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4Active Intervention for Promoting Physical Activity and Cognitive Flexibility Among Older Adults

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Abstract

Physical activity is essential to delaying cognitive decline and preventing cognitive impairment in older adults. We designed and implemented two-level 4Active intervention for older adults living in retirement communities. This study aimed to examine the effectiveness of the 4Active intervention in increasing physical activity and cognitive function in older adults. Fifty-eight eligible older adults with a mean age of 83.83 years (76.3% females) living in two retirement communities voluntarily participated in this study. Forty subjects participated in the two-level 4Active intervention for 12 weeks and 18 subjects were in the control group. Each participant was pre-and posted tested on physical activity (PA) and cognitive flexibility. Data were analyzed by means of descriptive statistics, independent sample t-tests, and Analysis of

Covariance (ANCOVA) with repeated measures. ANCOVA with repeated measures indicated that the intervention group had overall higher levels of the total PA and the moderate PA than the control group (F = 11.838, p = 0.001, η^2 = 0.180; F = 11.068, p = 0.002, η^2 = 0.170). For light PA, ANCOVA revealed a significant interaction effect between time and group (F = 8.477, p = 0.005, η^2 = 0.136). The intervention group showed increases in light PA (walking) with a medium effect size (Cohen's d = 0.538) over time, while the control group decreased light PA from baseline to the post-test. Regarding the results of cognitive flexibility, the ANCOVA with repeated measures revealed that intervention group had overall higher levels of cognitive function compared to the control group (F = 7.88, p = 0.007, η^2 = 0.129). Both groups showed significant increases in cognitive flexibility over time (F = 6.68, p = 0.013, η^2 = 0.112), but the intervention group had a smaller change in cognitive flexibility over time compared to the control group (F = 6.75, p = 0.012, η^2 = 0.113). Engaging in technology-enhanced multicomponent exercises is an effective approach to contributing to physically active and cognitively competent aging.

Keywords
Geriatric population; physical activity; wearable technology; cognition

1. Introduction

The prevalence of mild cognitive impairment associated with advanced age is alarming. The mild cognitive impairment incidence was 22.5% per 1000 person for older adults aged 75–79, 40.9% for ages 80–84, and 60.1% for ages 85+ [1]. Older adults aged 80 years and older accounted for 63% of older adults with dementia [2]. Moreover, the aging population is growing. By 2040, older adults are expected to comprise 21.7% of the US population, and the oldest-old population is projected to more than double from 2016 (129% increase) [3]. With this fast growing geriatric population, there is a public health urgency to identify effective intervention strategies for preventing or delaying the age-related cognitive decline and impairments in older adults [1-3].

In order to ensure healthy aging, the 2018 Physical Activity (PA) Guidelines recommend that older adults participate in at least 150 minutes of moderate PA per week (U.S. Department of Health and Human Services [4]. Unfortunately, a national survey with objective measures of PA showed that less than 3% of older adults met the recommended weekly minutes of PA [5]. In particular, older adults aged 80 years and over sharply decreased their PA levels compared to older adults aged 75-79 years [6]. Factors that facilitate or inhibit oldest-old adults' PA behaviors are significantly associated with age-related loss of functional fitness and stamina, chronic conditions, fear of falling, lack of self-efficacy and role model, social support, and weather and access to facilities [6-8]. Currently, 4-10% of older adults live in retirement communities [9]. Older women account for the majority of the residents in retirement communities as they live longer than men [6]. With greater levels of frailty, older women were less physically active compared to older men. In addition, residents living in retirement communities have lower overall PA levels than community-dwelling older adults [10]. They spend the majority of time sitting and only 10-15% are physically active [9].

PA is essential to delaying cognitive decline and preventing cognitive impairment in older adults. Several intervention studies have shown beneficial effects of aerobic exercise for cognitive functions in older adults [11-13]. Kramer et al. [12] reported that older adults aged 60-75 years participating in a 6-month aerobic activity (walking) intervention showed significantly increased executive functions compared to those in the stretching exercise control group. Similarly, Albient et al. [11] observed that older adults aged 65-78 years, who completed 12 weeks of aerobic training, demonstrated significantly greater improvement in cognitive performance on the Wisconsin Card Sorting Test than the participants in the stretching control group. In addition, previous studies have demonstrated positive effects of resistance training on cognition in older adults. Cassilhas et al. [14] showed that older adults aged 65-75 years improved their memory performance and verbal concept formation after completing a 6-month moderate-to-high intensity resistance training program. Liu-Amgrose et al. [15] reported older adults aged 65-75 years significantly improved their cognitive performance on the Stroop Test after completion of a 12-month resistance training program. Moreover, meta-analyses and reviews have reported that combining aerobic and strength training, balance and resistance training, or other multicomponent PA interventions produced greater improvement in cognitive function (i.e., memory, attention, and cognitive flexibility) compared to a single type of exercise regimen, alone [6, 7]. However, most of the existing research was conducted in young-old adults and limited research has been conducted in the old-old and oldest-old.

To effectively promote PA participation and to maximize its beneficial effects on cognitive functions in older adults in retirement communities, researchers have used the Social Ecological Model to design multilevel PA interventions. The Social Ecological Model posits that an individual's PA behaviors are shaped by the dynamic interaction between individual, interpersonal, and environmental factors, as well as public policy [16]. The individual-level refers to knowledge, skills, self-efficacy, motivation, and personal characteristics that are determinants of one's PA behavior change. The interpersonal-level involves social interaction, social relationship, and social support that are facilitating factors for an individual's PA behavior change [16]. Supporting the premise of the Social Ecological Model, a study [17] found that a 12-month multilevel PA (walking) intervention significantly increased moderate-to-vigorous PA (MVPA) by 56 minutes/week and light PA by 119 minutes/week among older adults with a mean age of 82 years, compared to no change in the control participants with a mean age of 85 years. This study was conducted in a temperate climate. However, a year-round multilevel walking intervention is not feasible for older adults living in other parts of the US. In addition, the PA Guidelines recommend that older adults should engage in multicomponent PA, including aerobic endurance, muscle-strength, flexibility and balance exercises [4]. In line with the PA guidelines, systematic reviews confirm that walking, strength, balance, and flexibility exercises are the most common forms of PA for older adults. These activities are low-to-moderate in intensity, safe, and suitable for older adults [18].

We used the Social Ecological Model as the framework for designing an interpersonal-level and individual-level multicomponent PA intervention, name 4Active, to increase PA participation and cognitive function in older adults living in retirement communities. The purpose of this study was to examine the effects of the two-level 4Active intervention on PA participation and cognitive function in older adults living in retirement communities. We hypothesized that the two-level 4Acctive intervention group would show greater improvement in weekly PA minutes and cognitive function than the attention control group. This study addresses a gap in the research related to the cognitive effects of exercise and PA behavior change in old-old and oldest-old adults.

2. Materials and Methods

2.1 Participants and Study Design

We recruited two local retirement communities to participate in this study, each with at least 150 residents and similar socioeconomic status and racial/ethnic backgrounds. Each located in the same township of the same state in Midwest region USA. We sent a letter of invitation to the site administrators and followed-up with emails and in-person meetings. After receiving administrative approval from each site, we recruited older adult residents to participate by distributing flyers, giving recruitment presentations and word-of-mouth. Eligibility criteria included being 65 years old or older with a Mini-Cog™ test score ≥3 [19] and able to: (a) walk for 10 feet without human assistance (with cane or walker use allowed); (b) read and write in English; (c) exercise safely as determined by a healthcare provider; (d) complete the study questionnaires and tests; and (e) provide written consent.

Trained research staff screened potential subjects (n = 62) by administering the Mini-Cog test followed by the Timed Up and Go (TUG) test [20]. Individuals were excluded if it took them more than 30 seconds to complete the TUG test with a walking aid if needed [20]. As a result of the screening test, 59 were eligible subjects for this study while three did not pass the TGU test. The University Institutional Review Board-Health Sciences and Behavioral Sciences (IRB-HSBS) approved this study (HUM00158279). We conducted this study in accordance with the principles of the Declaration of Helsinki. Participants signed a consent form prior to the start of the study. The ClinicalTrials.gov ID is NCT05233813.

This study used a two-arm, quasi-experimental design based on participants' preference to be the intervention or the control group. Forty-one older adults were in the intervention group and 18 were in the attention control group. One participant in the intervention group dropped off the study during the first week of the intervention because she disliked wearing the Fitbit tracker on her wrist due to a technical issue. Fifty-eight people with a mean age of 83.83 years (76.3% females) completed the study. The outcome measures were tested before (baseline) and after the 12-week intervention (post-test). Figure 1 illustrates the study design and enrollment.

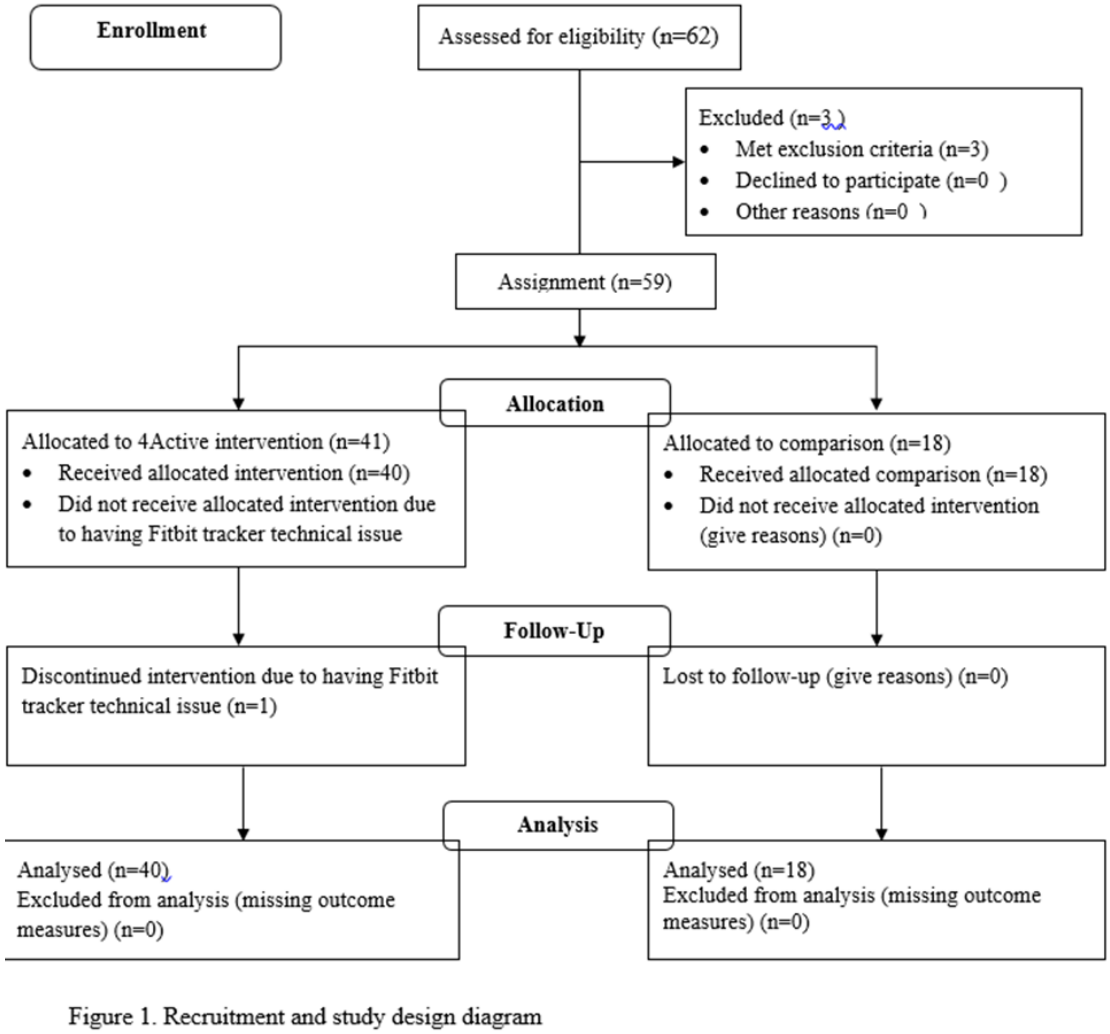

Figure 1 Recruitment and study design diagram.

2.2 Two-Level 4Active Intervention Group

The intervention group attended the two-level 4Active intervention over the course of 12 weeks. At the interpersonal-level, the participants attended 36, 45-minute multicomponent exercise sessions taught by well-trained, on-site exercise instructors (three, 45-min lessons per week for 12 weeks). Each exercise session used a structured format, consisting of 10 minutes of warm-up (e.g., walking in place with different directions, stretching exercises), 30 minutes of fitness exercises, including strength, balance, and coordination, and 5 minutes of cool down, containing stretching exercises and breathing.

The exercise instructors used physical fitness training principles such as progressively overloaded, specificity, and individual difference accommodation to designing the scope and sequence of the exercises sessions. The instructors started the exercise sessions in the first 4-week with light to moderate intensity levels of multicomponent exercises. For example, the participants performed marching in place slowly and a little fast, walking while changing basic steps to the music with 70-100 bpm; performed each strength exercise with 8-10 repetition and one set; balanced on both feet with focusing on shifting body weight, rocking; and performed stretching exercises with their preferred range of motion). Then, the instructors progressively increased some elements of intensity, duration, and types for the second 4-week exercise sessions (e.g., walking while changing directions, speeds, force, and walking patterns to the music with 100-120 bpm; performing each strength exercises with 10-12 repetition and using resistance bands and weighted balls, performing balances on one foot and alternate foot with extending free foot in different ways; slowing increasing the range of motion for specific stretching exercises). For the last 4-week exercise sessions, the instructors primarily used moderate intensity level of multicomponent fitness exercises. For instance, the participants walked with different steps, directions to the music 120-140 bpm; performed each strength exercises with moderate and/or heave resistance bands and increased weighted balls (e.g., 2 lbs. to 5 lbs.); increased variety of balance exercises (such as balance on one foot while making different shapes like trees, birds, airplanes); and performed stretching exercises with an increased range of motion. To accommodate individuals' differences, teaching each session, the instructors presented and demonstrated one or two modifications of performing each exercise task and invited the participants to choose whichever way they preferred to in terms of marching/walking pace, numbers of repetition, use or not use equipment, standing position or sitting position for performing strength exercises, adjust their range of motion to perform each strength exercise and stretching exercise. In short, presenting and demonstrating modification tasks for each exercise is a routinized instructional strategy.

At the individual-level, each participant wore a Fitbit (Model Inspire) activity tracker daily, 5 days a week for 12 weeks, to self-monitor daily PA behaviors. Prior to distributing the tracker, we created a synced Fitbit account using Fitabase software for the participants because most of them did not use a smartphone. We used a one-hour hands-on presentation to: (a) introduce the basic features of the trackers; (b) provide step-by-step hands-on guidance for how to initialize the tracker and how to self-check steps, distance traveled, calories burned, and heart rate; and (c) explain the protocols for wearing the Fitbit tracker and returning it each week to the designated place. The research team collected the trackers every Friday late afternoon, uploaded each participant's real time PA data using the Fitabase software, and charged the device over the weekend. We returned it to each participant every Monday morning.

We incorporated a goal-setting strategy into the individual-level intervention. Every Monday morning, we provided each participant with the Weekly Individual PA Report with graphs and numbers, showing their daily steps during the previous week. In conjunction with that, each participant received their personalized Daily Step Goal Sheet in which their current daily steps were highlighted and their daily step goal for the next two weeks was suggested. Accordingly, each participant was encouraged to increase their current daily step counts by 1,000 to 1,500 every two weeks with the ultimate goal of 7,500 steps per day [21]. Participants who reached 7500 steps/day were asked to maintain their PA level.

2.3 Control Group

The participants in the control group were asked to do their usual activities. For example, some of them indicated that they did exercises on their own like walking around the senior living apartment, and performing Tai Chi. We controlled for the attention received by the intervention group by sending the control group newsletters. The topics were physical, cognitive, social, and mental health benefits of PA every other week during the 12 weeks.

2.4 Outcome Measures

Outcome measures were conducted one week before and after the 12-week intervention at the two retirement communities. Trained research staffs administered the computerized tablet NIH Toolbox_Dimensional Change Card Sort Task (DCCS) and the International Physical Activity Questionnaire to each participant individually within a 30-minute testing schedule at pre-test and post-test. Prior to administer the IPAQ questionnaire, each trained research staff asked a participant to respond to a demographic questionnaire, consisting of age, gender, marital status, education, self-reported body weight and body height, and self-rated health, and then to complete the IPAQ, followed by taking the DCCS test.

2.4.1 The International Physical Activity Questionnaire-Short Form (IPAQ-S)

The participants responded to seven questions on the IPAQ-S [22] to self-report time spent in vigorous and moderate physical activity, walking, and sitting during the past 7 days. According to the standard scoring guidelines [22], times spent walking, in moderate-intensity PA, and in vigorous-intensity PA were multiplied by 3.3, 4.0, and 8.0 respectively to calculate the MET-min/week. A total PA MET-min/week was computed as the sum of the Walking + Moderate + Vigorous MET-min/week scores. A minimum of at least 600 MET-min/week for the total PA is indicative of “minimally active”. A minimum of at least 3000 MET-min/week for the total PA is considered to be “health-enhancing physically active”. Not meeting the criteria for the “minimally active” category is classified into the “inactive” category [22]. The IPAQ-S has proven to be a reliable and valid measure of physical activity for older adults [23].

2.4.2 The NIH Toolbox Dimensional Change Card Sort Task (DCCS)

The DCCS is an iPad-administered measure of cognitive flexibility and executive ability included as a subtest in the NIH Toolbox—Cognition Battery. The DCCS consists of three types of matching tasks with shapes and colors. Scoring is based on a combination of accuracy and reaction time. It takes 4 minutes to complete the test. The computed score for accuracy and reaction time is generated automatically by the NIH Toolbox—Cognition test apps and can range from 0-10 [24]. This test of executive function and mental flexibility has demonstrated superior test-retest reliability in adult populations [25].

2.5 Statistical Analysis

Descriptive statistics, skewness and kurtosis were calculated for all variables. The attendance rate was calculated by dividing the number of group exercise sessions attended by the total number of group exercise sessions. Wearing time for the Fitbit tracker was calculated by dividing the number of days worn by the number of total required days. The two groups were compared at baseline with independent sample *t*-tests (Welch’s test without equal variance assumption). If a covariate was significantly different at baseline between the two groups, it was controlled for in the Analysis of Covariance (ANCOVA) with repeated measures for the major outcomes. To test the intervention effect on cognitive function and PA variables, a 2×2 ANCOVA with repeated measures was computed. At pre-test, age and cognition were significantly different between the two groups. Therefore, age was controlled for each outcome and pretest cognition was controlled for all PA-related outcomes. All analyses were performed using SPSS 26.0, and the significance level was set at $p < 0.05$, throughout.

3. Results

3.1 Baseline Characteristics and Adherence Rates

Baseline characteristics and outcome variables are presented in Table 1. Forty-five percent of the intervention group were “old-old” (between 75-84 years,) and 55% were “oldest-old” (age of 85 years and the above) [26]. In contrast, 27.8% of the control group were “young-old” category (age ranging from 65-74 years), 27.8% were “old-old” and 44.4% were “oldest-old.” The intervention group was significantly older than the control group (t = 2.42, p = 0.025). The intervention group had a marginally higher score for self-rated health compared to the control group (t = 1.93, p = 0.059).

Table 1 Summary of baseline characteristics.

	Intervention group (n = 40)	Control group (n = 18)	Total (n = 58)	*p* value
Age (years)	85.4(5.18)	80.3(8.16)	83.4(6.61)	0.025*
65-74	0 (0%)	5 (27.8%)	5 (8.6%)	
75-84	18 (45%)	5 (27.8%)	23 (39.7%)	
≥85	22 (55%)	8 (44.4%)	30 (51.7%)	
Gender				0.327
Male	8 (20%)	6 (33.3%)	14 (24.1%)	
Female	32 (80%)	12 (66.7%)	44 (75.9%)	
Education				0.189
No high school	2 (5%)	1 (5.6%)	3 (5.2%)	
High school	21 (52.5%)	6 (33.3%)	27 (46.6%)	
Bachelor degree	17 (42.5%)	11 (61.1%)	28 (48.3%)	
Marital Status				0.204
Married	13 (32.5%)	9 (50%)	22 (37.9%)	
Not married	27 (67.5%)	9 (50%)	36 (62.1%)	
Self-rated health	3.43 (0.75)	3.00 (0.84)	3.29 (0.79)	0.059
Cognition	6.96 (0.80)	6.04 (1.76)	6.67 (1.25)	0.046*
Total PA (MET-min/week)	1195.0 (752.3)	828.1 (805.84)	1081.1 (781.2)	0.112
Vigorous PA (MET-min/week)	6.0 (27.9)	0 (0)	4.1 (31.5)	0.323
Moderate PA (MET-minutes/week)	698.5 (461.8)	237.8 (425.3)	555.5 (496.1)	0.001**
Light PA (MET-minutes/week)	490.5 (421.2)	575.6 (1.14)	521.5(471.6)	0.515

Note: **: $p < 0.01$; *: $p < 0.05$

Baseline cognitive function was significantly higher in the intervention group than the control group (t = 2.13, p = 0.046). The baseline Total PA was <3000 METs-min/week for both groups, indicating minimally active. At baseline the moderate PA METs-min/week was greater in the intervention group compared to the control group (t = 3.72, p = 0.001) and the other three baseline PA variables were not significantly different between the two groups (p > 0.05).

Regarding gender, the majority of the participants were women (75.95% vs. 24% men). The percentage of women (80%) in the intervention group was not significantly different from the percentage of women (66.7%) in the control group. For education, 48.3% of the participants had bachelor degree while 46.6% had high school diploma. Similarly, no significant difference in education between the intervention group (42.5% receiving bachelor) and the control group (61.1% receiving bachelor) was found. With respect to marriage, 62.1% of the participants did not married. No significant difference in marriage between the intervention group (67.5% not married) and the control group (50% no married) was observed.

Adherence to the interpersonal-level and individual-level intervention was high, the intervention group attended 86.9% of group exercise sessions and wore the Fitbit tracker on 97.5% of the required days.

3.2 Intervention Effects on PA

Table 2 presents descriptive statistics of cognitive function and PA variables at baseline and at post-test with the results of paired-sample t-tests and of effect size (Cohen's *d*) over time by group. Regarding the effect size seen in Table 2, the intervention group had large increase in light PA (walking), a moderate increase in vigorous PA, and total PA, and no change in moderate PA from baseline to the post-test. In contrast, the control group showed a moderate increase in moderate PA, no change in total PA and vigorous PA, but a moderate decrease in light PA (walking) over time.

Table 2 Cognitive function and PA variables at baseline and at post-test with paired-sample t tests.

	Intervention			**Control**		
	Mean	SD	*P* **Cohen's *d***	Mean	SD	*P* **Cohen's *d***
Baseline Cognition	6.96	0.8	0.153	6.04	1.76	0.013*
Post-test Cognition	7.21	0.94	**0.286**	6.7	1.28	**0.429**
Baseline Total PA	1195	752.3	0.025*	828.1	805.9	0.925
Post-test Total PA	1559	1080.4	**0.391**	844	727.8	**0.021**
Baseline Vigorous PA	6	27.9	0.129	0	0	0.187
Post-test Vigorous PA	150	602	**0.338**	20	61.7	**N/A**

Baseline Moderate PA	698.5	461.8	0.64	237.8	425.3	0.085
Post-test Moderate PA	657	466.7	**-0.089**	471.1	563.4	**0.467**
Baseline Light PA	490.5	321.2	0.011*	590.3	575.6	0.074
Post-test Light PA	752	608.3	**0.538**	352.9	292.6	**-0.52**

*Note: **: $p < 0.01$; *: $p < 0.05$.*

Table 3 presents the results of ANCOVA with repeated measures. For total PA and moderate PA, there was a significant main effect of group (F = 11.838, p = 0.001, η^2 = 0.180; F = 11.068, p = 0.002, η^2 = 0.170), but no significant main effect of time or interaction effect of time with group. The results indicated that the intervention group had overall higher levels of the weekly total PA and the weekly moderate PA than the control group. For vigorous PA, the ANCOVA with repeated measures showed no significant main effects for time, group or interaction between time and group.

Table 3 Results of ANCOVA with repeated measures for the outcomes.

	Cognition			Total PA			Vigorous PA			Moderate PA			Light PA		
	F	p	η^2	F	p	η^2	F	p	η^2	F	p	η^2	F	p	η^2
Time	6.68	0.013*	0.112	1.211	0.276	0.022	1.457	0.233	0.026	0.071	0.791	0.001	0.186	0.668	0.003
Group	7.88	0.007**	0.129	11.838	0.001*	0.18	1.557	0.218	0.028	11.068	0.002*	0.17	5.223	0.026*	0.088
T*G	6.75	0.012*	0.113	3.515	0.066	0.061	1.524	0.222	0.027	1.329	0.254	0.024	8.477	0.005**	0.136
Age	4.61	0.036*	0.08	7.387	0.009**	0.12	1.753	0.191	0.031	3.926	0.053	0.068	4.864	0.032*	0.083
Pre_C				0.983	0.326	0.018	0.007	0.934	0	0.244	0.623	0.005	1.654	0.204	0.03

Note: T*G: Time * Group; **: $p < 0.01$; *: $p < 0.05$, Pre_C: Pretest Cognition.

Regarding light PA minutes (walking), the ANCOVA revealed a significant interaction effect between time and group (F = 8.477, p = 0.005, η^2 = 0.136). The results indicated that the intervention group showed increases in weekly light PA with a medium effect size (Cohen's d = 0.538) over time, while the control group decreased weekly light PA minutes from baseline to the post-test. Age was a significant covariate for total PA (F = 7.387, p = 0.009, η^2 = 0.120) and light PA (F = 4.864, p = 0.032, η^2 = 0.083), but not for vigorous PA and moderate PA.

3.3 Intervention Effects on Cognition

Regarding effect size for cognitive function presented in Table 2, both groups showed moderate increase from baseline to post-test. As seen in Table 3, while statistically controlling for age and baseline cognition scores, the ANCOVA with repeated measures revealed significant main effects of time (F = 6.68, p = 0.013, η^2 = 0.112) and group (F = 7.88, p = 0.007, η^2 = 0.129). In addition, there was a significant interaction effect between time and group (F = 6.75, p = 0.012, η^2 = 0.113). The results indicated that both groups showed a significant increase in cognitive function from baseline to post-test, with intervention group's testing score in DCCS increasing from 6.96 to 7.21 and control group's testing score in DCCS increasing from 6.04 to 6.70. The intervention group had overall higher levels of cognitive function compared to the control group, but the intervention group had a smaller change in cognitive function over time compared to the control group. Age was a significant covariate of cognitive function (F = 7.88, p = 0.007, η^2 = 0.080).

4. Discussion

As hypothesized in this study, participants in the two-level 4Active intervention reported an increase in total PA compared to the counterparts in the control group. The reported increase in total PA was accomplished primarily by increasing energy expenditure in vigorous and light PA. Participants in the intervention group had a mean age 85.4 years, 45% were old-old and 55% were the oldest-old. In addition, 80% of the intervention participants were women. Although advanced age (80 years and over) and women were two sociodemographic factors contributing less physically active [6-9], the intervention participants with more than half being advanced age and most being women did not prevent them from making large increases in vigorous and light PA over time. The beneficial effects of this intervention are promising for old-old and oldest-old participants, especially for women.

It is of worth noting that the intervention participants essentially participated in little or no vigorous PA at baseline, but they reported the greatest magnitude of increase in light PA, followed by vigorous PA at post-test. In contrast, the control participants decreased their light PA engagement by-222.7 METs-min (38.7%), and almost did not engage in any vigorous PA from baseline to the post-testing, but doubled increases in moderate PA over time. Their total PA were relatively stable over time. One possible reason for the intervention group's pronounced increase in total PA, especially in vigorous and light PA, might be related to the participants' high adherence to attending group exercise sessions and engaging in daily Fitbit-based self-exercises. The findings are consistent with a prior research that studied a 12-month three-level intervention with individual-level (goal setting), interpersonal-level (group walks), and the community-level (pedestrian advocated improvement in walk ability) components [17]. In that study older adults in the intervention group, with a high adherence to attending group sessions (82%) and phone counseling (90%), and a daily increase of 1000 steps (90%), significantly increased their activity by 56 minutes a week of moderate-to-vigorous PA (MVPA) and by 119 minutes a week of light PA compared to no change in the control group [17].

This study suggests that the two-level 4Active intervention strategies were effective in increasing PA. The results are consistent with an exercise-specific self-efficacy enhancing intervention for middle-old adults with chronic disease [27, 28]. In addition, the strategies employed in this intervention are similar to the strategies employed in the self-efficacy enhancing intervention [27, 28]. At the individual-level participants were invited to use an iterative process of goal-setting, self-monitoring of daily steps, and weekly feedback for setting up their next daily step goal. At the interpersonal-level they had opportunities to interact with one another and provided social supports for each other. The group exercise sessions were conducive to developing a sense of community and dynamic coherence [27, 28].

We believe that regular participation in the group exercise sessions helped equip participants with knowledge and skills to perform multiple forms of exercise at home. They were encouraged to apply what they had learned from the group lessons to engage in the Fitbit-based self-exercises on a daily basis. The process of learning, applying, and mastering knowledge and skills further empowered the participants and gave them a sense of autonomy and competence for being physically active and socially engaged. These results are consistent with the Social Ecological Model [16].

Further confirming the hypothesis in this study, the results are promising in terms of the intervention effects on cognitive function for old-old and oldest-old participants. First, the intervention participants' significant increases in DCCS with a moderate effect size over time were observed, despite the fact that they started out with higher scores at baseline compared to the control group. The intervention participants' baseline testing score on the DCCS was 6.96 (SD = 0.80), almost identical to the median score (6.95) of the DCCS norms for older adults aged 75-85 years [24]. In contrast, the control participants' baseline DCCS score was 6.04 (SD = 1.76). Second, the intervention participants were old-old and oldest-old and previous studies have shown that declines in executive functions (i.e., inhibition control, cognitive flexibility, decision making) are typically observed at a very advanced age [29]. In addition, proportion of the intervention participants receiving a bachelor degree was 42.5%, while the proportion of the control participants receiving bachelor degree was 61.1%. Despite their age and education, the intervention group increased their DCCS score (Mean = 7.21) and came close to the 75th percentile for the DCCS norms (7.61) for older adults aged 75-85 years [24]. Conversely, although the control participants significantly increased their DCCS score (Mean = 6.70) with a moderate effect size over time, the DCCS score was lower than the median score of the DCCS norms for older adults. It is important to note that notwithstanding the ceiling effect, the intervention group demonstrated positive intervention effects on improving DCCS score.

Supporting the positive effects of PA on improvement in cognitive function for older adults [6, 7], the present study indicated that the intervention participants' increased weekly light PA (walking), vigorous PA, and total PA participation and maintenance of weekly moderate PA level over time were instrumental to improving their cognitive function, even though more than half of them were the oldest-old. On the other hand, the control group's moderate magnitude of increase in weekly moderate PA might be related to their increase in cognitive function over time as well.

Further, our study suggests that multicomponent exercises was particularly important in improving in cognitive function for the oldest-old and the old-old adults. Consistent with the present results, previous studies demonstrated that multicomponent exercises were more effective in enhancing cognitive function for older adults. For example, in a study of examining the effects of a 24-week combination of 45-minute multicomponent exercise and 15-minute Square-Stepping Exercise (SSE) (cognitive-motor dual task) on cognitive function in older adults, the intervention participants showed greater improvement in global cognitive functioning and memory than the control counterparts [30]. Similarly, after participating in the combination of 30-minute flexibility and strength exercises and 60-minute cognitive-motor dual tasks for 12 weeks, older adults significantly improved memory and executive functions, compared to 24 older adults who did their usual activities [31]. However, interventions that focus on a single physical activity such as walking have been less successful in improving cognitive function. In a 12-month multilevel walking intervention study by [32], the older adults engaged in goal setting with the use of pedometer to self-monitor their walking steps at the individual-level, and group walking at the interpersonal-level on the renovated walking paths at the community-level. Zlatar et al. [32] found that the intervention participants with a mean age of 82 years did not significantly improve their cognitive performance on the Trail Making Test over time, compared to the participants in the attention control group.

When performing stretching, strength, and balance exercises regardless of whether it is in a group setting or on their own, the older adults must pay attention to the execution of different exercise tasks and coordinate different body parts in a specific sequence to complete the task [29-31]. These coordinated neuro-motor exercises involve more cognitive functions, such as attention control, information processing, episodic memory, visual and spatial memory, task switching, decision making, compared to simple motor tasks, like walking [29-31]. Neuroimaging studies showed that when performing novel and complex cognitive and motor tasks in changing environments, the neural network between the cerebellum, basal ganglia, and prefrontal cortex are connected and co-activated [29, 33].

Despite the unique contributions to the theoretical and empirical literature on PA and cognitive function in older adults, this study has several limitations. First, the study design was limited to use of the quasi-experimental design. The participants were not randomly assigned to either the intervention or the control group although significant covariates at baseline between the two groups were controlled. Future studies may use a randomized controlled trial to avoid self-selection bias. Second, the duration of the two-level 4Active intervention was limited to 12 weeks. Implementation of a long-term intervention should be warranted in future studies. Third, the study was limited to examining the immediate effects of the 12-week two-level 4Active intervention on PA and cognitive cognition. The study took place during fall of 2019. Our original study design was to conduct a 6-month follow up test after the intervention, which was scheduled in May of 2020 in order to examine a long-term effect of the 12-week intervention on the two outcomes. However, we had to stop our follow-up test plan due to the outbreak of the COVID-19 in middle of March 2020 and the lock down order. Long-term effects of the intervention should be explored in future studies. Fourth, the generalizability of the results was limited to white older adults and future studies should include diverse geriatric populations. Last, the intervention participants were asked to wore the Fitbit tracker during weekdays (Monday through Friday) to self-monitor their PA data, however, they were not asked to wear it on Saturday and Sunday because these two days were used to download each tracker's data and to charge the battery of each tracker for the participant over the course of 12 weeks. This study suggests that future studies may consider to ask participants to wear it on both weekdays and one of weekend days to better serve the needs of participants who tend to engage in PA more on weekend days.

5. Conclusions

We conclude that regularly attending group-based multicomponent exercises and performing technology-enhanced self-exercises using self-efficacy strategies concurrently are effective intervention strategies for increasing overall weekly PA and Light PA (walking) for the old-old and the oldest-old adults. Further, performing cognitively-engaged and coordinated motor tasks simultaneously, both in group settings and on their own over the course of 12 weeks, show promising improvement in cognitive flexibility, one key component of executive functions among the old-old and the oldest-old adults. This study suggests that engaging in technology-enhanced multicomponent exercises is an empirically evident approach to contributing to physically active and cognitively competent aging.

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Author Contributions

WC: Conceptualization, Methodology, Investigation, Resources, Writing-Original draft preparation. **ZZ**: Methodology, Investigation, Formal Analysis, Writing-Original draft preparation. **BG**: Conceptualization, Methodology, Writing-Reviewing and Editing. **JL**: Conceptualization, Writing-Reviewing and Editing. All authors have read and approved the manuscript.

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Competing Interests

The authors declare that they have no competing interests.

Availability of data and materials

The data that support the findings of this study are available on request from the corresponding author [WC]. The data are not publicly available due to them containing information that could compromise the privacy of research participants.

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