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Effects of Physical and Cognitive Training on Gait Speed and Cognition in Older Adults: A Randomized Controlled Trial.

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Abstract

Gait speed is a measure of health and functioning. Physical and cognitive determinants of gait are amenable to interventions, but best practices remain unclear. We investigated the effects of a 12-month physical and cognitive training (PTCT) on gait speed, dual-task cost in gait speed, and executive functions (EFs) compared to physical training (PT) (ISRCTN52388040). Community-dwelling older adults, who did not meet physical activity recommendations, were recruited (n=314). PT included supervised walking/balance (once weekly) and resistance/balance training (once weekly), home exercises (2-3 times weekly) and moderate aerobic activity 150 minutes/week in bouts of >10 minutes. PTCT included the PT and computer training (CT) on EFs 15-20 minutes, 3-4 times weekly. The primary outcome was gait speed. Secondary outcomes were 6-minute walking distance, dual-task cost in gait speed, and EF (Stroop and Trail Making B-A). The trial was completed by 93% of the participants (age 74.5 [SD3.8] years; 60% women). Mean adherence to supervised sessions was 59-72% in PT and 62-77% in PTCT. Home exercises and CT were performed on average 1.9 times/week. Weekly minutes spent in aerobic activities were 188 (median 169) in PT and 207 (median 180) in PTCT.

No significant interactions were observed for gait speed (PTCT-PT, 0.02; 95%CI -0.03, 0.08), walking distance (-3.8; -16.9, 9.3) or dual-task cost (-0.22; -1.74, 1.30). Stroop improvement was greater after PTCT than PT (-6.9; -13.0, -0.8). Complementing physical training with EFs training is not essential for promotion of gait speed. For EF's, complementing physical training with targeted cognitive training provides additional benefit.

Key words: aging, walking, exercise, community-dwelling, executive functions

Introduction

Walking is a complex process involving the interaction of neuromuscular, sensory and cognitive functions (1,2), all of which deteriorate with aging (3-5). Gait speed is a recognized measure of health and functioning in older populations, as reduced gait speed is associated with signs of advanced aging (6), increased risk for disability (7), compromised brain health and reduced neurocognitive functioning (8). With respect to cognitive functioning, the executive functions (EFs) that regulate the dynamics of human cognition and actions (9) seem especially to be associated with walking (2). Earlier studies have shown that better EFs correlate with greater gait speed among older community-dwelling people (2,10). The association is stronger among those with slower gait speed or altered gait pattern and if the walking test used is difficult and/or challenging (2, 10). The associations between gait speed and EFs may stem from their overlapping brain areas and neuronal networks (11).

The key physical and cognitive determinants of walking are amenable to training interventions even in old age (12, 13), but best practices remain unclear. Large-scale trials have shown that physical training improves physical performance (14, 15) and reduces the risk of gait-related disability in some (14, 16) but not in all studies (12, 15). For example, an earlier resistance-training intervention among 65- to 75-year-old women significantly improved muscle power but not walking speed compared to a balance and toning control group (12). Accordingly, in a study involving 70- to 80-year-old women with a history of falls, supervised strengthening, balance and functional exercises program improved muscle strength and femoral neck bone mineral density, but results on gait speed were less clear as only one of the two study groups participating in the physical activity intervention improved the gait speed (15). Cognitive training has beneficial effects on cognition and there is suggestive evidence that computer-based cognitive training that includes tasks for executive functions may improve gait speed in older people (17, 18). A training program targeting both physical and cognitive determinants of walking may induce greater benefits on gait speed than a program targeting only one of these. As physiological and cognitive functions deteriorate with aging, strategies that help maintain these functions, and thus gait ability, may prevent future disability and other adverse outcomes in later life.

This study investigated whether a combination of physical and cognitive training (PTCT) has greater effects on gait speed compared to physical training (PT) alone among cognitively intact 70-85-year-old community-dwelling men and women who did not meet physical activity guidelines. In addition, we investigated whether the PTCT has greater effects than PT alone on dual-task cost in gait speed, 6-minutes walking distance and executive functions.

Materials and Methods

Study Design and Setting.

Promoting safe walking among older people: Physical and cognitive training intervention among older community-dwelling sedentary men and women (the PASSWORD) was a single-blinded, parallel-group randomized controlled trial. The study design, recruitment and methods have been published earlier (19). Ethical approval was received from the Ethical Committee of Central Finland Health Care District (14/12/2016, ref: 11/2016). All participants provided informed consent before the baseline measurements. The PASSWORD has been registered in International Standard Randomized Controlled Trial Number Register (http://www.isrctn.com/ISRCTN52388040).

Recruitment.

Participants were randomly selected from Finland's Population Information System administered by the Population Register Center (http://vrk.fi/en). Recruitment started with a letter containing information about the study and a phone interview to screen for inclusion and exclusion criteria related to mobility, physical activity and major chronic diseases. Those who fulfilled the inclusion criteria and did not report any exclusion criteria, were invited to the laboratory examinations. Clinical exclusion criteria were assessed, and health status was confirmed by a nurse and, if necessary, a physician and a clinical psychologist before the baseline assessments. A flow chart is shown in Figure 1.

Inclusion Criteria.

Eligible participants were community-dwelling 70- to 85-year-old men and women living in the City of Jyväskylä, Finland and who did not meet the physical activity guidelines; less than 150 min of moderate intensity aerobic activity in bouts of at least 10 minutes per week and no regular resistance training. We did this because a lower level of physical activity is associated with slower gait speed (20), and the level of physical activity can be assessed by self-report over the telephone making the initial participant recruitment and screening feasible. Other inclusion criteria were being able to walk 500 meters without assistance, and the Mini Mental State Examination (MMSE) test score ≥24 (range 0–30, higher score indicates better performance) addressed in face-to-face tests.

Exclusion criteria.

Exclusion criteria were severe chronic condition or medication affecting cognitive and/or physical function, contraindication for physical exercise or walking tests (21) or behavioral factors that in the judgment of the PI and the study physician may compromise participation in the study. The exclusion criteria also included excessive use of alcohol, difficulty in communication and another member of the household participating in PASSWORD (19).

Randomization and Blinding.

Participants were randomly assigned in a 1:1 ratio to receive the Physical and Cognitive Training (PTCT) or Physical Training alone (PT, control) intervention. A computer-generated random allocation sequence by gender and age (70-74, 75-79, 80-85) with randomly varying blocks of two and four was utilized. Investigators collecting the outcome data were blinded to group allocation and participants were asked not to disclose their study group to the personnel collecting the data.

Sample size calculations.

Sample size calculations for the primary outcome, 10-meter maximal gait speed, were based on group-time interaction favoring the PTCT vs. the PT group with a two-tailed, 0.05 significance level. The PT intervention was expected to induce a four-percentage point mean increase in both groups and a six percentage point higher mean in the PTCT than PT group with no change in standard deviation (SD) (20). The follow-up within-person correlation for the two measurements was estimated to be r=0.80, yielding 0.23 m/s as an estimate of the SD for change, and the dropout level was assumed to be 15 %. Under these assumptions, the randomization of 310 participants provides 80 % power to detect a 4 % increase in maximal gait speed due to PT in both training groups and an additional 6 % increase due to CT in the PTCT group.

Measures.

Background characteristics

Sex and date of birth were drawn from population registry. Body height (m) and weight (kg) were measured with standard procedures and body mass index (kg/m^2) was calculated. Fat percent was drawn from the total body dual-energy X-ray absorptiometry (DXA, LUNAR Prodigy, GE Healthcare) scanning. Highest education, marital and smoking status were self-reported. Education was categorized as low i.e. primary school or less, medium i.e. middle school, folk high school, vocational school or secondary school, or high i.e. high school diploma or university degree. Smoking status was categorized as never, former or current. Self-rated health was reported on a five-point scale from very good to very poor and dichotomized as very good/good and average/poor. Mood was assessed with the Geriatric Depression Scale (range 0–15; 5 points and above indicates decreased mood/depression). Clinical health data were based on self-reports and data collected from the National Health Service integrated patient information system and in a clinical examination (for details, see Table 1). Physical activity was measured with a hip-worn tri-axial accelerometer (UKK RM42, UKK, Tampere, Finland) for seven days. The mean amplitude deviation (MAD) of the resultant acceleration was analysed and mean MAD of each one-minute epoch was calculated. Mean daily activity was then divided into sedentary (<0.0167 g), light (0.0167 g to <0.091 g) and moderate-to-vigorous (≥ 0.091 g) activity. In addition, raw data were analysed for moderate-to-vigorous intensity activity accumulated in continuous bouts lasting at least ten minutes. Weekly minutes in moderate-to-vigorous activity in bouts of at least ten minutes were calculated by multiplying mean daily values with 7. Previously validated cut-offs were utilized, and the analysis process has been described by Savikangas et al (22). At baseline, perceived difficulty in using a computer was assessed with a question “How do you manage using a computer”? Response options were 1) Able to manage without difficulty, 2) Able to manage with some difficulty, 3) Able to manage with major difficulty, 4) Able to manage only with the help of another person, and 5) Unable to manage even with help.

Outcomes.

Outcomes were assessed at baseline and at 6 and 12 months thereafter. The primary outcome was 10-meter maximal gait speed (23). The participants were asked to walk over the 10 m course as fast as possible without compromising safety. They were allowed 2-3 meters for acceleration before the starting line allowing us to measure the full speed over the whole 10- meter distance. Time taken to complete the walk was measured by photocells and gait speed (m/s) was calculated. The best performance of two trials was used as the result.

Secondary outcomes were 6-minute walking distance, dual-task cost in gait speed and executive functions (EFs). In the 6-minute walking test, participants were encouraged to walk up and down a 20-meter circuit for six minutes at a comfortable speed and without resting. The number of full laps was calculated and the last, interrupted lap, was measured. Distance travelled in meters (m) was recorded as the result (24). The 6-minute walking test serves as a measure for community walking.

In the dual-task walking test, the participants walked along a 20-meter-long walkway at their habitual speed. They then repeated the walk while performing a visuospatial cognitive task (25). That task involved a display with three boxes side by side labelled A, B and C. Participants were asked to visualize a star located in one of the boxes making three movements. Prerecorded instructions delivered the random starting position and the direction of the three movements, i.e. left or right. An example of the instruction would be: "The star is in box A. It moves to the right, to the right, to the left." After each instruction, the participant responded out loud, in which box star was after those three movements. The instructions were delivered continuously throughout the walking trial through headphones. A new instruction was delivered within one second of the participant answering the previous question. Participants practiced the visuospatial task carefully before the dual-task walking test. Walking times were measured by photocells and the difference in time between the two walks (dual-task cost) was calculated. The dual-task walking test assesses the ability to perform motor and cognitive tasks simultaneously, a typical behavior in everyday walking activities.

EFs were assessed using the Stroop Color-Word Test, which measures response inhibition by deliberate overriding of dominant responses (26), and Trail Making test B-A (TMT, 27), which measures mental flexibility and set-shifting. In the Stroop, participants were asked to name colours under different conditions. First, they were asked to name color of colored letter X's. Then they were asked to read words naming colours (e.g., red, blue) printed in black. Finally, they were required to state the colour named by a word printed in an incongruent colour, e.g., the word "blue" printed in red ink. Participants were asked to do the tests as quickly and as accurately as possible. For the Stroop inhibition effect, the congruent-condition completion time was subtracted from the incongruent condition completion time.

In TMT A, participants were asked to draw a line from number one to number two and so on up to number 25. In TMT B, participants were asked to draw the line from number one to the letter A and then from number two to the letter B and so on. The difference in the time between trail A and trail B (TMT B-A) was calculated.

Exploratory outcomes included TMT A (visuomotor speed) and TMT B (set-shifting). In addition, updating and lexical access speed was assessed with the Verbal Fluency test (VF, 28). In this test, participants were asked to name as many words beginning with P, A and S as possible in one minute. One trial was performed for each letter and the number of words was summed. Global cognition was measured with the Consortium to Establish a Registry for Alzheimer's Disease (CERAD) total score (29) at baseline and 12 months. The CERAD is composed of five subtests: Category Verbal Fluency, Modified Boston Naming Test, Mini Mental State Examination (MMSE), Word List Memory, and Constructional Praxis. The total score range from 0 to 100 and higher value indicates better performance. Maximal grip and isometric knee extension forces were measured in a sitting position from the side of the dominant hand on a custom-made dynamometer chair (Good Strength; Metitur Oy, Palokka, Finland). In the knee extension force measurement, knee angle was set at 60° from full extension. After 2-3 practice trials, participants were encouraged to extend the knee to produce maximal force. In the hand grip force measurement, the elbow was flexed at an angle of 90° and arm was fixed to the armrest of the dynamometer chair. After 2-3 practice trials, participants were instructed to grip the handle as forcefully as possible. In the above muscle force tests, the contraction was maintained for 2-3 seconds with a rest period of 30 seconds between the trials. Three to five maximal attempts were performed and best performance was taken as the result. Leg extension power was measured by using Nottingham power rig. The seat position was adjusted for leg length. After 2-3 practice trials, participants were asked to push the pedal as hard and fast as possible 5 to 10 times, until no further improvement occurred. The inter-trial rest period was at least 30 seconds. The best performance was used for analysis. Lower extremity function was measured by Short Physical Performance Battery including habitual walking speed over four meters, five-time chair rise time and standing balance tests (total score range 0–12, higher score indicates better performance).

Interventions.

The interventions started with a 60-minutes introductory seminars that included a motivational lecture on physical activity and a description of the physical activity intervention. In addition, participants were given an individual time schedule for the supervised sessions and they had an opportunity to ask questions regarding participation in the study. The PTCT participants also attend an introductory seminar during which detailed information on cognitive training was given.

Interventions included supervised training sessions and home exercises. The multicomponent physical training (PT) program was adapted from the physical activity guidelines for older adults (30), from our earlier study (31) and the LIFE study (32). PT targeted physical determinants of walking, i.e. muscle strength and postural balance, and included walking exercises outdoors. Five to six different training periods with variation in training specificity, volume and intensity were designed to maintain physiological responses to training and to prevent overtraining and fatigue during the 1-year training intervention. Detailed descriptions of the training periods has been reported in Sipilä et al. (19). Participants attended supervised center-based sessions twice weekly: once for walking and dynamic balance training (total time 45 minutes) and once for one hour resistance and balance training. Walking sessions were organized outdoors on a 400-meter circular walking lane, and during the wintertime, indoors in a sports hall with a 200-meter oval track. These sessions began with a 5-minutes short walk at self-selected speed and 10 minutes of dynamic balance exercises of increasing difficulty. Participants then walked continuously for 10-20 minutes at a target intensity of somewhat hard to hard (13-15 on the Borg scale). Resistance training, aimed at increasing muscle strength and power, took place in senior gyms equipped with machines utilizing air pressure technology and Smart Card/Smart Touch Software (http://www.hur.fi/en). This system allowed progressive increase in the training loads. The resistance was increased by 1-2 kg if the predefined number of repetitions was exceeded. In addition, six-repetition maximum tests were performed three times during the intervention to determine and further adjust the training load. Each session started with a 10-minute warm-up and balance exercises followed by 8-9 resistance exercises for the lower body, trunk and upper body muscles.

The progressive, approximately 20-30 minutes, home exercise program was performed 2-3 times per week and included strengthening exercises for the lower limb muscles, balance exercises and stretching for major muscle groups. In the strengthening exercises, workload was increased with resistance bands of three different strengths. For the standing balance exercises, the level of challenge was increased by reducing hand, base and vision support. In addition to the strengthening and balance home exercises, we instructed the participants to accumulate moderate aerobic activity amounting to a total of 150 minutes per week in bouts of at least 10 minutes according to the physical activity guidelines.

The cognitive training (CT) started with supervised group sessions. During the first weeks of CT, peer support for the requisite computer skills was organized in collaboration with the local University of the Third Age. Participants who had the necessary computer skills and a computer at home, were allowed to start CT at home after 2-3 group sessions. Those who lack access to a computer at home had possibility to train at the University computer class and/or one of ten locations provided by the City of Jyväskylä (libraries, sheltered accommodation, etc.). In each location, support for computer skills was available during sessions. CT targeted the following EFs: inhibition, set-shifting and updating of working memory. It was based on the unity/diversity model of executive functions presented by Miyake et al. (9). The CT utilized a web-based in-house developed computer program (*i*PASS) modified from that used in earlier studies (33) among older people (34). During each training session, four different tasks organized into two blocks were practiced. Block 1 included letter updating, predictable set-shifting, spatial working memory maintenance, and color inference task to train inhibition. Block 2 included spatial updating, unpredictable set-shifting, spatial working memory maintenance, and number inference task to train inhibition. The difficulty levels of the tasks were adjusted individually as a function of prior performance level for each training task, except for the two shifting-tasks. Participants were instructed to do the tasks as quickly and as accurately as possible 3-4 times a week. One training session lasted for 15-25 minutes depending on participants skills and performance. The EF-tasks used in the training program were not identical to the tasks used to assess EF, differing on several critical dimensions such as stimulus-response mappings (e.g keypress vs. oral response) and task-format (e.g single item presentations on a computer-screen vs paper and pencil formats).

Adherence to supervised sessions was calculated as the percentage of scheduled sessions attended by participants and was based on login information stored in the resistance training machines. Adherence to cognitive training was based on login information stored in the *i*PASS program. Numbers of home exercises performed and weekly minutes spent in aerobic activities were obtained from the daily diaries that participants kept throughout the study.

Adverse Events.

The participants reported new symptoms, injuries, diseases and medications emerging during the study with a structured questionnaire every three months. The study nurse and study physician reviewed the reports and, if necessary, adjusted the training intervention. Diseases were confirmed during the six- and 12-month examinations by the nurse.

Statistical analysis.

Baseline characteristics were summarized by study group using mean and SD, or frequency and percentages. Treatment groups were compared with the two-tailed Fisher exact test on proportions of participants sustaining any adverse events for which they consulted study physician, general practitioner or physician at the emergency department.

The outcome effects of the intervention were assessed on the intention-to-treat principle. For the primary outcome, there were no missing data at the baseline. At the 12-month follow-up, 91 % of the participants in both study groups had acceptable gait speed value. For the secondary outcomes, there were no missing data at the baseline, except in TMT B-A where one PTCT participant had missing value. The lowest participation rates were observed in 12-month measurements ranging between 89 - 91 % in the PTCT group and between 90 - 93 % in the PT group. The rate of missing data was considered to warrant use of maximum likelihood-based method of analysis adapted for missing data generated due to the Missing-At-Random (MAR) mechanism. Outcomes were tested for group-interaction over time using an interaction contrast in a linear model for the longitudinal design that accounted for within-person correlation and the potentially different variances at the two time-points. The model included a within-subject part for the repeated measurements for each subject, and a between-subjects part contrasting the PTCT and PT groups. The model structure was set similar to the repeated measures ANOVA, except that it permitted more general outcome variance structure specification and flexible handling of missing data with the maximum likelihood approach. We report group means for each available measurement wave and group-by-time interactions as primary significance tests. As ancillary tests, we also report within-group contrasts comparing the means of the 12-month measures to the baseline.

We adjusted the secondary analyses for multiple testing using the Bonferroni correction. Exploratory analyses were not adjusted for multiple testing. The effect of the intervention on the primary outcome was also evaluated in predefined sub-analyses stratified by age, sex, baseline cognition (CERAD total score) and level of compliance to the intervention. P-values were obtained from the linear models for the longitudinal design.

Results

Figure 1 presents participant recruitment, participation and retention. A total of 2767 potential participants were screened between January 2017 and March 2018. Of these, 314 were randomized to the PTCT (n=155) and PT (n=159) groups. Participant mean age was 74.5 years (standard deviation, SD 3.8) and 60% were women (Table 1). Of the PTCT participants, 128 (83%) reported no or only slight difficulties in using computer, and 20 (13%) reported having either great difficulties or inability to use the computer without assistance of another person. Three people were unable to manage the computerized exercises even with help (2%) and four (3%) had missing information.

Mean adherence to the supervised walking and dynamic balance sessions was 59% (SD 32; median 68; IQR 33-87) in the PT and 62% (SD 27; median 69; IQR 49-83) in the PTCT group after excluding major medical leaves. The corresponding figures for the supervised resistance and balance sessions were 72% (SD 26; median 82; IQR 64-90) and 77% (SD 19; median 81; IQR 69-89). Participants in both groups performed home exercises on average 1.9 (SD 0.6 for PT and 0.8 for PTCT) times per week. The number of participants reporting their weekly aerobic activity, varied from 128 to 149 in the PT group and from 126 to 150 in the PTCT group. Mean of minutes spent in aerobic activities per week was 188 (SD 120; median 169; IQR 93) in PT group and 207 minutes per week (SD 119; median 180; IQR 96) in PTCT group. CT training was performed on average 1.9 times per week (SD 1.3; median 1.8; IQR 0.9-2.8).

Primary Outcome

No significant interaction of group by time was observed for the maximal gait speed (Table 2). As an ancillary result, both groups increased their gait speed similarly during interventions: mean increase was 4% (SD 13) in the PTCT and 3% (SD 11) in the PT group (Table 2).

Secondary outcomes

6-min walking distance increased significantly in both groups during the intervention: mean increase was 7% (SD 7) in the PTCT and 8% (SD 10) in the PT group with no significant difference between the study groups (Table 2).

No significant interaction of group by time was observed for the dual-task cost in gait speed. Both groups improved their performance (i.e. declined the cost) similarly during interventions: mean decline was 25% in the PTCT and 24% in the PT group (Table 2).

The decline in Stroop effect was significant in both groups after the intervention but significantly greater in the PTCT than the PT group (Table 2). The difference between the study groups was significant already after six months of training. TMT B-A improved significantly in the PTCT group during the intervention, but the change was not significantly different from that in the PT group (Table 2).

Subgroup analyses

The pre-specified subgroup analyses showed that intervention-induced changes in maximal gait speed did not significantly differ by age, training adherence or baseline cognition (Figure 2). However, among men, gait speed tended to increase more in the PTCT than PT group ($p=0.055$).

Adverse events

Adverse events are presented in Table 3. Approximately 40% of the participants experienced adverse events during the study. In each group, 10% reported intervention-related adverse events or symptoms. These were mostly transient non-severe pain and/or discomfort in the joints and/or muscles of the lower body.

Discussion

The one-year physical and cognitive training intervention did not improve gait speed over physical training alone in older community-dwelling men and women who did not meet the physical activity guidelines prior to the intervention, and who did not have cognitive impairment. Identical results were obtained for secondary gait variables, 6-minute walking distance and dual-task cost in gait speed. However, the combination of physical and cognitive training induced greater improvements in EFs than physical training alone, especially in response inhibition task. This trial provides evidence that complementing physical training with a cognitive training program targeting EFs may not enhance the training effects on gait speed in older community-dwelling populations. For the maintenance or improvement of EFs, targeted cognitive training provides additional benefits on top of physical training.

Earlier cross-sectional and follow-up studies have suggested that good EFs is associated with greater gait speed among older people (2, 8). It has also been suggested that training EFs would provide beneficial effects on gait speed, especially under challenging walking conditions (17). The associations between gait and EFs has been explained by overlapping brain areas and neuronal networks and accordingly, the positive effects of EFs training on gait speed has been suggested to be mediated through frontosubcortical circuits (17). Based on these earlier findings it was reasonable to think that complementing physical training with training targeting EFs would yield synergistic or even additive effects on gait speed. This was not, however, the case in this study, as the improvement in gait speed was comparable in both study groups. Similarly, the increase in 6-minutes walking distance was comparable in both study groups. Our findings are in line with a few smaller-scale studies with identical groups of older people and rather similar interventions, where improvements in gait speed after a multicomponent physical exercise program with and without a cognitive training component were identical (35, 36). It may be that the exercise program targeting multiple physiological systems such as cardiovascular, neuromuscular and postural control has the capacity to challenge not only the physical but also the cognitive components of walking. For example, dynamic balance exercises and walking outdoors are activities that require selective information processing (attention) and active maintenance and manipulation of information received (working memory) (37). It may also be, that other gait parameters, such as step length, would have been more sensitive measures to detect differences between the physical and combined physical and cognitive training groups. Based on this study, adding specialized training of EFs into the multicomponent physical training regimen has not added benefits on gait speed among relatively well functioning older people with no cognitive impairments.

Sex-based subgroups analysis revealed borderline significant improvement in maximal gait speed among men. Reasons for the difference in training response may lie in sex-specific muscle and metabolic biomarkers that are associated with gait speed and cognition (38). Even though the subgroup analyses of this study were preplanned, the number of participants in these analyses do not allow us to draw definite conclusions. Thus, further studies are needed to examine the interaction between sex and cognitive and physical training on gait speed.

The dual-task cost in gait speed is the time difference between the walk tests conducted with and without a cognitive task and it examines the cognitive component of gait and assess the ability to divide resources and attention between the motor and cognitive activity. Dual-task cost in gait speed decreased similarly in both study groups, even though the cognitive training in this study specifically targeted aspects of executive functions that are known to correlate with dual-task gait performance (1, 17). It is possible that the multicomponent physical exercise program had the capacity to challenge also the cognitive component of walking thereby undoing the expected effects of EFs training on dual-task cost performance. Unfortunately, we did not measure other dual-task cost gait parameters than speed. An array of spatiotemporal gait parameters could have shed further light on the potential differences between the interventions on the ability of the participants to divide resources and attention between the motor and the cognitive activity. Moreover, some of the earlier studies suggest that physical and cognitive training performed simultaneously (dual/multiple-task training) may have greater effect on e.g. dual-task gait performance than the combined physical and cognitive training organized separately (39). Simultaneous training is applicable especially in the rehabilitation settings, but not necessarily in training classes targeting the general older public. The interventions in our study were based on the current guidelines and population-based large-scale trials, thus the results of this study inform policies and practice targeting relatively healthy community living older people who, for various reasons, do not follow physical activity recommendations.

The combination of physical and cognitive training induced greater improvements in the response inhibition EF task (Stroop test) than physical training alone. Set-shifting performance (TMT B-A) improved in the combination intervention group but not to a greater extent than in the physical training-alone group. According to the unity/diversity model by Miyake and Friedman (9), EFs are portrayed as a collection of related (common EF abilities) but also distinct control processes (e.g., set-shifting and updating). It has been proposed that common EFs reflect goal maintenance in which a key requirement is response inhibition (40). This may suggest that the current EFs training program (*i*PASS) fosters goal maintenance, which is captured by the Stroop task in this study.

These findings of positive effects on EFs after combined training are in line with those of previous research and are supported by a meta-analysis showing that interventions combining physical and cognitive training lead to greater improvements in the cognition of healthy older adults than physical training alone (41). Moreover, recent meta-analysis and systematic review suggest that although multimodal physical exercise programs seem to benefit cognitive function in older people, the effects of physical exercise may be smaller than previously reported (42). The results of this study emphasize the importance of cognitive training for improvement in select cognitive tasks in older populations and highlight the importance of training specificity.

This study has several strengths. First, the study population were recruited from the Population Information System administered by the Population Register Center of Finland, comprising a representative sample of community-dwelling 70- to 85-year-old people who did not meet physical activity recommendations but were relatively healthy and able to safely participate in a yearlong physical training intervention. Second, the single-blinded RCT study design with intention-to-treat analysis was robust and able to capture the synergistic effects of a combination of physical and cognitive training on primary and secondary outcomes compared to physical training alone. Third, this study had a very low attrition rate (7%), relatively high adherence to the long-term training interventions, and supervised weekly training sessions. Fourth, both the PT and CT interventions had been tested separately in earlier trials. Both interventions were proven feasible and effective, when utilized separately, in respectable randomized controlled trials involving older adults. Fifth, the PT intervention chosen as the control condition followed the current physical activity guidelines for older adults.

This study also has its limitations. First, the results may not be generalizable to those who did not meet the eligibility criteria. Second, the inclusion criterion on the level of physical activity was self-reported over a telephone interview. This may have resulted in the selection of participants who were relatively active in terms of walking for exercise or running daily errands. This may have resulted in a smaller change in gait speed than would have been the case had they been more sedentary. The community structure of the city of Jyväskylä includes walkways and pedestrian streets and favor active forms of commuting. Third, all adverse events were self-reported. We also want to emphasize that conclusion on the effects of cognitive training alone on gait speed or EFs cannot be drawn from this study.

In conclusion, a yearlong physical and cognitive training intervention improved gait speed to a similar extent as physical training alone in older community-dwelling men and women who did not meet the physical activity guidelines prior to the intervention. However, the combination of physical and cognitive training induced greater improvements in common executive functions than physical training alone.

Perspective

Our data indicate that, in older relatively well-functioning community-dwelling men and women, complementing physical training with separate cognitive training targeting EFs has no additional effects on gait speed or dual-task cost in gait speed compared to physical training alone. Multicomponent physical training program that follows the physical activity guideline may have the capacity to challenge key neuromuscular and cognitive factors that are needed for gait speed which is a recognized vital sign of health and functioning in older populations (6, 7, 8).

Multicomponent physical training program is beneficial for EFs of older people (40), but this study showed that targeted cognitive training provides additional benefits on top of physical training. For the promotion of physical and cognitive functioning of older populations, multifaceted progressive interventions and strategies may be needed for the most efficient outcome.

Conflict of interest.

The authors declare that they have no competing interests. Dr. Fielding reports grants from National Institutes of Health (National Institute on Aging) during the conduct of the study; grants, personal fees and other from Axcella Health, stock options from Inside Tracker, grants and personal fees from Biophytis, grants and personal fees from Astellas, personal fees from Cytokinetics, personal fees from Amazentis, grants and personal fees from Nestle', personal fees from Glaxo Smith Kline, outside the submitted work.

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Data analysis or interpretation of data: Sipilä, Törmäkangas (data analysis); Sipilä, Tirkkonen, Savikangas, Hänninen, Laukkanen, Alen, Fielding, Kivipelto, Kulmala, Rantanen, Sihvonen, Sillanpää, Stigsdotter Neely, Törmäkangas (interpretation).

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Approved the submitted manuscript and agreed that the questions related to the accuracy or integrity of this study are appropriately investigated and resolved: Sipilä, Tirkkonen, Savikangas, Hänninen, Laukkanen, Alen, Fielding, Kivipelto, Kulmala, Rantanen, Sihvonen, Sillanpää, Stigsdotter Neely, Törmäkangas

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Figure legends

Figure 1. Enrollment, randomization, and follow-up of participants.

Figure 2. Forest plots of the differences in change in gait speed from baseline (BL) to post-intervention (FU) between physical training (PT) and physical and cognitive training (PTCT) by subgroups.

[a] Cognition is based on baseline CERAD total score: High CERAD score ≥69, Low CERAD score <69.

[b] Compliance is based on participation in supervised training sessions. In PT, the high compliance subgroup participated in at least 50% of the supervised walking/dynamic balance sessions and in at least 50% of the resistance/balance training sessions. In PTCT, the high compliance subgroup participated in at least 50% of the supervised walking/dynamic balance sessions and in at least 50% of the resistance/balance training sessions and performed CT at least twice a week.

Table 1. Baseline characteristics of participants by physical and cognitive training (PTCT) and physical training (PT) groups.

	PTCT (n=155)	PT (n=159)
Age, mean (SD), y	74.4 (3.9)	74.5 (3.7)
Women no. (%)	96 (62)	92 (58)
Height, mean (SD), m	1.66 (0.09)	1.66 (0.09)
Weight, mean (SD), kg	76.9 (14.5)	76.9 (14.0)
Body mass index, mean (SD), kg/m^2	28.0 (4.9)	27.9 (4.5)
Fat percent, mean (SD)	36.4 (8.3) (n=154)	35.9 (8.1)
Marital status, no. (%)		
Cohabiting	102 (66)	97 (61)
Other	53 (34)	62 (39)
Education, no. (%)		
Low	23 (15)	25 (16)
Medium	94 (61)	106 (67)
High	38 (25)	28 (18)
Smoking status, no. (%)		
Never smoker	94 (61)	97 (61)
Former smoker	52 (34)	57 (36)
Current smoker	9 (6)	5 (3)
MMSE, mean (SD) [a]	27.9 (1.4)	27.4 (1.5)
Physical activity; Accelerometer, min/d mean (SD) [c]	(n=145)	(n=148)
Sedentary time (<0.0167g)	604 (86)	601 (80)
Light-intensity activity (≥0.0167 to <0.091g)	215 (65)	206 (67)
Moderate-to-vigorous-intensity activity (≥0.091)	32 (19)	33 (21)
Moderate-to-vigorous intensity activity in bouts of ≥10 min, min/week, mean (SD)	80 (83)	86 (88)
median (IQR)	58 (13; 106)	62 (16; 128)
Self-rated health, no. (%)		
very good/good	73 (47)	68 (43)

average/poor	82 (53)	91 (57)
GDS score [d]		
mean (SD)	1.4 (1.4)	1.8 (1.9)
≥5, no. (%)	7 (5)	14 (9)
Self-reported long-term pain [e], no. (%)	121 (78)	121 (76)
Chronic conditions, no. (%)		
Musculoskeletal diseases [f]	64 (41)	62 (39)
Metabolic diseases [g]	101 (65)	117 (74)
Cardiovascular diseases [h]	46 (30)	49 (31)
Pulmonary diseases [i]	26 (17)	17 (11)
Mental health diseases [j]	5 (3)	8 (5)
Neurologic diseases [k]	8 (5)	6 (4)

[a] Mini Mental State Examination, total score, range 0–30, higher score indicates better performance

[b] Short Physical Performance Battery, total score, range 0–12, higher score indicates better performance

[c] Mean amplitude deviation

[d] Geriatric Depression Scale, range 0–15, < 5 points indicates normal mood

[e] Self-reported, daily or almost daily pain lasting for at least one month during the past six months in neck/shoulders, arms/hands, lower back, hip, knees, or ankles/feet

[f] Including: arthrosis, endoprosthesis, osteoporosis, back diseases, joint pain, conditions causing pain in neck and upper extremities, muscular dystrophy, hernia; and inflammatory diseases including rheumatoid diseases, arthritis, psoriatic arthritis, fibromyalgia, polymyalgia, gout

[g] Including: type 2 diabetes, hypertension, hypercholesterolemia and other lipid storage disorders

[h] Including: myocardial infarction, stroke, intracranial haemorrhage, coronary artery disease, transient ischaemic attack, peripheral arterial disease, intermittent claudication, arrhythmias, heart defect, heart failure, pacemaker

[i] Including: chronic obstructive pulmonary disease, asthma, pulmonary fibrosis, bronchiectasis

[j] Including: depression, stress, bipolar disorder, disorientation, adjustment disorder

[k] Including: poliomyelitis, migraine, epilepsy, Parkinson’s disease, peripheral neurological diseases, polyneuropathy

Table 2. Primary, secondary and exploratory outcomes at baseline and after 6 and 12 months of physical and cognitive training (PTCT) or physical training alone (PT).

	PTCT, n=155			**PT, n=159**			**Group x time interaction (PTCT–PT)**	
Outcomes	Mean (SE)	Difference (95%CI)[a]	N[b]	Mean (SE)	Difference (95%CI)[a]	N[b]	Difference (95%CI)[a]	P Value
Primary outcome								
10-m Maximal Walking Speed, m·s^{-1}								
Baseline	1.98 (0.03)		155	1.95 (0.03)		159		
6 months	2.02 (0.03)	0.04 (0.01 to 0.07)	148	2.00 (0.03)	0.04 (0.01 to 0.08)	148	-0.002 (-0.05 to 0.04)	.93
12 months	2.06 (0.04)	0.08 (0.04 to 0.12)	141	2.01 (0.04)	0.06 (0.02 to 0.09)	144	0.02 (-0.03 to 0.08)	.45
Secondary outcomes								
6-min Walking Distance, m								
Baseline	478.8 (6.9)		155	472.0 (7.0)		159		
6 months	499.0 (7.2)	20.2 (11.3 to 29.1)	148	496.4 (7.2)	24.4 (15.6 to 33. 2)	146	-4.2 (-16.7 to 8.4)	>.99*
12 months	512.1 (7.3)	33.3 (24.6 to 42.0)	138	509.1 (8.0)	37.1 (27.2 to 46.9)	143	-3.8 (-16.9 to 9.3)	>. 99*
Dual-Task Cost, s [c]								
Baseline	4.53 (0.53)		155	3.80 (0.32)		159		
6 months	3.65 (0.30)	-0.88 (-2.05 to 0.29)	147	3.66 (0.52)	-0.14 (-1.36 to 1.08)	148	-0.74 (-2.43 to 0.95)	>.99*
12 months	3.38 (0.31)	-1.15 (-2.40 to 0.10)	140	2.87 (0.25)	-0.93 (-1.79 to -0.07)	144	-0.22 (-1.74 to 1.30)	>.99*
Stroop effect, s [d]								
Baseline	45.1 (1.7)		155	48.1 (2.3)		159		

6 months	34.2 (1.6)	-10.9 (-15.1 to -6.7)	148	46.8 (2.1)	-1.3 (-5.5 to 2.8)	151	-9.6 (-15.5 to -3.6)	.004*
12 months	33.9 (1.4)	-11.2 (-15.5 to -6.9)	141	43.8 (1.7)	-4.3 (-8.6 to -0.1)	148	-6.9 (-13.0 to -0.8)	.02*
TMT B–A, s [e]								
Baseline	87.2 (4.4)		155	89.1 (3.9)		158		
6 months	77.7 (4.0)	-9.5 (-17.9 to -1.2)	148	86.6 (3.3)	-2.6 (-10.8 to 5.6)	151	-6.9 (-18.7 to 4.8)	.84*
12 months	78.2 (4.9)	-9.0 (-16.6 to -1.4)	141	84.1 (4.0)	-5.1 (-14.0 to 3.9)	147	-3.9 (-15.7 to 7.8)	>.99*
Exploratory outcomes								
TMT A, s								
Baseline	43.5 (1.1)		155	43.5 (1.1)		158		
6 months	42.0 (1.1)	-1.6 (-3.5 to 0.3)	148	41.1 (1.0)	-2.4 (-4.2 to -0.7)	151	0.8 (-1.7 to 3.5)	.51
12 months	41.0 (1.3)	-2.6 (-4.5 to -0.6)	141	42.5 (1.1)	-1.0 (-2.9 to 0.9)	147	-1.5 (-4.3 to 1.2)	.27
TMT B, s								
Baseline	130.7 (5.0)		155	132.8 (4.4)		158		
6 months	119.8 (4.7)	-10.9 (-17.3 to -4.5)	148	127.7 (3.7)	-5.1 (-10.9 to 0.69)	151	-5.8 (-14.5 to 2.8)	0.19
12 months	119.3 (5.4)	-11.4 (-16.7 to -6.1)	141	126.7 (4.3)	-6.1 (-12.4 to 0.2)	147	-5.3 (-13.5 to 3.0)	0.21
Letter fluency, n [f]								
Baseline	42.3 (1.1)		155	40.9 (1.0)		159		
6 months	42.7 (1.1)	0.4 (-1.1 to 1.8)	148	40.9 (1.0)	-0.02 (-1.1 to 1.1)	151	0.40 -1.435 2.232	0.94
12 months	46.0 (1.2)	3.7 (2.1 to 5.2)	141	44.2 (1.1)	3.3 (2.0 to 4.6)	148	0.39 (-1.65 to 2.42)	0.89
CERAD score [g]								
Baseline	79.50 (0.64)		155	78.81 (0.65)		158		
12 months	80.54 (0.71)	1.04 (0.02 to 2.06)	141	80.71 (0.67)	1.90 (0.98 to 2.82)	147	-0.86 (-2.23 to 0.52)	0.23

SPPB [h]								
Baseline	10.2 (0.1)		155	10.1 (0.1)		159		
6 months	10.7 (0.1)	0.52 (0.39 to 0.66)	148	10.4 (0.1)	0.35 (0.15 to 0.55)	151	0.17 (-0.07 to 0.41)	0.17
12 months	10.8 (0.1)	0.60 (0.40 to 0.81)	141	10.8 (0.1)	0.70 (0.50 to 0.89)	146	-0.09 (-0.38 to 0.19)	0.52
Leg Extension Power, W								
Baseline	125.3 (4.6)		145	126.9 (4.9)		148		
12 months	144.2 (4.5)	18.9 (14.8 to 23.1)	123	151.4 (4.9)	24.5 (20.6 to 28.3)	132	-5.6 (-11.2 to 0.13)	0.06
Grip force, N								
Baseline	263.5 (8.2)		154	281.2 (8.8)		159		
12 months	281.4 (8.9)	17.9 (10.3 to 25.5)	138	290.3 (8.7)	9.1 (1.4 to 16.9)	146	8.8 (-2.1 to 19.6)	0.11
Knee Extension force, N								
Baseline	356.4 (9.7)		152	369.0 (9.1)		159		
12 months	395.2 (9.9)	38.7 (31.5 to 46.0)	130	413.1 (9.0)	44.2 (36.0 to 52.3)	140	-5.4 (-16.4 to 5.5)	0.33

* Bonferroni-corrected

[a] Difference relative to baseline

[b] Observed sample size

[c] Walking speed with a cognitive task – walking speed without a cognitive task

[d] Stroop incongruent – Stroop neutral

[e] Trail Making Test B – Trail Making Test A

[f] Naming as many words as possible beginning with letters P, A and S in one minute; number of words was summed.

[g] CERAD includes verbal fluency (animal naming), modified Boston naming test, world list learning, constructional praxis, word list recall and word list recognition. Range 0-100; higher score indicate better performance.

[h] Short Physical Performance Battery. Range 0-12; higher score indicate better performance.

Table 3. Number of participants reporting adverse events during the 12-month study in Physical and Cognitive Training (PTCT) and Physical Training (PT) groups, n (%)

	No. (%)		
	PTCT (n=155)	PT (n=159)	p
Any adverse events	61 (39)	60 (38)	.82
Any adverse events appearing during or after exercises related to the interventions	16 (10)	18 (11)	.86
Fractures [a]	3 (2)	10 (6)	.07
Other injuries [b]	11 (7)	8 (5)	.46
Joint replacement	1 (1)	3 (2)	.62
Musculoskeletal diseases/diagnoses [c]	8 (5)	5 (3)	.41
Musculoskeletal pain/discomfort [d]	28 (18)	22 (14)	.36
Cardiovascular diseases [e]	4 (3)	7 (4)	.54
Cardiovascular symptoms [f]	3 (2)	6 (4)	.50
Pulmonary diseases [g]	2 (1)	1 (1)	.62
Pulmonary symptoms [h]	3 (2)	1 (1)	.37
Depression/depressive mood	–	3 (2)	.25
Neurologic symptoms [i]	2 (1)	2 (1)	>.99
Cancer	2 (1)	1 (1)	.62
Dizziness	5 (3)	2 (1)	.28

[a] Including: fractures of clavicle, radius, wrist, finger, rib, hip, fibula, ankle, or toe

[b] Including: strains and sprains, severe wounds, pain and other injuries except fractures

[c] Including: arthrosis, fibromyalgia, polymyalgia, hernia inguinalis

[d] Including: muscle and joint pain, inflammations, swelling, numbness, limpness, cramps, and other self-reported musculoskeletal symptoms causing pain or discomfort

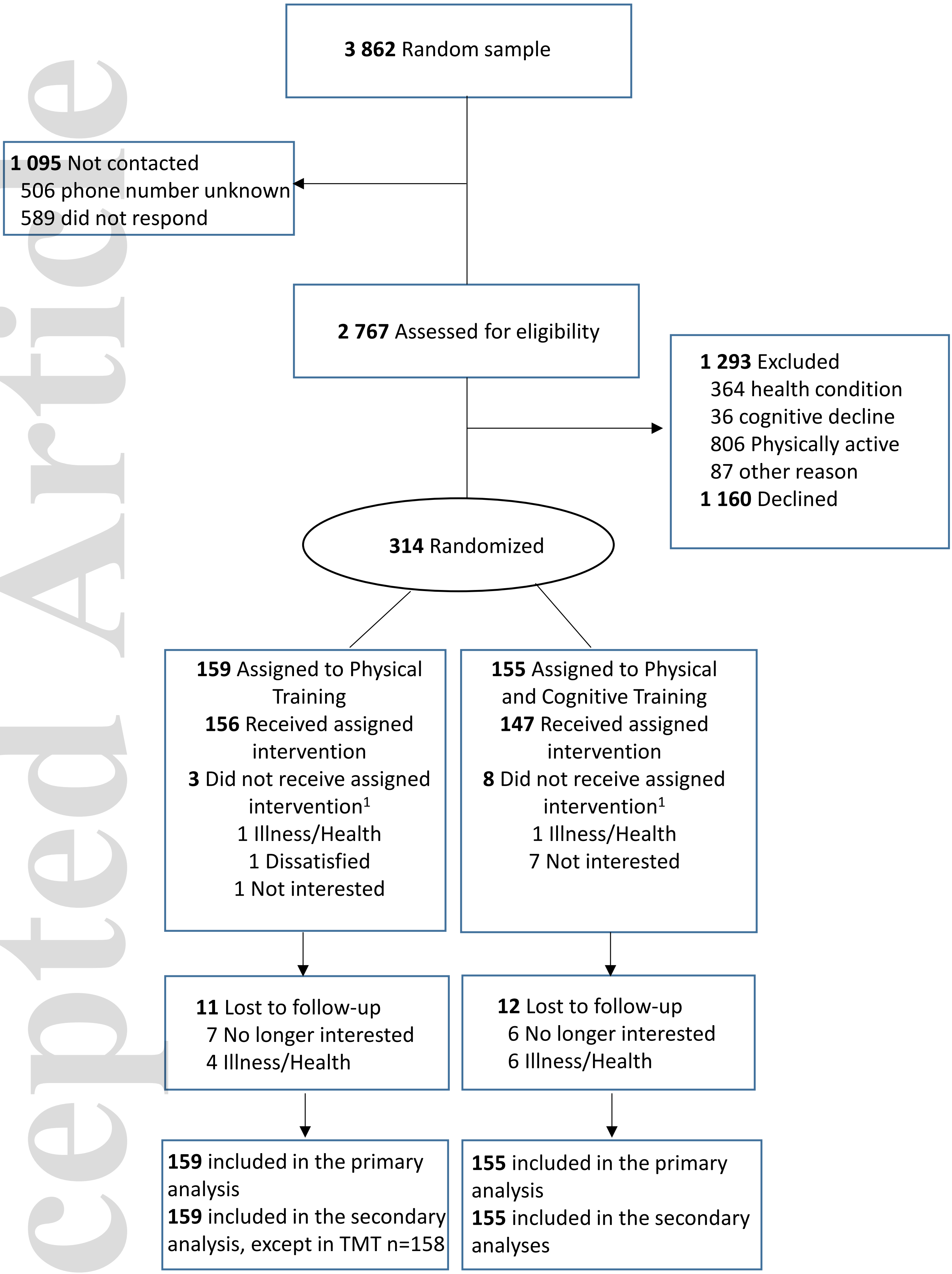
[e] Including: intracranial haemorrhage, coronary artery disease, verified arrhythmias and heart failures

[f] Including: unspecified chest-pain and arrhythmia

[g] Including: chronic obstructive pulmonary disease, asthma

[h] Including: asthmatic symptoms

[i] Including: anxiety, tremble, headache, problems with vision, balance and/or memory



[1]Participants who did not attend any intervention session

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Subgroup	PTCT mean, CI95%	PT mean, CI95%	Difference in change mean, CI95%	Interaction p-value
Overall	BL 1.98 (1.92 to 2.03) FU 2.06 (2.06 to 2.12)	BL 1.95 (1.89 to 2.02) FU 2.01 (1.94 to 2.08)	0.02 (-0.03 to 0.08)	p=0.446
Sex				
Men	BL 2.17 (2.06 to 2.27) FU 2.33 (2.23 to 2.44)	BL 2.07 (2.00 to 2.20) FU 2.15 (2.03 to 2.26)	0.09 (-0.002 to 0.18)	p=0.055
Women	BL 1.86 (1.81 to 1.91) FU 1.89 (1.82 to 1.96)	BL 1.87 (1.80 to 1.94) FU 1.92 (1.84 to 1.99)	-0.02 (-0.081 to 0.05)	p=0.586
Age				
70-74	BL 2.05 (1.98 to 2.12) FU 2.15 (2.07 to 2.22)	BL 2.00 (1.92 to 2.07) FU 2.08 (1.99 to 2.16)	0.02 (-0.05 to 0.09)	p=0.666
75-79	BL 1.91 (1.80 to 2.02) FU 1.99 (1.86 to 2.12)	BL 1.95 (1.83 to 2.07) FU 1.97 (1.85 to 2.08)	0.06 (-0.02 to 0.15)	p=0.130
80-85	BL 1.72 (1.58 to 1.86) FU 1.69 (1.44 to 1.93)	BL 1.71 (1.56 to 1.85) FU 1.75 (1.56 to 1.94)	-0.08 (-0.29 to 0.13)	p=0.473
Cognition [a]				
High CERAD	BL 2.01 (1.95 to 2.07) FU 2.09 (2.02 to 2.16)	BL 1.98 (1.91 to 2.04) FU 2.04 (1.97 to 2.11)	0.02 (-0.04 to 0.08)	p=0.521
Low CERAD	BL 1.68 (1.54 to 1.81) FU 1.72 (1.57 to 1.86)	BL 1.76 (1.54 to 1.98) FU 1.78 (1.58 to 1.98)	0.02 (-0.14 to 0.18)	p=0.785
Compliance [b]				
High Compliance	BL 2.01 (1.94 to 2.07) FU 2.14 (2.06 to 2.22)	BL 2.02 (1.94 to 2.10) FU 2.09 (2.01 to 2.17)	0.06 (-0.02 to 0.13)	p=0.132
Low Compliance	BL 1.96 (1.88 to 2.04) FU 2.00 (1.90 to 2.10)	BL 1.84 (1.74 to 1.95) FU 1.86 (1.75 to 1.97)	0.03 (-0.06 to 0.11)	p=0.522