The Longitudinal Associations Between Change in Physical Activity and Cognitive Functioning in Older Adults With Chronic Illness(es)

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Research Article

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Abstract

Background Regular physical activity (PA) is potentially beneficial for age-related cognitive decline. Although moderate-to-vigorous physical activity (MVPA) is mostly advised, older adults with chronic illnesses (OACI) might benefit more from light physical activity (LPA), as they suffer from mobility problems, pain and fatigue, limiting high intensity PA. Therefore, the longitudinal association between change in respectively LPA and MVPA on the one hand and the change in cognitive functioning (CF) on the other hand is investigated in OACI.

Methods In total 432 OACI (≥65 years) with at least one chronic illness participated in this longitudinal observational study. Longitudinal associations between accelerometer assessed change in PA (LPA and MVPA) and change in CF, measured with an objective validated neuropsychological test battery were tested with multivariate linear regressions.

Results An increase in LPA between baseline and six months follow-up was significantly associated with improved short-term verbal memory and inhibition over the first six months. In addition, the change score in LPA over the first six months was predictive for the change score in short-term verbal memory over 12 months. Furthermore, an increase in MVPA between baseline and six months follow-up was significantly associated with a decrease in longer-term verbal memory scores over the same six month period.

Conclusions Increase in LPA over the first six months is associated with better short-term verbal memory scores over the same period and this is extended to better short-term verbal memory scores over the whole year. Increase in LPA over the first six months is also associated with better inhibition scores over the same period, however this doesn't seem to extend to the long run (i.e change in inhibition in 12 months). Remarkably, an increase in MVPA over the first six months was associated with a decrease in longer-term verbal memory scores over the same six month period. Thus, for OACI who experience issues with being sufficiently active this seems good news as LPA is more achievable for them to improve CF than MVPA.

Trial Registration Netherlands Trial Register NL6005; Date of Registration 21-03-2017; https://www.trialregister.nl/trial/6005

Background

Cognitive decline can impair the quality of life of older adults and reduce their independence [1]. Especially older adults with chronic illnesses (OACI) are prone to have lower levels of cognitive functioning (CF) compared to healthy older adults [2]. Regular physical activity (PA) has been argued as an important protective factor against age-related cognitive decline, with PA at a moderate-to-vigorous intensity mostly being advised [3–5]. However, OACI can experience issues with being sufficiently physically active due to mobility problems, pain and fatigue [6]. Therefore, performing activities at a lighter intensity is more achievable for OACI. However, only few studies investigated the relationship between light physical activity (LPA) and CF [7–9]. Hence, the longitudinal association in OACI between change in respectively both LPA and moderate-to-vigorous physical activity (MVPA) on the one hand and the change in CF on the other hand are investigated.

The association between PA and CF has been confirmed in both cross-sectional and longitudinal cohort studies [10, 11]. However, evidence from studies regarding the effect of PA interventions on CF in older adults is incoherent [12]. Some meta-analyses have found moderate cognitive improvements as a result of PA interventions in older adults [4, 13–15]. Yet, other meta-analyses demonstrated none to limited cognitive improvements, even when the intervention lead to increased fitness and PA behavior [16–18]. Besides the wide variety in interventions (different type of PA activities, duration and frequency of the sessions, and the duration of the program), one of the possible explanations for this discrepancy can be found in the many different ways how PA was assessed [19].

For example, PA can be assessed subjectively with self-report questionnaires or objectively with accelerometers, and can be categorized into different intensity levels; sedentary, low, moderate and vigorous. Examples of LPA activities are walking at a low speed or light household chores. Bicycling at a low speed, vacuuming or walking briskly are examples of moderate intensity PA. And running, carrying heavy loads or swimming laps are examples of vigorous intensity PA. The effects of PA on physical health outcomes can be different at different intensity levels. Until recently, most research investigating the physical health benefits of PA, relied mainly on self-reported PA and often did not make a distinction between PA intensities. However, people's ability to recall PA of MVPA is much more accurate than that of LPA [20]. Currently, guidelines prescribe at least 150 minutes of MVPA spread over preferably multiple days per week to achieve physical health benefits [21], such as lower risk for obesity, cardiovascular disease, some types of cancer, osteoporosis and pre- mature death, hereby overlooking the role of LPA [22]. However, more recent evidence from studies assessing PA with accelerometers proved that LPA can have physical health benefits too [23–25]. These studies suggest that LPA is inversely associated with all-cause mortality risk and associated favourably with some cardio metabolic risk factors including waist circumference, triglyceride levels, insulin, and presence of metabolic syndrome.

Next to the physical health benefits of PA, the evidence for cognitive health benefits of PA grows. PA can promote cognitive brain health (i.e. ability to remember, learn, plan, concentrate and maintain a clear, active mind) and counteract many effects of cognitive aging [13]. In line with research into the physical health benefits of PA, research into the cognitive health benefits of PA have also mainly focused on MVPA. When looking at effects of MVPA on CF, the executive functions (inhibition, shifting and updating) seem to benefit the most [13, 15]. Executive functions are higher-order cognitive processes that are necessary to control cognitive behavior. Nonetheless, studies so far neglected the relation of PA on a lower intensity level with CF, but it appears that LPA could also be beneficial for CF [26–28]. In recent studies LPA has been positively associated with shifting, word fluency, processing speed and a reduced rate of cognitive ability decline [7–9]. However, until now there is little information on whether LPA influences different constructs of CF than MVPA does.

Despite the promising benefits of PA as described above, older adults are the least physically active age group, especially when they suffer from chronic illnesses [29, 30]. Fatigue and pain are examples of PA-related barriers experienced by OACI that may result in these low levels of PA [6, 29]. Increasing PA in general, especially through MVPA, is often difficult, and is sometimes accompanied by risks of injury and deterioration as a result of physical complications. Furthermore, increasing LPA is probably easier and safer for older adults. Therefore, it would be justified to determine which intensities of PA are associated with CF. Taking into account the fact that LPA (light housework, slow walking) is the dominant type of PA in older adults, especially in those who suffer from chronic illnesses, and that few of these older adults participate in meaningful amounts of MVPA, it is crucial to know how change in both LPA and MVPA are related to change in CF.

In a previous study on the effects of a computer-tailored PA stimulating intervention for OACI, we found no intervention effects on CF both six and 12 months after baseline (Volders et al., under review). This was most likely caused by the very limited objectively measured intervention effects on PA in this population [31]. However, the intervention group showed significantly more increase in some self-reported PA activities.

Despite the fact that our intervention had limited effects on PA behaviour and no effects on CF, it is relevant and scientifically valuable to investigate whether and how the change in PA, operationalized as MVPA as well as LPA, is related to a change in CF in OACI, independent of the intervention. Innovative and powerful for the current study is the objective measurement of PA by accelerometers, taking into account the limitations of self-reported PA. We hypothesize that participants who increased their PA (i.e. between baseline and six months follow-up, between six months follow-up and 12 months follow-up, and between baseline and 12 months follow-up), showed more progress on the CF tests than those who did not increase their PA. Furthermore, we hypothesize that associations between change in PA en change in CF are expected to be stronger when similar time periods are compared in comparison to different, non-parallel time periods, as potential associations can fade away over time. As different concepts of CF can respond differently to PA [13, 27], we analyse the associations between change in PA (LPA and MVPA) and CF for different concepts of CF. The selected concepts of CF are verbal memory, shifting, inhibition, and information processing because these concepts are known to deteriorate with age and can possibly improve with increased PA [10, 16, 32–35].

Methods

Study design and population

The present manuscript on the association of changes in LPA and MVPA over six and 12 months respectively with changes in CF outcomes over the same period, was part of the Active Plus and Cognitive Functioning project [36]. This project concerned a clustered two-group randomized controlled trial (RCT) with a waiting list control group with assessments at baseline, six and 12 months focused on the effect of the Active Plus intervention on CF. Data of all participants who completed the RCT study were used in the present manuscript. Ethical approval for the study was obtained from the Research Ethics Committee (cETO) of the Open University and the trial is registered in the Dutch Trial Register, protocol number NL6005. An elaborate explanation of the study protocol was published elsewhere [36].

Six hundred and twenty-three participants were recruited from seven municipalities, whom invited between 500 and 4000 independently living adults aged 65 years or older through an invitation letter via post. The participants met the following criteria: (1) aged 65 years or older; (2) fluent in the Dutch language; (3) suffering from at least one self-reported chronic illness that affects mobility (e.g., chronic obstructive pulmonary disease, osteoarthritis, chronic heart disease) or other physical problems (e.g., visually or hearing impaired) that may affect mobility; (4) no self-reported severe cognitive problems, and (5) no wheelchair user. All participants provided written informed consent.

Procedure

At baseline and at six and 12 months the following procedure was adhered to: PA was assessed with an accelerometer (ActiGraph GT3X-BT) placed on the participants' right hip for 7 consecutive days prior to the CF tests. The CF tests were conducted by a trained researcher or student at the participants' home. Inquisit 5 software [37] was used on a tablet (iPad Air 2) to execute the CF tests. The CF tests started with the first part of the Verbal Learning Test (VLT), followed by the Trail Making Test (TMT) part A and B, the Stop-signal Task (SST), the Letter Digit Substitution Test (LDST), and the second part of the VLT. After completing the CF tests, participants received a questionnaire to fill out within two weeks. The questionnaires were used to gather information on demographic variables, but also on concepts that are outside the scope of this manuscript (e.g., self-reported PA, self-reliance, health related quality of life). The 4 months lasting intervention started directly after completing the baseline measurement.

Outcome measures

Cognitive functioning

Table 1 provides an overview of all outcome measures. The concepts of CF (e.g., verbal memory, shifting, inhibition, processing speed) assessed in this study are chosen because they are known to deteriorate with age and can possibly improve with increased PA (Table 1) [10, 16, 32–36].

In the Verbal Learning Test (VLT) [33, 38], which assesses verbal memory, 15 common monosyllabic words representing concrete objects were presented one by one on an iPad screen in fixed order, with a presentation time of 1 second and an interstimulus interval of 1 second. Afterwards participants were asked to verbally recall the words they had remembered. The first trial was followed by four more trials in which the words were presented in identical order and each followed by an immediate free recall procedure. After a delay of 15–25 minutes in which the remaining CF tests were assessed, and unexpectedly for the participants, the instruction was given to recall the 15 words learned once more. Finally, a recognition trial was administered where participants had to recognize the 15 learned words out of 30 words. Outcome measures for the VLT were the learning curve ratio over trials 1–5, the mean number of recalled words in trial 1–5, and the number of words recalled in delayed trial (Table 1).

During the Trail Making Test (TMT) part A and B [39], which is used to asses shifting, participants had to draw lines with their fingers on a iPad screen connecting 25 randomly placed numbers in the correct order (part A) or numbers and letters alternatively (part B). The time in seconds required to complete the task was noted for each task. The outcome measure shifting was operationalized as the time to complete part B minus the time to complete part A.

In the Stop-Signal Task (SST) [40], which is an inhibition task, participants had to quickly press the left-hand button if the arrow on the iPad screen pointed to the left and press the right-hand button if the arrow pointed to the right. However, when a signal beep was played after the presentation of the arrow, participants had to inhibit their reaction and withheld from pressing either of the buttons. These beeps occurred in 25% of the trials. Firstly, participants could practice the task in a block of 32 trials. Afterward, three blocks of 64 trials were completed with 10 seconds of rest in between blocks. The stop-signal delay (SSD) between presentation of the arrow and signal beep was varied and depended on participants' performance. The delay, which started at 250 milliseconds (ms), was increased with 50 ms if the previous inhibition was successful. The delay got smaller with 50 ms if the previous inhibition was unsuccessful. This SSD staircase design ensured that participants were able to inhibit their response on approximately half of all trials. The inhibition outcome measure was operationalized as the stop-signal reaction time (SSRT).

During the Letter Digit Substitution Test (LDST) [34], which is a processing speed task, participants were presented with a matrix. Odd rows contained letters; even rows contained empty answer boxes. The task was to translate the letters by clicking the corresponding digits with the help of a provided key. After a practice round of 10 letters, the participant had 60 seconds to replace as many randomized letters with the appropriate digit indicated by the key. The outcome measure for the LDST was the number of correct substitutions made in 60 seconds.

Physical activity

PA was objectively measured using the ActiGraph GT3X-BT (ActiGraph, Pensacola, FL, USA). The accelerometer was placed on the right hip with an elastic belt. Participants were asked to wear the accelerometer for 7 consecutive days. However, during the night participants were not obliged to wear the device. While showering or swimming, the meter had to be removed.

Table 1

Outcome measures [b]

Measurement Instrument	Concept	Measure	Scoring/ missing items	Scoring range	Higher score indicates	% valid [a]
Primary outcome measures						
VLT	Verbal memory	Learning curve ratio	(Trial 1 + (Trial 2-Trial 1) + (Trial 3-Trial 2) + (Trial 4-Trial 3) + (Trial 5-Trial 4)) / 5	0–3 words per trial	Better learning capacity	98%
		Mean number of recalled words trial 1–5	(Trial 1 + Trial 2 + Trial 3 + Trial 4 + Trial 5) / 5	0–15 words	Better short-term verbal memory	
		Number of words recalled in delayed trial		0–15 words	Better long-term verbal memory	
TMT	Shifting	Time to complete part B minus time to complete A in sec		0-∞ sec	Worse shifting capacity	96%
SST	Inhibition	SSRT in ms	The SSRT is estimated in accordance with De Jong et al. [41] and Tannock et al. [42]. Negative SSRT values are excluded from the analyses [43].	0-1500 ms	Worse inhibition	90%
LDST	Processing speed	Number of correct substitutions		0-125 subs	Better processing speed	96%
Physical activity						

Abbreviations: VLT, verbal learning test; TMT, trail making test; SST, stop-signal task; LDST, letter digit substitution test; PA, physical activity; SSRT, stop-signal reaction time; MVPA, moderate-to-vigorous physical activity; LPA, light physical activity. [a] Test outcomes were excluded if scores were deemed invalid by test administer when 1) technical problems occurred, 2) participants refused to complete a test or lacked motivation, 3) participants had physical limitations (arm amputated, hearing loss etc.) or cognitive restrictions (participant is unable to understand the instruction), or 4) participants deviated from the instructions. [b] Derived from Table 1 in Volders et al., under review.

Measurement Instrument	Concept	Measure	Scoring/ missing items	Scoring range	Higher score indicates	% valid [a]
ActiGraph GT3X-BT	PA	MVPA minutes per week	Data downloaded with frequency extension on [44]. Valid if worn 4 days during 10 hours or more [45]. Non-wear definition by algorithm of Choi et al. [46]. PA scoring by Freedson-VM cut-off points [47] and by Aguilar-Fariaz cut-off points [48].	0-6720 min	More MVPA	96%
		LPA minutes per week		0-10080 min	More LPA	

Abbreviations: VLT, verbal learning test; TMT, trail making test; SST, stop-signal task; LDST, letter digit substitution test; PA, physical activity; SSRT, stop-signal reaction time; MVPA, moderate-to-vigorous physical activity; LPA, light physical activity. [a] Test outcomes were excluded if scores were deemed invalid by test administer when 1) technical problems occurred, 2) participants refused to complete a test or lacked motivation, 3) participants had physical limitations (arm amputated, hearing loss etc.) or cognitive restrictions (participant is unable to understand the instruction), or 4) participants deviated from the instructions. Derived from Table 1 in Volders et al., under review.

Demographic and health characteristics

Demographics and health characteristics were part of the Active Plus and Cognitive Functioning project [36]. As age, gender, educational level, marital status (living together with a spouse or living single), body mass index (BMI), and physical impairment, are known to influence PA [49] and some also CF[50], these factors assessed at baseline, were taken into account in the current study. Educational level is categorized into low (i.e., primary, basic vocational, or lower general school), moderate (i.e., medium vocational school, higher general secondary education, and preparatory academic education), or high (i.e., higher vocational school or university level) according to the Dutch educational system.

BMI is defined as the body mass (in kg) divided by the square of body height (in cm). The degree of physical impairment is measured with a self-report questionnaire [51]. The participant stated for 14 common chronic illnesses (e.g., cardiovascular, osteoarthritis) and physical conditions (e.g., hearing or visually impaired) to what degree he/she was limited in his/her PA by one of the illnesses mentioned or by another illness not mentioned. For each chronic illness, the participant scored the degree of impairment on a 5-point scale ranging from 0 = not applicable, 1 = not at all/hardly, 2 = a little, 3 = very, to 4 = extremely. Consequently, degree of impairment was computed into 3 categories following the next rules: (1) Little impaired: a maximum score of 1 on at least one question, (2) Medium impaired: a maximum score of 2 on at least one question, (3) Very impaired: at least a score of 3 or 4 on at least one question.

Statistical analyses

Baseline characteristics are described for all participants who finished the RCT using means and standard deviations for normally distributed continuous variables, medians and inter-quartile differences for non-normally distributed continuous variables and frequency and percent for categorical variables. For further analyses, we log transformed the non-normally distributed TMT outcome measure. To assess predictors of dropout at 12 months, logistic regression with baseline outcome measures, demographics, and degree of impairment regarding chronic illnesses was performed and odd-ratios (OR) are noted.

We tested the following longitudinal associations between PA and CF using multivariate linear regressions (Fig. 1). 1) Associations between change in PA over the first six months and change in CF outcomes over the same period; 2) Associations between change in PA between six months and 12 moths follow-up and change in CF outcomes over the same period; 3) Associations between change in PA between baseline and 12 months follow-up and change in CF outcomes over the same period. 4) Associations of the predictive value of change in PA between baseline and six months follow-up for change in CF outcomes between baseline and 12 months follow-up.

Change in LPA and MVPA was calculated by subtracting the former PA score from the latter follow-up score, only if scores on both time points were known. Otherwise, these scores were not taken into account in the analyses. Only valid CF tests were included in the analyses. The regressions were adjusted for age, gender, educational level, marital status, BMI, degree of impairment, baseline or six months follow-up CF construct score and condition (whether the participant was part of the intervention group or the control group). Continuous covariates were standardized. To assess which PA component was the more predominant factor in relation to cognitive function, both MVPA and LPA were analysed simultaneously (in the same model). Furthermore, confidence intervals (CI) were calculated for all outcomes. Analyses were conducted on all available and valid data without any ad hoc imputation [52]. Significance levels for all analyses were set at $p < 0.05$. All analyses were conducted using R [53].

Results

The seven municipalities invited a total of 14.576 inhabitants, of whom 623 provided informed consent. Thirty-eight participants withdrew from the study without completing any baseline measurements. At six months 19.1% (112/585) of the participants dropped out and at 12 months this rate was 26.2% (153/585). At both six and 12 months, drop-out was more likely for persons with a higher age (6m: OR = 1.06, 95% CI = 1.01;1.12, $p = 0.027$; 12m: OR = 1.05, 95% CI = 1.00;1.10, $p = 0.038$).

As shown in Table 2 the mean age of the participants was 73.7 (± 6.1) years with 46.8% female participants. The majority of the participants was living together with a spouse (82.1%), and 48.3% was low-educated (i.e., primary, basic vocational, or lower general school). Most participants (47.7%) were medium impaired. The most frequent chronic illnesses participants suffered from and impaired PA were osteoarthritis (51.7% of all participants), vascular diseases (44.6%) and heart diseases (37.2%). Participants suffered from an average of 3.5 chronic illnesses or physical impairments.

Table 2
Baseline participant characteristics (*N = 432*).

Demographic characteristics	
Age in years, mean (SD)	73.7 (6.1)
Gender, *N* (%)	
Male	230 (53.2%)
Female	202 (46.8%)
Marital status, *N* (%)	
Living single	76 (17.9%)
Living together	348 (82.1%)
Education, *N* (%)	
Low	202 (48.3%)
Moderate	89 (21.3%)
High	127 (30.4%)
Health-related characteristics	
BMI, median (IQR) □	26.9 (24.3–29.4)
Degree of impairment, *N* (%)	
Little impaired	49 (11.4%)
Medium impaired	205 (47.7%)
Very impaired	176 (40.9%)
LPA in min/wk, mean (SD)	2524 (622)
MVPA in min/wk, median (IQR) □	159 (66.3–292.3)
CF outcomes	
VLT – learning curve ratio, mean (SD)	1.85 (0.55)
VLT – mean no. words recalled trial 1–5, mean (SD)	7.24 (2.08)
VLT – no. words delayed recall, mean (SD)	7.57 (3.15)

Abbreviations: SD, standard deviation; IQR, Inter Quartile Distance; BMI, body mass index; LPA, minutes of light physical activity per week; MVPA, minutes of moderate-to-vigorous physical activity per week; CF, cognitive functioning; VLT, verbal learning test; TMT, trail making test; SST, stop-signal task; SSRT, stop-signal reaction time; LDST, letter digit substitution test. □ non-normally distributed variables.

Demographic characteristics	
TMT – time B-A in sec, median (IQR)	27.98 (12.79–49.39)
SST – SSRT in ms, mean (SD)	155.94 (75.94)
LDST – no. correct subs, mean (SD)	11.33 (4.26)

Abbreviations: SD, standard deviation; IQR, Inter Quartile Distance; BMI, body mass index; LPA, minutes of light physical activity per week; MVPA, minutes of moderate-to-vigorous physical activity per week; CF, cognitive functioning; VLT, verbal learning test; TMT, trail making test; SST, stop-signal task; SSRT, stop-signal reaction time; LDST, letter digit substitution test. non-normally distributed variables.

Associations between change in PA and change in CF over similar time periods

Table 3 shows the results of the associations between the change in PA in the first six months with change in CF outcomes over the same period. An increase in LPA between baseline and six months follow-up was significantly positively associated with change in mean number of words recalled in the first 5 trials of the VLT test (Coeff. = 0.18, $p \leq 0.01$) over the same period, showing better short-term memory functions by an increase in LPA over time. Furthermore, an increase in LPA was significantly negatively associated with change in SSRT of the SST over the same period, indicating better inhibition scores after an increase in LPA (Coeff. = -9.84, $p = 0.03$). An increase in MVPA between baseline and six months was significantly negatively associated with change in the number of words recalled in the delayed recall trials of the VLT over the same period (Coeff. = -0.21, $p = 0.04$). This, in contrast to the results of LPA, shows that an increase in MVPA over six months was associated with lower retention capacity. As there were no significant associations between the change in PA and CF over the 6–12 month period, nor between baseline-12 months period these results are not displayed here but are added as supplementary files (Supplementary table 1 and 2).

Table 3
Association between change in PA 0–6 months and change in CF over the same period.*

		Δ LPA 0–6				Δ MVPA 0–6			
Change in CF 0–6	N	**Coeff.**	**SE**	**95% CI**	p	**Coeff.**	**SE**	**95% CI**	p
VLT – learning curve ratio	372	0.02	0.02	-0.01;0.06	0.22	-0.00	0.02	-0.04;0.04	0.88
VLT – mean no. words recalled trial 1–5	372	0.18	0.07	0.05;0.32	**0.008**	-0.05	0.07	-0.19;0.08	0.45
VLT – no. words delayed recall	373	0.19	0.10	-0.01;0.38	0.07	-0.21	0.10	-0.41;-0.01	**0.044**
TMT – time B-A in sec [a]	359	0.00	0.01	-0.02;0.02	0.79	-0.01	0.01	-0.03;0.02	0.62
SST – SSRT in ms	313	-9.84	4.38	-18.47;-1.21	**0.026**	-0.45	4.51	-8.42;9.32	0.92
LDST – no. correct subs	362	-0.19	0.15	-0.49;0.11	0.21	0.18	0.16	-0.13;0.49	0.26

Abbreviations: PA, physical activity; LPA, change in light physical activity minutes per week between six months follow-up and baseline; MVPA, change in moderate-to-vigorous physical activity minutes per week between six months follow-up and baseline; SE, standard error; CI, confidence interval; ES, effect size; CF, cognitive functioning; VLT, verbal learning test; TMT, trail making test; SST, stop-signal task; SSRT, stop-signal reaction time; LDST, letter digit substitution test. [a] TMT – time B-A in sec was log transformed. * Models are adjusted for baseline CF score, the covariates, and condition (control or intervention group).

The influence of change in PA in the first six months on CF change over a year

Table 4 shows the associations of the predictive value of change in PA in the first six months for change in CF outcomes between baseline and 12 months follow-up. Increased LPA between baseline and six months follow-up was significantly positively associated with change in the mean number of words recalled in the first 5 trials of the VLT test over 12 months (Coeff. = 0.18, $p = 0.02$), showing an increase in LPA is of predictive value for better short-term memory functions over an extended period. No other significant relations were found.

Table 4
Association between change in PA 0–6 months and change in CF 0–12 months.*

		Δ LPA 0–6				Δ MVPA 0–6			
Change in CF 0–12	N	**Coeff.**	**SE**	**95% CI**	p	**Coeff.**	**SE**	**95% CI**	p
VLT – learning curve ratio	372	0.03	0.02	-0.01;0.06	0.18	-0.02	0.02	-0.06;0.02	0.33
VLT – mean no. words recalled trial 1–5	372	0.18	0.07	0.03;0.33	**0.016**	-0.08	0.07	-0.23;0.07	0.32
VLT – no. words delayed recall	374	0.20	0.11	-0.02;0.42	0.08	-0.00	0.11	-0.23;0.22	0.97
TMT – time B-A in sec [a]	360	-0.01	0.01	-0.03;0.01	0.25	-0.00	0.01	-0.02;0.02	0.91
SST – SSRT in ms	306	0.98	4.28	-7.44;-9.40	0.82	-6.76	4.36	-15.35;1.82	0.12
LDST – no. correct subs	350	0.12	0.17	-0.20;0.45	0.46	-0.13	0.17	-0.47;0.20	0.44

Abbreviations: PA, physical activity; LPA, change in light physical activity minutes per week between six months follow-up and baseline; MVPA, change in moderate-to-vigorous physical activity minutes per week between six months follow-up and baseline; SE, standard error; CI, confidence interval; ES, effect size; CF, cognitive functioning; VLT, verbal learning test; TMT, trail making test; SST, stop-signal task; SSRT, stop-signal reaction time; LDST, letter digit substitution test. [a] TMT – time B-A in sec was log transformed. * Models are adjusted for baseline CF score, the covariates, and condition (control or intervention group).

Discussion

The aim of this study was to investigate the longitudinal association in OACI between change in respectively both LPA and moderate-to-vigorous physical activity (MVPA) on the one hand and the change in CF on the other hand. An increase in LPA in the first six months was significantly associated with an increase in short-term verbal memory scores (higher mean number of words recalled during the first 5 trials of the Verbal Learning Test) and improved inhibition (lower Stop Signal Reaction Time on the Stop Signal Task) over the same period. In addition, the change in LPA over the first six months was predictive for the change score in short-term verbal memory over 12 months. Contrastingly, an increase in MVPA in the first six months was significantly associated with worse longer-term verbal memory scores (lower number of words recalled during the delayed recall trial of the Verbal Learning Test). No significant associations were found between change in PA and change in CF constructs between baseline and 12 months follow-up and between six months follow-up and 12 months follow-up.

The present study established that an increase in objectively measured LPA is beneficial for some CF constructs in OACI. The results of the few past longitudinal studies are controversial. Stubbs et al. [54] found that a higher level of objectively measured LPA, independent of MVPA, was prospectively associated with better cognitive ability in community dwelling older adults. In addition, objectively assessed MVPA was also associated with better cognitive status. Although objectively assessed PA was only measured at baseline in the study of Stubbs et al., which bars the capability to examine the relationship between changes in LPA and cognitive ability, it was one of the first longitudinal studies to find that LPA is beneficial for cognitive ability in older adults. However, cognitive ability was tested with a self-report questionnaire instead of the more objective psychological test used in our study. Contrastingly, Zhu et al. [55] found that a dose-response relationship exists between engagement in MVPA and cognitive performance, tested with neuropsychological tests, over time. Yet, no relationship between LPA and cognitive performance over time was found. Notwithstanding, this study also only assessed PA at baseline, contrary to our study. It is clear that this field of research is in need for more studies of higher quality.

A possible explanation for the finding that only an increase in LPA was positively associated with change in CF, and that an increase in MVPA was even negatively associated with change in one CF outcome, can be found in the type of activities belonging to LPA and MVPA. Typical LPA activities are casually walking and household chores. Conceivably, these activities offer more opportunity for cognitive engagement with other people, listening to music or enjoying the outdoors. For it is known that social and intellectual activities of daily life are associated with higher cognitive performance [56, 57]. Whereas common MVPA activities, such as brisk walking or bicycling, are possibly too exhausting for further cognitive engagement, especially for OACI. However, a recent study suggests that MVPA activities that do require a greater cognitive engagement, such as dancing, do lead to greater training effects on cognition and brain connectivity than exercise requiring lower cognitive loads, such as walking briskly, in healthy elderly [58]. Nonetheless, these greater cognitive enhancing MVPA activities are generally not preferred by OACI [59].

Our findings are important in the context of the suitableness of the prescription of LPA to OACI. OACI often have limited mobility and suffer from pain and fatigue [29]. As a result OACI may be deconditioned or are not used to exercise and thus restricted to LPA only. LPA activities such as casual walking, gardening and household chores, are preferred PA activities for older adults [60]. Moreover, LPA may also offer opportunities to interact with other people and as a result reduce the risk of social isolation. Furthermore, increasing PA in general, especially through MVPA, is often challenging, and sometimes comes along with risks of injury and deterioration as a result of physical complications. Increasing LPA is on the other hand probably easier and safer for older adults and OACI in special [8]. Furthermore, it is probably easier to maintain in the long term. Therefore, this study reveals that it would be warranted to prescribe LPA for OACI to gain both health benefits and cognitive benefits. Future interventions, PA guidelines and PA programs should address this finding.

This study has several strengths. Firstly, we objectively assessed PA with accelerometers. Although they have some limitations in distinguishing between type of activities, they are considered a better measurement tool for PA than self-report questionnaires [61]. These questionnaires are prone to over reporting and have issues with validly assessing LPA [20, 62]. Secondly, our research population is reasonably representative for the general older adult population as almost equal groups of males and females participated and a most of the participants were low educated (e.g., 51%) [63]. Furthermore, BMI levels and the mean number of comorbidities (3.5) are also comparable to the general older adult population of the Netherlands [64, 65]. Therefore, these results should be generalizable to the OACI population or even to the general older adult population of the Netherlands.

This study also had some limitations. First, this study only tested the associations of change in LPA and MVPA with change in CF. To test the actual effects of change in PA on CF, a RCT has to be carried out with at least three groups (LPA intervention, MVPA intervention, control group). As our own Active Plus intervention was mainly aimed at stimulating MVPA, and we only included one experimental group in the RCT [36], we could not test the effects of change in LPA and MVPA on CF separately. In addition, isolating the independent contribution of both PA intensities is difficult. Furthermore, the study period of one year was quite short. Future longitudinal research of longer duration is required to verify our one year findings. Another limitation was that we performed multiple tests to analyse the associations of PA with CF. This gives a broader perspective on CF functioning instead of assessing one specific test. However, the more tests done, the more likely faulty conclusions are drawn, because the probability of a Type 1 error is increased [66]. A Bonferroni correction, however, assumes that all of the hypothesis tests are statistically independent, which is not the case in the current study as these constructs of CF are dependent. Therefore, a Bonferroni correction would be overly conservative. However, the results of this study should be considered with caution.

Conclusions

An increase in LPA in the first six months is associated with better short-term verbal memory and inhibition over the same period. Furthermore, an increase in LPA in the first six months was a predictive value for change in short-term verbal memory over a 12 months period. MVPA however, is at the first six months associated with worse longer-term verbal memory scores. It may be that LPA activities offer opportunities for PA with greater cognitive engagement than MVPA activities. For OACI who experience issues with being sufficiently active this is good news as LPA is more achievable for them than MVPA in order to improve CF.

List Of Abbreviations

BMI – body mass index

cETO – Research Ethics Committee of the Open University

CI – confidence intervals

CF – cognitive functioning

OACI – older adults with chronic illness(es)

ES – effect size

ICC – intra cluster correlation

IQR – inter quartile distance

LDST – letter digit substitution test

LPA – light physical activity

MMSE – mini mental state examination

MVPA – moderate-to-vigorous physical activity

OR – odds-ratio

PA – physical activity

RCT – randomized controlled trial

SD – standard deviation

SE – standard error

SSD – stop-signal delay

SSRT – stop-signal reaction time

SST – stop-signal task

TMT – trail making test

VLT – verbal learning test

Declarations

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Author Contributions

Conceptualization: EV, CB, RG, LL; Data curation: EV; Formal analysis: EV; Funding acquisition: CB, RG, LL; Investigation: EV; Methodology, EV, CB, RG, LL; Project administration: EV; Supervision: CB, RG, LL; Writing – original draft: EV; Writing – review and editing: CB, RG, LL.

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Ethics approval and consent to participate

Ethical approval for the study was obtained from the Research Ethics Committee (cETO) of the Open University and the trial is registered with the Dutch Trial Register, protocol number NL6005. All participants have provide written informed consent prior to commencing the study. The study was conducted following the Declaration of Helsinki.

Consent for publication

Not applicable.

Availability of data and material

Study data are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Figures

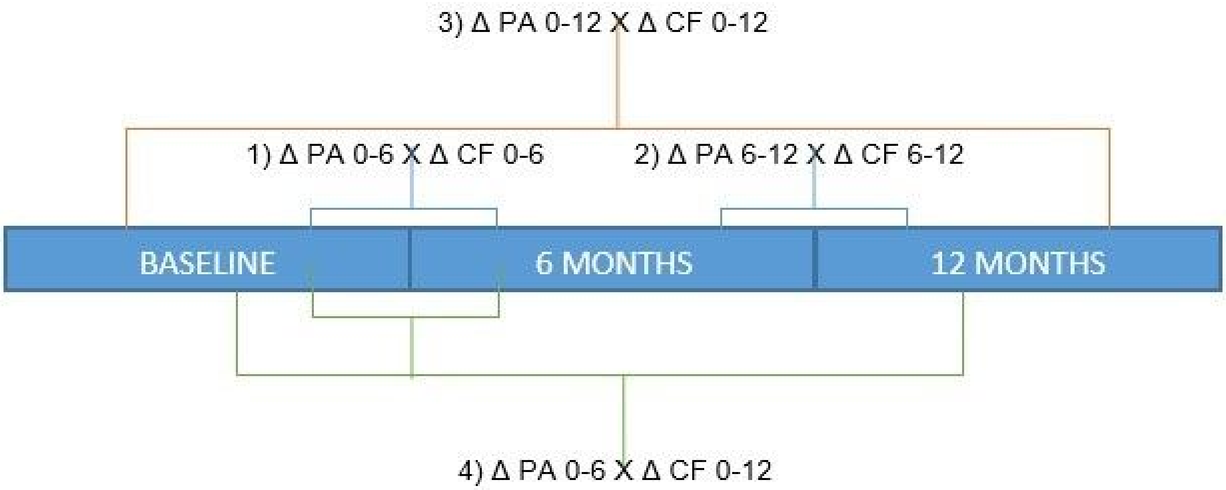

Figure 1

Overview of tested associations

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