	Baseline: 45 (4.00) End point: 40 (4.00)	0.00	2.83	.005	.63
Trail-Making Test B*	Baseline: 140.00 (7.00) End point: 135.00 (2.00)	8.00	2.81	.004	.62
Stroop color*	Baseline: 72.00 (4.00) End point: 74.00 (2.00)	9.50	2.11	.035	.41
Stroop word*	Baseline: 74.00 (4.00) End point: 75.00 (4.00)	12.50	1.84	.066	.36
Stroop color–word	Baseline: 34.00 (3.00) End point: 36.00 (2.00)	0.00	3.28	.001	.64
Stroop interference*	Baseline: −3.24 (1.50) End point: −1.25 (2.50)	1.00	2.70	.007	.60
SPPB balance score*	Baseline: 3.50 (1.00) End point: 4.00 (1.00)	0.00	2.24	.025	.50
SPPB walk score	Baseline: 4.00 (1.00) End point: 4.00 (1.00)	0.00	2.00	.126	.39
SPPB strength score*	Baseline: 3.00 (1.00) End point: 4.00 (1.00)	0.00	2.88	.004	.65
SPPB total score*	Baseline: 10.00 (2.00) End point: 12.00 (1.00)	0.00	2.70	.004	.62

Note. For Trail-Making Test A and B performance assessed by number of seconds required to complete the task. For Stroop test performance assessed by number of correct responses provided in 45 s. Results are presented as median score (IQR). IQR = interquartile range; SPPB = Short Physical Performance Battery.
*Outcome is significant at the $p < .05$ level.

each training session were able to complete the entire session without the need for a break. Also, four out of the eight initial participants in the development phase also completed the impact phase. These participants had a direct influence on the characteristics of the follow-on intervention. Our results reveal that when older adult community members were oriented to the SMARTfit system to evaluate the training activities, they were able to provide valuable information allowing our team to develop an appealing and enjoyable training experience.

Cognitive Function

We discovered favorable changes in the TMT-A and -B scores as well as in the color and color–word conditions of the Stroop. Effect sizes ranged from 0.57 to 0.64 based on the results of the Wilcoxon signed-rank tests. Scores on executive functions including attention, working memory, task-switching, and interference inhibition improved. Executive functions are widely defined as mental processes that are responsible for our ability to concentrate, mentally process new information, and quickly adapt to different contexts (Diamond, 2013; Miyake et al., 2000). In everyday life, these functions allow us to plan, make decisions, and carryout other activities necessary to maintaining independence (Barberger-Gateau & Fabrigoule, 2003). Declining executive function is commonly seen in aging (MacPherson et al., 2002). The Stroop test is used to measure our ability to inhibit cognitive interference or distractions and to enable selective attention.

While direct scores on the Stroop, including color, word, and color–word, are widely accepted and have been reported to measure executive functions such as cognitive flexibility and working memory, the literature regarding indirect scores has yielded mixed opinions (Jensen & Rohwer, 1966; Periáñez et al., 2020). Many studies using the Stroop choose not to include indirect scores, whereas those that do have been able to associate interference scores directly with cognitive functions like response inhibition, working memory, and conflict monitoring (Cox et al., 1997; Kluttz & Golden, 2016; Periáñez et al., 2020). Among studies that have reported interference scores since 2017, most have utilized the equation derived from Golden (1978). One systematic review comparing studies choosing to evaluate indirect scores from the Stroop found that of 27 studies, 16 used Golden's standardized equation (Scarpina & Tagini, 2017). Studies choosing to report the interference score but that did not use Golden's standardized equation used novel formulas based on a decrease in the time interval from 45 s (Barbarotto et al., 2004; Brugnolo et al., 2016; Valgimigli et al., 2010). Furthermore, 17 of 21 studies reviewed by Scarpina and Tagini used an equation measuring correct answers within the 45 s time interval, 16 of which relied on Golden's standardized formula. Given the ubiquity of Golden's scoring method in the existing literature, we too selected it, understanding that a consensus has not been reached regarding how best to derive the interference score. Further study of this aspect of the Stroop is needed to identify which is the optimal method to derive an interference score.

In our study, we found that while the interference score did improve after DTT, it was still negative postintervention, improving from −3.24 to −1.25, indicating an impairment in interference inhibition may have persisted after DTT. Previous studies have shown that, with regard to the Stroop test in particular, those with MCI perform worse than healthy controls, especially in the incongruent condition (Bélanger et al., 2010; Traykov et al., 2007). Morrow et al. (2013) found that among cognitively healthy older adults, the mean score on the incongruent condition was equal to 45.4 (10.4). We reported a median equal to 34.00 (3.00) on the incongruent condition among our participants with MCI. In previous studies, adjusting for individual differences in processing speed and baseline performance resulted in no differences in interference inhibition between healthy controls and those with MCI (Borella et al., 2017; Zhang et al., 2008). Our finding that the interference score remained negative at end point is reasonable given the short duration and relatively low training volume. A longer duration study with a larger sample size may yield different results. In addition, our small study did not allow us to develop a more comprehensive model that adjusted for relevant participant-level covariates. Future studies will include an attention-control group design and an adequate sample size to explore these associations in greater depth.

The TMT reflects a wide variety of cognitive processes, including attention, visual search and scanning, sequencing, and shifting, psychomotor speed, abstraction, flexibility, ability to execute and modify a plan of action, and ability to maintain two trains of thought simultaneously (Periáñez et al., 2020; Salthouse et al., 1995). These are functions that are essential for coping with everyday challenges older adults must face. Results of the impact phase revealed favorable changes in both Stroop assessments and both TMT assessments perhaps showing that participants improved in their ability to carry out executive functions.

Physical Function

In addition to cognitive improvements, participants of the impact phase showed improved balance and lower limb strength, both of which are predictors of fall risk in older adults (Rapport et al., 1998; Tinetti et al., 1988). Approximately 28%–35% of people aged 65 and over fall each year, increasing to 32%–42% for those over age 70. Previous studies demonstrate that individuals with MCI are at greater risk of falls compared with those without MCI (Liu-Ambrose et al., 2008). Promising changes in balance performance and repeated chair stand show that our intervention has the potential to decrease risk of falling in older individuals with MCI. Future studies should be implemented to understand the utility of SMARTfit as a fall-preventative option for at-risk cognitively impaired adults. By the end of the 12 weeks, participants in the study did not improve in their 4-m walk times. This might in part reflect the limitations of the assessment of walking that we utilized. It may be that the 4-m walk test was not sufficient to detect changes in walking performance as it only allows for measurement of walking speed over a relatively short distance. We did not assess parameters of gait quality that may have been impacted by the DTT program (König et al., 2017). In addition, it may be that the duration of the intervention was not long enough to elicit improvements in walking speed.

Current evidence suggests that at present there is no consensus on the optimal intervention duration that will produce favorable changes in walking ability (Varela-Vásquez et al., 2020). More high-quality studies are clearly needed to provide deeper insights on the impact of DTT on walking ability in the context of aging and MCI. Furthermore, the exact dose of exergaming on the SMARTfit system that enhances walking ability in older adults has not yet been elucidated. Our approach to delivering simultaneous dual-task cognitive-motor training on the SMARTfit system is unique and has not been used previously among older adults with MCI. Without diminishing the cognitive focus of the intervention, gait-specific training could easily be integrated to allow for more opportunities to improve walking ability while still training cognition. This reflects the flexibility and potential to personalize SMARTfit training based on the needs of individual participants. Further research is needed regarding the ideal intervention length, exercise selection, and training progression methodology to utilize that will yield optimal cognitive and physical outcomes in this population.

Limitations

Although both the implementation and outcomes of the SMARTfit Intervention were encouraging, there are some limitations that must be discussed to inform future larger scale RCTs. The small sample size and prepost design did not allow for development of a more comprehensive statistical model to examine change over time or adjust for relevant covariates including baseline performance. In addition, the pilot nature and one-group design prevented inference of causation and limits generalizability. In addition, due to the community-based recreational nature of the study, we did not collect more comprehensive participant-level anthropometric/clinical data, such as body mass, body composition, or blood pressure, and therefore could not explore their associations with SMARTfit training. Another limitation we must acknowledge is that we did not estimate exercise intensity during the training sessions using heart rate or rating of perceived exertion. Our future trial that is currently in development is being designed to assess exercise intensity during SMARTfit training via both accelerometry and rating of perceived exertion.

As we touched on previously, in examining changes in the Stroop interference score, we must acknowledge that while the interference score did improve after 12 weeks of DTT, we cannot be certain this improvement reflects an enhanced ability to inhibit interference. The derivation of the interference score suggested by Golden (Ivnik et al., 1996) is impacted by both the color and word scores. Therefore, improvements in the color or word condition will also drive the interference score higher. In our study, we did observe improvements in the color–word (incongruent condition) score, and we are encouraged that SMARTfit DTT will enhance interference inhibition. We must also state that while small improvements in physical function were observed, it is likely given the study population's relatively high functional capacity, there was a ceiling effect with regard to scores on the SPPB, wherein our participants demonstrated high performance at baseline and therefore could not experience substantial improvements postintervention. Our future studies will integrate physical assessments that better capture changes appropriate in older adults with MCI (Puthoff, 2008).

The intent of this study was to demonstrate that a university–community partnership can be established, can enroll older adults, and implement an engaging, appealing DTT program in an underserved community. Our current efforts are focused on expanding this SMARTfit MCI program to other community organizations, to broaden our reach and test this form of DTT in a more diverse group of older adults with varying needs and resources. Our future studies are being designed with attention-control groups to compare cognitive performance between SMARTfit-trained and untrained individuals and to develop more comprehensive analysis of covariance models that better characterize the association between DTT and cognitive and physical functioning in the context of MCI. Finally, we recognize that the SMARTfit system is a specialized piece of technology to which not all community organizations have access with a current cost of approximately $20,000. This is an important consideration for future studies and for the dissemination of this technology. However, our partnership received a grant from a local health foundation to purchase the system to be left to the YMCA after completion of the initial pilot. Fortunately, this community organization has sustained the SMARTfit training as part their regular programming provided each week. This highlights the very real possibility that in an underserved neighborhood setting, we can successfully engage community and university stakeholders to invest in the health and longevity of our community members. We have shown that we can aid in mobilizing key resources and bring awareness to the need for additional support. Our future studies will seek to expand into other communities in need by first identifying key stakeholders and opportunities to invest in these important communities.

Conclusions

Existing literature that highlights the feasibility and efficacy of DTT in diverse and real-world community settings is limited. Studies similar to this have compared the efficacy of combining physical-cognitive interventions to a physical-alone or a cognitive-alone therapy (Anderson-Hanley et al., 2012; Basak & Qin, 2018; Hagovska & Nagyova, 2017). The debate remains whether interventions that deliver cognitive and physical exercise simultaneously yield superior cognitive outcomes than interventions conducted sequentially (Combourieu Donnezan et al., 2018). A recent meta-analysis of studies that included both cognitively impaired as well as healthy participants found that implementing simultaneous cognitive-motor training yielded larger improvements in cognitive functioning (Gheysen et al., 2018). However, there is a paucity of studies comparing simultaneous to sequential intervention in MCI patients in real-world community settings with varying needs and resources. Having demonstrated favorable changes in our key outcomes, our results will ultimately contribute to the growing body of evidence that supports simultaneous physical and cognitive training for older adults seeking a proactive strategy to maintain or even improve their function, independence, and quality of life. Our team is positioned to build upon these results with larger scale RCTs that robustly explore the impacts and implementation of DTT on cognition and physical function in older adults.

This is the first study to utilize the SMARTfit Cognitive-Motor Exercise System to deliver DTT in the context of MCI. In addition, there are few studies in this area that have utilized a distinct development phase to enable shared decision making and direct participant feedback regarding the appeal of intervention activities. Both the social support built into the intervention and the opportunity for shared decision making may have contributed to the high satisfaction scores reported by participants. A previous study that utilized a similar shared decision-making approach in addition to prioritizing a social component found that the high satisfaction scores were the strongest indicator of long-term adherence. (Bae et al., 2019). Long-term adherence to our program could prove instrumental in improving function and quality of life for participants. Follow-up RCTs are required to determine the efficacy of SMARTfit DTT on enhancing cognitive and physical function and whether long-term adherence can slow MCI or AD progression in older adults.

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