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Alzheimer's & Dementia

Featured Article

Feasibility of an at-home, web-based, interactive exercise program for older adults

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Abstract

Introduction: Increased physical exercise is linked to enhanced brain health and reduced dementia risk. Exercise intervention studies usually are conducted at facilities in groups under trainer supervision. To improve scalability, accessibility, and engagement, programs may need to be structured such that individuals can execute and adjust routines in their own homes.

Methods: One hundred eighty-three healthy older adults from two sites (the United States and Sweden) were screened. One hundred fifty-six subjects (mean age 73.2), randomly assigned to one of four interventions (PACE-Yourself physical exercise program, mindfulness meditation, or Cogmed® adaptive or nonadaptive computerized working memory training) began the study. All interventions were structurally similar: occurring in subjects' homes using interactive, web-based software, over five weeks, ∼175 minutes/week. In the PACE-Yourself program, video segments presented aerobic exercises at different pace and intensity (P&I). The program paused frequently, allowing subjects to indicate whether P&I was "too easy," "too hard," or "somewhat hard." P&I of the subsequent exercise set was adjusted, allowing subjects to exercise at a perceived exertion level of "somewhat hard." Program completion was defined as finishing ≥60% of sessions.

Results: A high percentage of participants in all groups completed the program, although the number (86%) was slightly lower in the PACE-Yourself group than the other three. Excluding dropouts, the PACE-Yourself group had a lower adherence rate of 93%, compared with the other three (∼98%). Over the five weeks, PACE-Yourself participants increased exercising at the highest intensity level, consistent with augmented aerobic activity over time. The number of exercise sessions completed predicted the postintervention versus preintervention increase in self-reported level of physical activity.

Discussion: This study supports the feasibility of a home-based, subject-controlled, exercise program in which P&I is regulated via real-time participant feedback, which may promote self-efficacy. Further study is needed to determine if similar results are found over longer periods and in more diverse populations.

Keywords: Physical exercise program; Older adults; Brain health; Dementia risk; Adherence; Feasibility; Interactive; Self-efficacy; Web-based; At-home

The authors have declared that no conflict of interest exists.

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1. Background

Physical exercise has been shown to be a critical component of health and well-being. There is evidence that increased physical activity may reduce the risk of cardiovascular disease, diabetes, cognitive decline, and dementia, improve mood and sleep, and decrease the likelihood of falls in older adults [1–8]. Epidemiological studies suggest that physical inactivity substantially increases the risk of developing dementia [9,10] and that individuals who engage in higher levels of physical activity are less likely to become demented [11,12]. Although results have varied, intervention studies suggest that physical exercise programs can lead to improvements in cognitive functioning among older adults [1,13–15].

The world's aging population is increasing at a faster rate than ever before. In 2016, the World Health Organization and the U.S. Census Bureau estimated there were 617 million people aged 65 years or older and projected a nearly three-fold increase to 1.6 billion by 2050 [16]. Most older adults experience some degree of cognitive decline due to normal aging [17,18], but many will suffer from debilitating symptoms of dementia [19–21]. Without the development of effective interventions, in the United States alone, the number of older adults living with Alzheimer's disease is expected to increase from approximately 5.7 million in 2018 to 14 million by 2050 [22].

The World Health Organization and the U.S. Department of Human and Health Services recommend that adults (including those 65 years and older) should complete 150 minutes of moderate-intensity aerobic exercise per week, 75 minutes of vigorous-intensity aerobic exercise per week, or an equivalent combination of the two intensities, with supplemental muscle-strengthening activities on two or more days of the week [23,24]. However, the Centers for Disease Control reported in 2018 that only 23% of Americans were meeting physical activity guidelines [25]. Clearly, participating in sufficient physical activity is not easily achieved. Some strategies that individuals might use to maintain consistent exercise habits include joining fitness centers, enrolling in fitness programs, or hiring personal trainers. However, many individuals cannot afford these kinds of opportunities. In addition, as a group, older adults face barriers to accessing such resources, including lack of reliable transportation [26]. In addition, environmental challenges, such as snow and ice during the winter or heat and humidity in the summer, are potentially dangerous for older adults and may discourage them from physical exercise [14]. An at-home, web-based physical exercise program would not only address these limitations, but also increase accessibility by allowing exercise programs to be scaled for participation by a larger number of people [27–29]. To date, single-domain interventions for older adults that have focused on exercise [13,15], or multidomain interventions [30,31] that have included exercise as a critical component, usually required participants to exercise at designated facilities, often in groups under trainer supervision. Even under these closely monitored and highly structured programs, adherence to the prearranged physical activity intervention has been challenging. For example, in the ground-breaking Finnish Geriatric Intervention Study to Prevent Cognitive Impairment and Disability (FINGER), only 48.5% of participants were adherent to the physical exercise component (i.e., completing $\geq$66% of prescribed interventions) compared with a 73.5% adherence rate to the nutrition component [30,32].

The present study investigated the feasibility of an at-home, web-based fitness program designed for older adults. Studies suggest that web-based exercise programs can be effective and economical [27–29]. Previous research has been directed toward young or middle-aged adults. To the best of our knowledge, none has concentrated on older adults. Our web-based fitness platform was designed to allow participants to exert real-time control over the pace and intensity (P&I) of their effort. There is evidence to suggest a link between self-efficacy (i.e., the belief in one's capacity to successfully execute courses of action) [33] and increased willingness to engage in higher levels of physical activity [34–36]. We compared completion rates and adherence rates of this physical exercise program to three other intervention arms of the same study. All arms were similar in that they were home-based, web-accessed, and computer-delivered, but the other three focused on cognitive stimulation and mindfulness.

2. Materials and methods

2.1. Participants and assessment

The Successful Aging and Enrichment study was a randomized controlled, two-site, single-blind trial of normal older adults. Participants were recruited (through community announcements) from the Boston, Massachusetts metropolitan area (population of ∼4,776,000) [37] and the Växjö municipality, a rural region in Sweden (population of ∼90,000) [38]. The study was approved by the respective ethical review boards at the participating research centers (Boston, Partners Human Research Committee; and Linnaeus University, Regional Ethical Committee). Before enrollment, participants completed written informed consent. They also completed a comprehensive screening assessment, including a structured interview to obtain a medical, neurological, and psychiatric history; a neurological examination; a neuropsychological evaluation; and a set of questionnaires surveying mood and daily living activities, including amount of physical activity as measured by the International Physical Activity Questionnaire (IPAQ) [39].

To be included in the study, participants had to be 65 years or older, English- or Swedish-speaking, have an estimated intelligence quotient (IQ) $\geq$90, as measured by the American or Sweden National Adult Reading Test (AMNART,

NART-SWE) [40,41]; score ≥26 on the Mini–Mental State Examination (MMSE); perform within one standard deviation of the mean for published age-based norms on the Logical Memory II test, a measure of delayed recall, from the Wechsler Memory Scale-Third Edition (WMS-III); and naming to confrontation, as measured by the Boston Naming Test [40]. In addition, participants had to be deemed by a physician to be healthy enough to exercise, regardless of the intervention arm to which they were randomized. This determination occurred before randomization.

Participants were excluded if they had a history of a central nervous system disease or a major ongoing psychiatric disorder based on DSM-IV criteria [42], demonstrated clinically significant symptoms of depression, with a score of ≥15 on the Geriatric Depression Scale [40], had focal abnormalities characteristic of a brain lesion as determined by a neurological examination, or a history of clinically significant medical diseases. Clinical history and baseline performance on neuropsychological tests helped identify subjects with mild cognitive impairment or early dementia, which would have excluded them from the study; however, none of the volunteers met criteria for either of these clinical entities.

2.2. Experimental procedure

Participants were randomized into one of four intervention groups: adaptive computerized working memory (WM) training, nonadaptive computerized WM training, mindfulness meditation, and physical exercise. Each of the interventions was structurally similar and conducted in subjects' homes, using interactive, web-based software over the course of five weeks. Participants completed five sessions per week and each session lasted for 35-40 minutes. Research assistants (RAs) offered in-person support by visiting subjects' homes to provide a 15.4″ laptop computer, internet access if needed, and an introduction to the training program that included a supervised demonstration session. RAs then communicated with subjects weekly by phone to address questions and to provide encouragement. RAs did not share training strategies.

In the following, we briefly summarize the four interventions, with an emphasis on the details of the PACE-Yourself physical exercise training program.

2.2.1. Working memory training and mindfulness meditation programs

The Cogmed® adaptive WM training was a program whose difficulty level was continually adjusted to ensure a consistently challenging task. The Cogmed® nonadaptive WM training was a program whose difficulty level remained the same. The mindfulness meditation training consisted of guided meditation and mindfulness-in-action tasks. See Supplementary Material S.1 for more information about these three interventions.

2.2.2. PACE-Yourself physical exercise program

The PACE-Yourself physical exercise program included 12 aerobic exercise routines prerecorded by the study team as video segments, accessible via a secure website. Examples of exercises include jogging-in-place, jumping jacks, and high-knees-to-elbows (Fig. 1). All exercises were recorded three times, each reflecting different degrees of P&I: low, medium, and high. For instance, the low P&I "jumping jack" consisted of toe taps from side to side, the medium P&I included arm movements, and the high P&I further added a jump to comprise a traditional jumping jack. Six additional exercises were recorded as warm-up and cool-down exercises, such as shoulder rolls, upper back spinal flexion stretch, and lunge stretch with hands on thighs. In each video, the instructor demonstrated a standing version, whereas one assistant demonstrated the exercises sitting in a chair and a second assistant demonstrated the exercise standing behind a chair for support. The instructor and two assistants were all older adults.

Participants were instructed to exercise at a perceived exertion of "somewhat hard," as characterized by the Borg Rating of Perceived Exertion (RPE) [43]. Studies applying the RPE suggest that an individual's perceived level of exertion correlates with heart rate and effort [43]. "Somewhat hard" requires moderate effort and encompasses activities such as brisk walking that increase heart and breathing rate, but not to the point that individuals feel out of breath [43].

The program software enabled subjects to make real-time adjustments to their exercise P&I, with the goal of maintaining an RPE of "somewhat hard." The exercise video paused every few minutes, asking subjects to indicate via touch screen or mouse whether the exercise P&I was "too hard," "too easy," or "somewhat hard," which determined the difficulty level demonstrated in the next set of exercises. If a subject selected "too easy," the following exercises were shown at a more challenging P&I. Selecting "too hard" decreased the P&I of the next set of exercises and selecting "somewhat hard" led to no change in P&I. Subjects were asked to match the demonstrated P&I as closely as possible. The software program also recorded the start and stop times for each

Fig. 1. Screenshot of exercise video.

session and number of exercises completed at each of the three levels of P&I. For each exercise, the duration of the three P&I options was approximately equal.

2.3. Outcome variables

Completion and adherence rates were calculated for participants in all four intervention arms. Completion of the intervention was defined as ≥60% of sessions completed; dropout as <60% of sessions completed. Completion rate was the number of individuals who completed the intervention divided by total participants. For all participants who completed the intervention, adherence rate was calculated as the number of completed sessions divided by total possible sessions. The data were analyzed to determine if results differed across groups.

For participants in the PACE-Yourself program, the amount of time spent at each of the three P&I intensity levels was recorded for each session and the percentage of time spent at each intensity level relative to the total time spent exercising at all of the intensity levels was calculated for each of the 5 weeks. The data were analyzed to establish if there were changes over the five weeks in the percentage of time spent at each intensity level.

Participants filled out the IPAQ before and after completing the intervention. The IPAQ surveys the amount of time subjects spent on vigorous, moderate, walking, or sitting activities over the past seven days. Data were then translated into a continuous score (MET minutes/week) to describe subjects' physical activity. The relationship between number of PACE-Yourself sessions completed per week and change in IPAQ score was tested using linear regression analysis.

3. Results

3.1. Participants

Participant enrollment is shown in Fig. 2, according to the CONSORT diagram. A total of 183 adults were screened for eligibility. Three did not satisfy inclusion criteria. The remaining 180 were randomly assigned to one of the four interventions. Twenty-four elected not to begin the program, evenly distributed across the assigned interventions (Kruskal–Wallis H test). These 24 subjects did not differ from the 156 subjects who began the program in terms of age, sex, education, or MMSE (Mann–Whitney U test). Table 1 provides the baseline demographic and neuropsychological

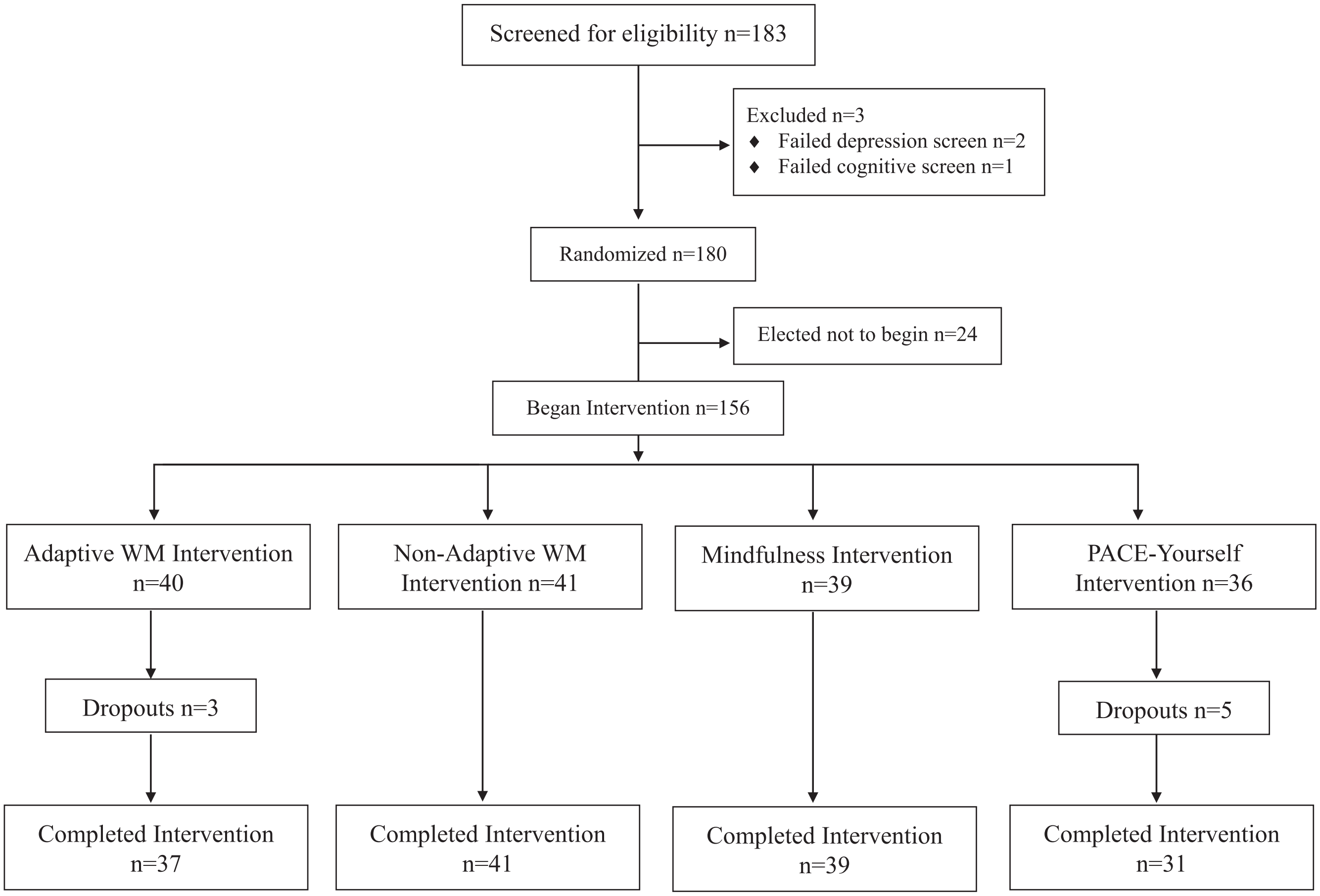

Fig. 2. CONSORT diagram of participant enrollment. Abbreviation: WM, working memory.

Table 1
Demographic information

	Adaptive (n = 40)	Control (n = 41)	Mindfulness (n = 39)	Physical (n = 36)	*P* value
Age (years)	73.0 (5.7)	73.8 (6.5)	72.3 (5.6)	73.6 (6.8)	.69*
Sex (M/F)	14/26	14/27	8/31	15/21	.26†
Education (years)	17.1 (8.6)	14.9 (4.0)	15.3 (3.7)	15.5 (4.0)	.29*
MMSE	29.3 (1.1)	29.1 (1.4)	29.3 (0.9)	29.3 (0.9)	.77*
NART (Estimated IQ)	123.5 (5.6)	120.2 (6.4)	124.2 (5.3)	125.4 (6.1)	.001*

*ANOVA.
†Kruskal–Wallis H Test.

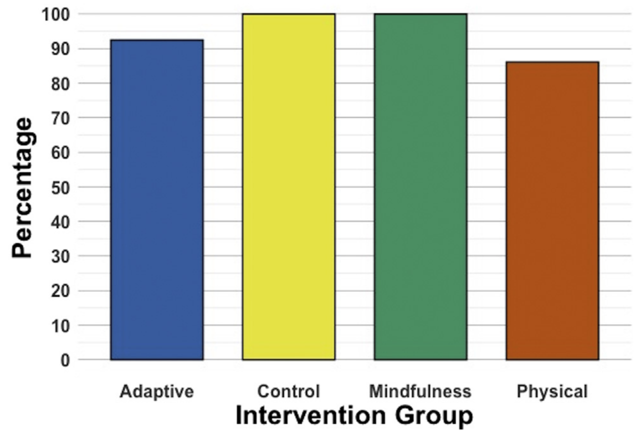

Fig. 3. Completion rate.

characteristics of the 156 participants, comparing subjects from each of the four interventions. There were no group differences in age, sex, education, or MMSE score. Participants in the nonadaptive WM training condition had slightly lower estimated IQ scores than those of the other three groups ($P < .001$). No serious adverse events occurred in any intervention group.

3.2. Completion rates across intervention groups

To determine attrition, we calculated the completion rate for each intervention group (Fig. 3). Three participants in the adaptive WM training program dropped out, one because of arm pain while using the computer mouse and two for unknown reasons. Five participants in the PACE-Yourself condition dropped out, one because of personal illness, one because of an emergent family obligation, one for lack of time, and two for unknown reasons. A two-way ANOVA with intervention and site as between-subject variables was conducted. There was an effect for intervention, $F(3, 148) = 3.27$, $P < .05$, $\eta 2 = 0.062$, and post hoc tests with Bonferroni-corrected significance showed that the PACE-Yourself group had a lower completion rate than the mindfulness and nonadaptive WM training groups (*P*'s < .05), with no difference between the PACE-Yourself and the adaptive WM training group ($P > .1$). The completion rate in the adaptive group also did not differ from either the mindfulness or nonadaptive WM training group (*P*'s > .1). There was no effect of site, and no interaction between intervention and site.

3.3. Adherence rates across intervention groups

We calculated adherence rate for subjects who completed the intervention to investigate how consistently subjects from each group were able to follow the program (Fig. 4). The PACE-Yourself group's adherence rate was 93% whereas the other three groups adhered between 98% and 99%. A two-way ANOVA was conducted with intervention group and site as between-group variables. There was an effect of intervention, $F(3, 140) = 7.09$, $P < .001$, $\eta 2 = 0.132$, which was present because the PACE-Yourself group had a lower adherence rate than the other three groups (Bonferroni-corrected *P*'s < .05). There was no effect of site, or site by intervention interaction.

3.4. Participant performance in the PACE-Yourself intervention group

During the five-week intervention, PACE-Yourself participants who completed the intervention spent increased time exercising at the highest intensity level. A repeated measures ANOVA was conducted, with exercise week (one-five) and percentage of time spent at each intensity level (high, medium, low) as the within-subject variables and site as the between-subject variable. There was an interaction between intensity level and exercise week, $F(8, 232) = 2.6$, $P = .01$, $\eta 2 = 0.082$, which was not modified by site. This interaction was present because the percentage of time spent doing high-intensity exercise increased over the course of the study, $F(4, 116) = 3.31$ $P < .02$, $\eta 2 = 0.10$, whereas the time spent doing low-intensity exercise decreased over the course of the study, $F(4, 116) = 6.09$, $P < .001$, $\eta 2 = 0.17$. No changes were noted over time for medium-intensity exercise.

Fig. 5 illustrates the relationship between the number of exercise sessions per week and the change in the IPAQ score for subjects who completed the PACE-Yourself program. Six participants from the Swedish site did not have either preintervention or postintervention IPAQ scores recorded and were not included in this portion of the analysis. The number of exercise sessions completed predicted postintervention minus preintervention change in IPAQ score ($r = 0.54$, $P < .01$).

4. Discussion

Engaging in physical exercise promotes health and well-being [1–8]. Of particular importance, participating in higher levels of physical activity has been linked to improved cognitive function and a lower likelihood of

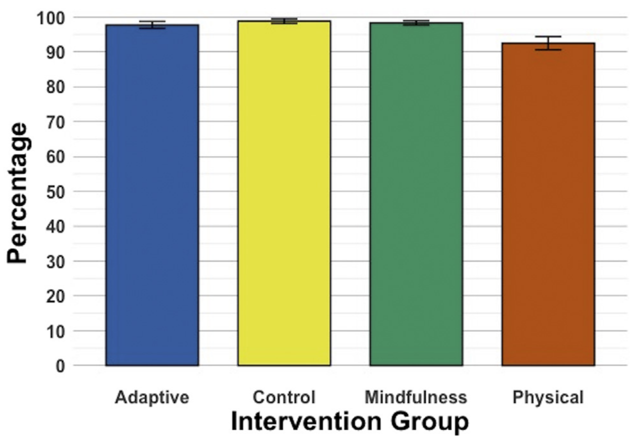

Fig. 4. Average adherence rate (mean [standard error of the mean]).

developing dementia. These effects on cognitive aging are a pertinent public health concern in light of the growing number of older adults. Unfortunately, a high percentage of individuals in the United States are failing to meet recommended physical activity guidelines [25]. Thus, it is critical to find novel ways to facilitate increased physical activity.

Our study compared the completion and adherence rates of four structured interventions in older adults: physical exercise, adaptive computerized WM training, nonadaptive computerized WM training, and mindfulness meditation. The interventions were structurally similar in that all were carried out in participants' homes via a web-based platform over the course of five weeks, with greater than 175 minutes of activity per week. The investigation demonstrated that participants across all arms of the study had high completion rates and high adherence rates, despite the demanding time commitment and stringent criterion for being considered as someone who completed the program. Overall, more than 86% of subjects in the PACE-Yourself physical exercise group finished the program and completers had a 93% adherence rate. Subjects in the PACE-Yourself program exercised at higher P&I over time.

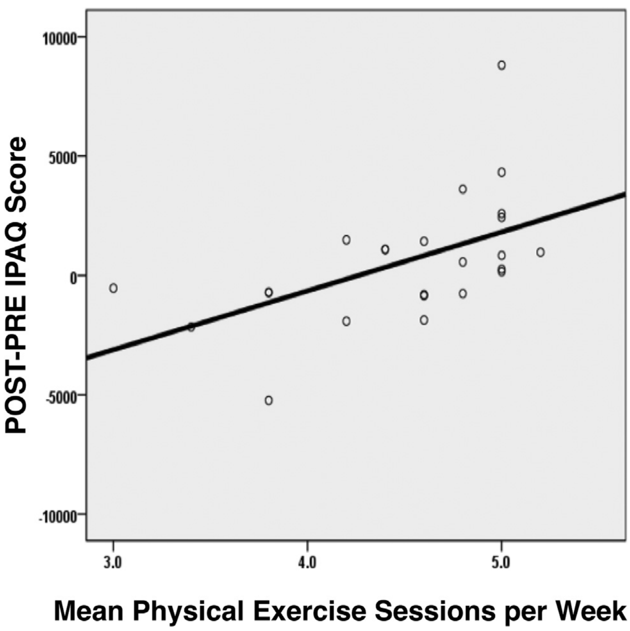

Fig. 5. Relationship between delta IPAQ scores and mean number of physical exercise sessions per week. Abbreviation: IPAQ, International Physical Activity Questionnaire.

Although not measured directly, the motivation and engagement of our participants appeared high. While the interventions were designed to be accessed via computer, human connection was established at the start of the intervention when RAs visited participants in their homes, and the relationship was maintained through weekly telephone calls. We suspect that active communication and remote monitoring by study personnel contributed to high completion and adherence rates [44]. Additional research is necessary to understand how critical an ongoing relationship between program personnel and participants is to the success of web-based, at-home interventions.

When compared with the other three interventions, the PACE-Yourself group had a slightly lower completion rate. However, the amount of variance explained by intervention group variable was relatively small ($\eta2 = 0.062$), and there were no reliable differences between subjects in the PACE-Yourself and the adaptive WM training group, both of which may have been more demanding than the other two intervention programs [32]. Although the adherence rate in the PACE-Yourself group was high (93%), it was still lower than that of the other three arms of the study. Several factors may help explain this result. For many individuals, physically demanding activities may be more subjectively challenging than mentally demanding tasks. In addition, the PACE-Yourself participants may not have been accustomed to pushing themselves to exercise at an exertion level of "somewhat hard." [45] It is unclear whether adherence rate would have been higher if participants had been given a longer period before reaching this level of difficulty.

The results of our study add to a growing literature focused on investigating online exercise interventions [27,46,47]. Enthusiasm for this approach is consistent with the increasing integration of internet-based activities and readily accessible devices into many different aspects of daily life. Escalating use of technology has been observed across all strata of society, including individuals with lower socioeconomic status [28,48]. Capitalizing on the internet's easy accessibility, web-based exercise programs have been shown to be both efficacious and cost-effective [27–29]. Our study of the PACE-Yourself program strongly suggests that older adults can also take advantage of an internet-based, at-home exercise platform that is accessible, less costly, and scalable.

A novel aspect the PACE-Yourself program is that it allows participants to control their exercise intensity level, which may promote greater participation and adherence.

A review of 72 online exercise interventions demonstrated varying degrees of attrition, with higher rates in studies that lasted six months or greater [27]. Finding ways to maintain participant engagement seems to be critically important. Especially relevant to this issue may be the concept of self-efficacy, which reflects a person's confidence in the ability to exert control over one's own behavior [33,49]. Studies evaluating self-efficacy using validated scales have revealed that individuals who successfully participate in exercise programs are more likely to score higher on self-efficacy measures. The ability to regulate the level of challenge is an important component to maintaining engagement. In the PACE-Yourself program, the power to adjust P&I likely provided participants the opportunity to enhance their self-efficacy. Participants elected to increase their P&I over time, which could represent a natural tendency for individuals to challenge themselves, especially if they feel in control. Successful engagement in physical activity may follow the principles of the Yerkes–Dodson law [50], which posits that highest performance occurs when individuals reach an intermediate level of physiological or mental arousal (neither extremely high nor extremely low). Participants in the PACE-Yourself program had the ability to modify P&I to their own perceived level of "somewhat hard," which may reflect an optimal level for sustaining effort and arousal. As the study proceeded, participants were able to spend more time at higher exercise intensity levels while maintaining their perceived exertion as "somewhat hard." To accommodate this tendency, future studies of longer duration should include more than three levels of P&I intensity.

There are limitations to the generalizability of the findings of our study. The high educational status and estimated IQ of our subjects are not representative of the overall population. However, it is notable that study participants came from diverse demographic and cultural backgrounds, having been recruited from an urban community in the United States and a rural community in Sweden. The main findings of the investigation were not modified by research site, which suggest that study results are not dependent on the geographic location or ethnic background of participants.

Further study is required to test the feasibility of the PACE-Yourself program across individuals with different levels of education, socioeconomic status, motivation, and fitness. Additional investigation is also needed to measure the impact of the program on objective markers of physical exercise and fitness (e.g., changes in daily step counts and maximal oxygen uptake, $VO2_{max}$). Future research also must determine if engagement in the PACE-Yourself program can be sustained over longer periods, and whether this web-based exercise program is as clinically effective as traditional ones that take place at designated facilities under the direct supervision of trainers [30,31].

The PACE-Yourself program appears to be the first home-based, participant-controlled, interactive exercise training platform in which P&I level is regulated via real-time participant feedback. The program provided an accessible, adaptable form of physical exercise that successfully engaged older adults and can serve as a foundation for future research on this important topic.

Acknowledgments

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Supplementary Data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.trci.2019.10.005.

RESEARCH IN CONTEXT

1. Systematic review: The authors reviewed the physical exercise intervention literature available in major databases. The beneficial effects of exercise are well studied, but such investigations are often conducted at facilities with groups of individuals under the supervision of trainers. There also is a burgeoning interest in investigating online-based exercise interventions. However, these studies have not focused on older populations.
2. Interpretation: Our study supports the feasibility of a novel, interactive, home-based physical exercise program for older adults. The program design allows for improved scalability, accessibility, and engagement in exercise programs.
3. Future directions: Additional research is necessary to determine if the results of the present study would be observed in interventions involving longer periods and in more diverse populations.

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