Preserved differentiation between physical activity and cognitive performance across young, middle, and older adulthood over 8 years..

Article:

Bielak, AA, Cherbuin, N, Bunce, D et al. (1 more author) (2014) Preserved differentiation between physical activity and cognitive performance across young, middle, and older adulthood over 8 years. Journals of Gerontology, Series B, 69 (4). 523 - 532. ISSN 1079-5014

https://doi.org/10.1093/geronb/gbu016

Appears in *Journal of Gerontology Psychological Sciences* (Accepted version)

January 30, 2014

Running Head: PHYSICAL ACTIVITY AND COGNITIVE CHANGE

Preserved differentiation between physical activity and cognitive performance across young, middle, and older adulthood over 8 years.

llison A. M. Bielak[1], Nicolas Cherbuin[2], David Bunce[3], & Kaarin J. Anstey[2]

[1] Department of Human Development and Family Studies, Colorado State University, Fort Collins, USA

[2] Centre for Research on Ageing, Health and Wellbeing, The Australian National University, Canberra, Australia

[3]Institute of Psychological Sciences, Faculty of Medicine and Health, University of Leeds, Leeds, UK

Corresponding author – A. Bielak
Department of Human Development and Family Studies
1570 Campus Delivery
Colorado State University
Fort Collins, Colorado 80523-1570
Ph: (970) 491-7608
Fax: (970) 491-7975
allison.bielak@colostate.edu

Abstract

Objectives: A critical question in the activity engagement literature is whether physical exercise alters the trajectory of age-related cognitive decline (differential preservation), or is associated with enhanced baseline cognitive ability (preserved differentiation). Further, investigations considering that these relations may differ across young, middle, and older adulthood are rare. Method: We evaluated data from the PATH Through Life Project, where participants 20-24 years, 40-44 years, and 60-64 years at baseline (*n*=6869) completed physical activity (mild, moderate, and vigorous) and cognitive measurements thrice over 8 years. Results: Multilevel models accounting for employment status, sex, education, health, and mental and social activity showed that between-person differences in physical activity participation positively predicted baseline performance on fluid cognitive ability (perceptual speed, short-term memory, working memory, and episodic memory). These effects were similar across age groups, but strongest for the youngest cohort, for whom there was also evidence of covariation between within-person change in physical activity and cognitive score. Physical activity was not associated with change in cognition over time. Discussion: Results support preserved differentiation, where physically active adults have higher initial cognitive ability, and the advantage is maintained over time. Physical activity appears to be unique in showing differences across young, middle, and older adulthood in predicting cognition.

Keywords: Cognitive change, Activity engagement, physical activity, adulthood, longitudinal

Word count: 5884

Being physically active or spending time engaging in mild, moderate, or vigorous exercise has been consistently demonstrated to be one of the most effective lifestyle behaviors one can take to reduce their risk of dementia and cognitive decline (Ahlskog, Geda, Graff-Radford, & Petersen, 2011; Flicker, 2010). Compared to the relative risk ratios of various modifiable factors including diabetes, midlife obesity, depression, and smoking, physical inactivity contributed to the largest proportion of Alzheimer disease cases in the United States, and was the third largest contributor worldwide (Barnes & Yaffe, 2011). Randomized controlled trials and interventions introducing physical activity to older adults have demonstrated cognitive and neurological benefits (Hillman, Erickson, & Kramer, 2008; Hindin & Zelinski, 2012; Langlois et al., 2012)(but see (Plassman, Williams, Burke, Holsinger, & Benjamin, 2010), and prospective studies echo the positive correlation between physical exercise and cognitive functioning (e.g., Weuve et al., 2004). Even animal research in controlled environments has shown consistent positive findings (Pietrelli, Lopez-Costa, Goni, Brusco, & Basso, 2012).

Physical activity levels at midlife have been shown to be related to later-life cognitive ability, dementia risk, and likelihood of developing mild cognitive impairment years later (e.g., Andel et al., 2008; Dik, Deeg, Visser, & Jonker, 2003; Rovio et al., 2005). There are two possible explanations for these associations (see Salthouse, 2006). The first is termed *differential preservation*, and states that engaging in exercise changed the developmental course of age-related cognitive development, for example allowing those who were active at midlife to show less cognitive decline as they aged. The second possibility is that the association is instead static, and only reflects the higher level of cognitive ability amongst those who are physically active, and does not influence cognitive *change* per se. In other words, this effect termed *preserved differentiation*, could be found between any two time points in the life span (e.g., physically active 70 year olds show higher cognitive scores at age 80 than inactive 70 year olds) and would simply indicate that physical activity is associated with enhanced baseline ability but is not related to changes in the cognitive trajectory. The challenge is distinguishing which of these two possibilities has actually occurred[1].

One method of investigation is to assess both the link between level of physical activity and baseline cognitive score, and level of physical activity with change in cognitive score. If the latter is not significant, the initial association between exercise and mental ability is stable over time rather than influencing developmental change. This analysis can be taken a step further and include an examination into whether the association was caused by between-person or within-person differences when both cognition and activity have been assessed at multiple time points (see Hoffman & Stawski, 2009). Our earlier paper (Bielak, Anstey, Christensen, & Windsor, 2012) found participants' average level of engagement in mental and social activities across 8 years (representing between-person differences) was positively associated with their baseline scores on tests of perceptual speed, short-term memory, working memory, episodic memory, and vocabulary. Average activity engagement was not linked to cognitive changes over 8 years however, thus supporting preserved differentiation. In addition, changes in mental and social activity across the testing occasions, or from one measurement point to the next (within-person differences) did not significantly covary with changes on any of the cognitive tests.

---

[1] Interventions that introduce physical activity to a group of participants and contrast any cognitive changes that may have occurred with a control group also cannot differentiate between the two explanations. An intervention may only act as a single boost to cognitive ability even if the gain is maintained over time, and is not technically indicative of differential preservation. The question is whether the differences between the groups grows even after completion of the intervention, indicating differential preservation, or remains stable years later, suggesting preserved differentiation (i.e., the groups differ but follow the same age-related cognitive trajectory).

Few studies have evaluated the issue of preserved differentiation and differential preservation in regards to physical activity and cognition. Gow, Mortensen, and Avlund (2012) found physical activity level at both ages 60 and 70 predicted change in general cognitive ability from ages 60 to 80, supporting differential preservation. In contrast, coordinated analyses across four longitudinal studies of aging (55 years and older at baseline) with four cognitive domains found only two instances of baseline physical activity predicting cognitive change, specifically change in verbal fluency (Lindwall et al., 2012). However, fluctuations in the amount of physical activity corresponded with fluctuations in reasoning, verbal fluency, and memory across time, suggesting physical engagement may demonstrate a link with cognition on a within-person basis. Between-person changes in physical activity were found to be dynamically linked to changes in verbal speed and episodic memory over 12 years in sample aged 55 to 94 years at baseline, where both physical activity influenced cognitive change, and cognitive ability influenced physical activity change (Small, Dixon, McArdle, & Grimm, 2012).

There has also been greater interest in evaluating the relative contribution of the various activity types on cognition (Bielak, 2010; Hertzog, Kramer, Wilson, & Lindenberger, 2009), although few studies investigating physical activity and cognition have controlled for other types of engagement (Lee et al., 2013; Miller, Taler, Davidson, & Messier, 2012). There is some suggestion that accounting for cognitive engagement may eliminate the predictive effects of physical activity. Sturman et al. (2005) found physical activity no longer predicted 6-year cognitive decline following the addition of cognitive activity to the model. Similarly, the effect of physical activity on memory ability 9 years later was attenuated after accounting for spare-time activity (e.g., chess, church attendance, playing a musical instrument), although the link between physical activity and memory change was not affected (Richards, Hardy, & Wadsworth, 2003). Consequently, it is of interest to evaluate multiple activity domains within the same analysis.

Finally, investigations covering young, middle, and older adulthood are rare in the physical activity literature (Hillman, et al., 2008). The majority of work with cognitive ability focuses on older adulthood, presumably when age-related cognitive change becomes noticeable. Salthouse (2008) noted the weakness of this method which overlooks that cognitive change is a continuous process that begins years earlier. Further, the determination of whether physical activity and cognitive function have the same association throughout the lifespan is amongst the pressing research problems in the exercise and cognition literature (Spirduso, Poon, & Chodzko-Zajko, 2008). Although interventions are hypothesized to be most effective before cognitive decline is apparent (Hertzog, et al., 2009; Salthouse, 2008), observational research is needed to investigate the relationship between physical activity and cognition across adulthood.

Compared to younger cohorts (i.e., 15-39 years; 18-27 years), cross-sectional comparisons have found physical activity to be a stronger predictor of executive function (Hillman et al., 2006) and visual imagery performance (Newson & Kemps, 2006) for those 40-71, and 65 years and older, respectively. However, the associations were identical between the age groups for processing speed (Hillman, et al., 2006). A meta-analysis focusing exclusively on older adulthood (55-80 years) found the greatest effect of exercise specifically amongst those aged 66 to 70 years (Colcombe & Kramer, 2003), but another meta-analysis including the full span of adulthood (18-90 years) found the largest association was for those between 40 and 60 years old (Etnier et al., 1997). In contrast, compared to self-reported retrospective reports of physical activity at ages 30, 50, and 70, physical engagement as a teenager was most protective against the risk of cognitive impairment in older age (Middleton, Barnes, Lui, & Yaffe, 2010).

One of the few longitudinal studies including middle aged adults found higher levels of physical activity at age 36 were associated with a reduced rate of memory decline from ages 43 to 53, but physical activity level at age 43 attenuated the association (Richards, et al., 2003). Overall, the conclusions regarding physical activity participation and cognitive functioning across adulthood remain equivocal.

The present study aimed to investigate two research questions in a population-based longitudinal dataset covering those aged 20-24, 40-44, and 60-64 years at baseline. First, we analyzed how the between-person (level) and within-person differences (individual change) in physical activity engagement were related to a composite of fluid cognitive ability both tested thrice over 8 years. The differentiation of activity permitted greater evaluation of which aspect of physical activity was related to cognitive ability: being more physically active compared to others, or showing greater individualized change in physical activity over time. Based on earlier results evaluating mental and social activity (Bielak, et al., 2012), we hypothesized that the between-person effects would show a stronger relation to cognitive performance than the within-person variations in physical activity level. Further, this evaluation allowed examination of the type of association between physical activity and cognitive ability that existed across adulthood: preserved differentiation or differential preservation. As the literature is inconsistent, and this conundrum may vary by activity domain, we did not have a specific expectation about whether between-person physical activity would be related to cognitive change over time (i.e., differential preservation), or only be associated with average cognitive performance (i.e., preserved differentiation). Second, we analyzed whether possible age differences existed in the associations between physical activity and cognition. A paper focused on mental and social activity that used the present sample failed to find significant age differences (Bielak, et al., 2012), however, physical activity has rarely been investigated across young, middle, and older adulthood. Consequently, we did not have a specific hypothesis about age differences. Finally, this investigation also occurred over and above the between- and within-person components of mental and social activity, providing comparison of the relative contribution of physically-based engagement to cognitive performance.

Method

Participants

The study sample was drawn from the Personality and Total Health (PATH) Through Life Project, a longitudinal study which has followed three age cohorts of adults (i.e., 20s, 40s, 60s) for 8 years with repeat testing at 4-year intervals (see Anstey et al., 2012 for further information).

Potential participants included those aged 20-24 years on January 1, 1999; those aged 40-44 years on January 1, 2000; and those aged 60-64 years on January 1, 2001, who were Australian citizens and living in the community in the city of Canberra or the neighboring town of Queanbeyan, Australia. Participants were identified from the electoral roll, for which registration is compulsory for Australian citizens. Participants who agreed to participate in the study totaled 7, 485 (20s: *n*=2,404; 40s: *n*=2,530; 60s: *n*=2,551), and approximately half of each age cohort was female.

There was limited sample attrition over the course of the study, with 6,680 participants returning for Wave 2, and 5,996 participants also completing Wave 3. Participants who reported having a history of stroke, and older participants who scored less than 24 on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) at any time point were excluded from the present analyses. Only participants with available baseline data for all covariates were included, resulting in 6, 869 participants. There was a mean length of follow-up of 7.00 years (*SD* = 2.45). At each testing wave, participants completed a sequence of questionnaires and tests that assessed a series of constructs, including their well-being, mental and physical health, cognitive function, and activity participation. The majority of the assessment was administered on a hand-held or laptop computer, and was completed under the supervision of and with the assistance of an interviewer.

Measures

Physical Activity Participation. Participants were asked in an open-ended format to report the average weekly number of hours spent engaging in physical activity at a level similar to particular sports or activities. The three questions asked for time spent in a) mildly energetic (e.g., walking, weeding, general housework), b) moderately energetic (e.g., dancing, cycling, polishing car), and c) vigorous activity (e.g., running, squash)[2]. The data were first trimmed for physical activity outliers due to the extensive range in reported activity (e.g., ten participants reported 70 hours of mild physical activity each week, when the overall average was under 7 hours). As we wanted to focus on the average adult for the present analyses (i.e., non-athlete), we excluded entries that were + 2 SDs for that exercise type for each wave (calculated at baseline for entire sample). This trimming maintained physical activity data for 95% of the sample for mild activity, and 97% of the sample for moderate and vigorous activity.

In order to provide a holistic view of physical activity level, each participant's estimated weekly values for the three activity types were combined. However, in order to account for the fact that each activity type requires different energy and exertion levels, we used standard

---

[2] Immediately prior to these questions, three additional questions asked participants to rate their weekly physical activity level on a 4 point scale (i.e., from 3 times/week to never/hardly ever). These questions provided further examples regarding what classified as mildly, moderately, and vigorously energetic activity.

metabolic equivalent values (MET; mL of used oxygen/minute) that corresponded to each physical activity type to calculate the combined value. On average, light intensity is < 3 METs, moderate intensity is 3-6 METs, and vigorous intensity is ≥ 6 METs (Physical activity guidelines advisory committee, 2008). This scale parallels the assumption that light intensity exercise is 1/3 of the intensity of vigorous activity, and ½ the intensity of moderate activity. Following this scale, physical activity for the present analyses was calculated for each individual as mild sessions + (2 x moderate sessions) + (3 x vigorous sessions) to produce a value on the same scale[3].

The physical activity scores were converted into *T*-scores (*M* = 50, *SD* = 10) using the baseline means and standard deviations across age groups. Physical activity was then divided into two components: PA-between represented the between-person effect of physical activity, and was obtained by calculating each individual's average combined physical activity score across the waves. PA-within represented the within-person effect of physical activity, and was obtained by subtracting each individual's combined physical activity score for that wave from their average level of combined physical activity participation.

Fluid Cognitive Ability. A fluid cognitive composite was used as similar activity effects were previously found across measures of perceptual speed, short-term, working, and episodic memory (Bielak, et al., 2012), and a combined variable has greater reliability of cognitive performance than a single construct. Participants completed a series of cognitive tests that assessed components of fluid intelligence (Horn, 1987), including perceptual speed, short-term memory, working memory, and episodic memory. Perceptual speed was assessed using the

---

[3] MET has been demonstrated to vary by a multitude of individual factors including body fat percentage, sex, activity level, efficiency of movement, and age (Ainsworth et al., 2011). However, there are criticisms regarding corrected MET values (Howley, 2011), and we chose to implement the same calculation across all participants, and for each wave.

Symbol Digit Modalities Test (Smith, 1982) which presented participants with a coding key pairing numbers 1 through 9 with nine symbols. Participants were given 90 seconds to transcribe as many numbers that corresponded to the random-ordered presented symbols as possible. Short-term memory and episodic memory were measured by the immediate and delayed recall of the first list of the California Verbal Learning Test (Delis, Kramer, Kaplan, & Ober, 1987). Participants were read a list of 16 words from 4 taxonomic categories (e.g., fruits, tools) presented in unblocked order, and asked to immediately recall as many words as possible (short-term memory). Following a short interval (i.e., completing a grip strength task), participants were again asked to recall as many words as possible (episodic memory). Working memory was assessed using digit span backwards from the Wechsler Memory Scale (Wechsler, 1945). Participants were read 10 sets of 3 to 7 numbers, and after each set asked to repeat the presented numbers backwards.

Scores on each of the four tasks were converted to *T*-scores using the baseline sample. The scores were then combined to form a fluid cognitive composite for each individual at each wave. Further information regarding change for these individual tests can be found in Bielak et al. (2012).

Covariates

As cognitive ability and physical activity participation may also vary by sex, employment status, education, and physical and mental health (Paillard-Borg, Wang, Winblad, & Fratiglioni, 2009; Parisi et al., 2012), these effects were controlled for in all analyses. *Employment status* was based on participant's self-report of working full-time, part-time, or being unemployed. *Education* was assessed by years of formal schooling, and *diabetes* was based on the self-reported presence of the disease at any wave. *Hypertension* was determined from blood pressure readings at each wave, and any participant scoring above 140 systolic or 90 diastolic, or reporting taking blood pressure medication at any wave was coded as having hypertension. *Physical and mental health* were measured using the RAND-12 assessment (Hays, 1988), and the baseline score for each component was included in the analyses. *Anxiety* and *depressive symptoms* were based on responses to the Goldberg Anxiety and Depression Scale (Goldberg, Bridges, Duncan-Jones, & Grayson, 1988), and were entered into the models separately as time-varying anxiety and depression scores.

Mental and social activity were assessed using a shortened version of the RIASEC Activity List (Parslow, Jorm, Christensen, & Mackinnon, 2006), asking participants to report if they engaged in 16 different activities over the past 6 months (yes/no). Examples of items included reading, completing puzzles, artistic activities (e.g., sketched, drawn, or painted), attending cultural activities (e.g., recitals, concerts, musicals), helping others with personal problems, leading a group in accomplishing a goal, and serving on a committee of a group (see Bielak, et al., 2012 for further description). The total score of mental and social activity was recorded and divided into its between-person (individual-based average mental and social activity score across waves; MS-between) and within-person (mental and activity score at each wave – individual-based average mental and social activity score; MS-within) components. This division is consistent with the procedure applied previously (Bielak, et al., 2012).

Statistical Analysis

Cognition was modeled across a time in study metric as not all participants were tested at precise 4-year intervals. First, a model including age group as a fixed predictor of the cognitive intercept and slope were conducted, including estimation of the random intercept and slope effects (see supplementary appendix A). The model included the covariates sex, employment status, history of hypertension and diabetes, physical and mental health, depressive and anxiety symptoms, and education, and both between- and within-person components of mental and social activity. This permitted evaluation of whether significant change occurred across the 8 years, and to examine age group differences in cognitive change. Verification of significant variation in physical activity across time was also conducted using a similar model[4] with total physical activity as the dependent variable. Next, the physical activity variables, PA-between and PA-within, were added to the model. PA-between was added as a time-invariant predictor of both cognitive level and slope, allowing investigation of whether between-person differences in activity were associated with average cognitive ability and the rate of change. PA-within values were added as a time-varying predictor of cognitive performance, elucidating whether significant time-varying covariation between physical activity and fluid performance existed. Finally, the interaction between the physical activity measures and age group was added to the model. All models were also run with physical activity in raw scores to permit easy conversion of results to hours per week of physical activity. Results were identical to those conducted with physical activity in T-score units.

Results

Sample Characteristics

Descriptive information by each cohort at baseline is presented in Table 1. The cohorts significantly differed in the majority of baseline characteristics. Where significant, group comparisons were completed using least significant difference posthoc tests. Of note, all three groups were different from one another in mild activity participation (*p*s<.001), with the oldest group engaging in the most activity. In contrast, the 20s group engaged in the most moderate

---

[4] Due to the close association between activity types, mental and social activity were not included in this model.

physical activity compared to the 40s ($p<.01$) and 60s ($p<.001$), who did not significantly differ from one another. The youngest cohort also engaged in the most vigorous physical activity, next followed by the middle-aged cohort, and finally the oldest cohort (all ps<.001). The overall total of combined physical activity however was not different between the cohorts. The oldest group engaged in fewer mental and social activities on average (ps<.001) than the two younger groups. In contrast to the other groups, the youngest group tended to do fewer mental and social activities at baseline than average (ps<.001), while the oldest group did more of these types of activities at baseline than average (ps<.001). The middle-aged group showed little change at baseline from their average. The cognitive and physical activity data for each cohort at each wave is available in supplementary Table 1.

Change in Fluid Cognitive Composite

An initial unconditional model (i.e., random intercept only) showed an intraclass correlation of 74.6%, indicating a large proportion of the variance in the fluid cognitive scores over time was associated with between-person differences. The conditional model to explain these differences with age and all covariates showed the 20s cohort had the highest initial cognitive performance ($\gamma_{00\text{-}20s=}$44.49), followed by the 40s cohort ($\gamma_{00\text{-}40s}$=42.86), and finally the 60s cohort ($\gamma_{00\text{-}60s}$=40.00). Note that group contrasts were conducted using the same model but with different coding for age group. All groups were significantly different from one another ($\gamma_{01s;}$ ps<.001). Only the 60s group experienced average decline in performance across the 8 years ($\gamma_{10\text{-}60s}$=-.26), while the 20s showed an increase ($\gamma_{10\text{-}20s=}$.29) and the 40s did not significantly change over time ($\gamma_{10\text{-}20s=.}$05). All group comparisons for slope were significant ($\gamma_{11s;}$ ps<.001).

Change in Physical Activity Composite

An unconditional model predicting total physical activity had an intraclass correlation of 38.8%, indicating primarily within-person variation in physical activity participation. A conditional model found the youngest cohort participated in more hours of weekly physical activity ($\gamma_{00\text{-}20s}$=50.82) compared to the oldest cohort ($\gamma_{00\text{-}60s}$=49.84; p_{diff}<.01), but neither group was significantly different from the middle-aged group ($\gamma_{00\text{-}40s}$=50.34). Both the youngest and oldest cohorts also increased their frequency of participation over time ($\gamma_{10\text{-}20s=}$.36; $\gamma_{10\text{-}60s=}$.24), but this change was greater amongst the 20s cohort (p_{diff}<.05). The middle age group did not significantly change their exercise frequency ($\gamma_{10\text{-}40s=}$.02) in contrast to the two other groups ($\gamma_{11s;}$ *p*s<.001).

Relationship Between Physical Activity and Fluid Cognitive Composite

The addition of the physical activity variables significantly improved model fit (*p*<.001; see Table 2). The between-person effect of physical activity was significant over and above mental and social activity. An additional hour in average weekly physical activity participation was associated with 0.5 higher initial score on the fluid cognitive composite. Within-person variation in participation in physical activity across the waves also covaried with cognitive performance. On occasions where the average individual engaged in an additional hour of physical activity, they scored 0.1 higher on the cognitive composite for that wave. Average physical activity level was not associated with rate of cognitive change however. The average amount of mental and social activity across the waves was also a significant predictor of the baseline fluid cognitive composite. The mental and social activity effect was approximately double that associated with average physical activity. Consistent with prior work (Bielak, et al., 2012), mental and social activity did not significantly covary with cognitive performance, nor influence the rate of change in cognitive performance.

We next investigated possible variation in the relationship between physical activity and the cognitive composite by age cohort. Given the lack of a significant effect of PA-between X time, and to provide a parsimonious model, age contrasts for the PA-between X time effect were not included in the final model[5]. The addition of age group by the physical activity measures significantly improved model fit (*p*<.05). Variation between-persons in physical activity participation significantly predicted baseline cognitive performance for all three age groups. Of note, all three effects were in the positive direction, where more physically active adults showed a higher cognitive score. The effect was largest for the 20s cohort ($\gamma_{00\text{-}20s=}$.08, *SE*=.01, *p*<.001), followed by the 60s ($\gamma_{00\text{-}60s}$=.04, *SE*=.02, *p*<.05) and 40s cohorts ($\gamma_{00\text{-}40s=}$.03, *SE*=.02, *p*<.05), who did not statistically differ from one another. For the average individual in the 20s cohort, regularly participating in another hour of weekly physical exercise was associated with a 0.8 increase in baseline cognitive composite. Regular physical activity participation was only associated with baseline cognitive performance, as it did not significantly predict the cognitive slope. Within-individual changes in physical activity engagement were associated with changes in the fluid cognitive composite across the eight years. However, this association was only apparent for the youngest age group ($\gamma_{20\text{-}20s=}$.03, *SE*=.01, *p*<.001), which was significantly different from the 40s ($\gamma_{20\text{-}40s}$ -.004, *SE*=.01, *ns*), but not the 60s cohort ($\gamma_{20\text{-}60s}$=.01, *SE*=.01, *ns*). Therefore, on occasions where the average person in the 20s age group exercised one hour more than their typical exercise level, their cognitive score tended to be 0.3 higher.

Discussion

Using a population-based sample spanning young, middle, and older adulthood, the present study investigated the associations of within-individual and between-person physical

---

[5] Additional analyses including these contrasts found all age X PA-between X time contrasts were indeed not significant.

activity participation in the prediction of fluid cognitive ability and change over 8 years. The influence of cognitive and social activity engagement was additionally accounted for, and we examined possible variations in the associations according to stage of adulthood.

Consistent with prior research (Gow, Corley, Starr, & Deary, 2012; Weuve, et al., 2004), there was a positive association between physical activity and baseline cognition, where individuals who exercised more on average tended to have higher initial scores on the fluid cognitive composite. For the average adult, participating in one additional hour of physical activity per week was associated with an additional 0.5 higher baseline cognitive score. There was differentiation by cohort, where a young adult who tended to engage in one more hour of physical activity than their peers performed 0.8 higher on the initial measurement of the cognitive composite, whereas the association was approximately halved for those in their 40s and 60s. However, as noted by Lindwall et al. (2012), associations with baseline cognitive ability fail to provide additional insight into why such a relation exists.

Rather, the presence or absence of a significant relationship between cognitive slope and average physical activity is more informative. Cognitive change was not associated with the between-person effect of physical activity in the present analysis, thus supporting preserved differentiation. This indicates that physically active adults appeared to have a higher starting point in terms of their cognitive ability, and this advantage was maintained over time, rather than differentially affecting their trajectory of cognitive change (e.g., showing less cognitive decline). Further, this result was consistent across adulthood. Another study dividing physical activity into its between- and within-person components also failed to find associations with change in semantic knowledge, memory, and reasoning, but did find a significant effect for change in verbal fluency (Lindwall, et al., 2012). However, Gow et al. (2012) did find physical activity level at age 60 and 70 was predictive of slope on a cognitive composite that did not include a metric of verbal fluency. Both studies were also limited to older age cohorts (i.e., 55 and 60 years or older), but there is evidence of baseline physical activity predicting change in verbal memory even amongst those aged 36 years at baseline (Richards, et al., 2003). Consequently, variation by cognitive domain may exist, but the present study is the only example of an investigation across the adult lifespan.

The present findings of support for preserved differentiation reiterate the possibility that finding a midlife physical activity association with later cognitive change is not necessarily indicative of a preferential developmental trajectory for the active adults. Further, the conclusion of preserved differentiation still adds positively to the larger aim of how to possibly improve cognitive functioning as individuals grow older (see Bielak, et al., 2012; Hertzog, et al., 2009). Lifestyle factors that are associated with level of cognitive ability may inform potential interventions as possible methods of providing a one-time boost to cognition (i.e., assuming causality), even if alterations to cognitive slope are not likely.

Unlike changes at the between-person level, individual-based changes in physical activity level from wave to wave were associated with corresponding changes in cognitive performance, but only for the youngest age cohort. Specifically, when an average person in the 20s age group exercised one hour more than their own usual activity level, their cognitive performance was approximately 0.3 higher for that wave. One possible explanation is that this finding reflects greater neuroplasticity in earlier adulthood (Couillard-Després, 2013). Lindwall et al. (2012) also found evidence of within-person covariation across four longitudinal studies, but the samples were limited to those age 55 and older. The 20s cohort showed the greatest fluctuation in their frequency of physical activity from wave to wave, which may reflect the larger number of life transitions that tend to occur in younger adulthood (e.g., full time employment, marriage, and parenthood). In turn, younger adults may still be adjusting their physical activity schedule to one that appropriately fits their new roles and demands. The greater within-person change in physical exercise for this cohort however may be necessary to observe significant covariation with cognition. An additional planned wave of measurement for the present sample will help to elucidate whether within-person covariation with cognition is possible amongst middle-aged and young-old adults. Further, studies of individuals from birth that measure the development of cognitive ability and physical activity patterns are also required to fully understand the complex interrelationship.

The result that the youngest adults demonstrated the strongest relation between physical activity and baseline cognitive score is in contrast to studies that found a greater association for older compared to younger cohorts (e.g., Hillman, et al., 2006; Newson & Kemps, 2006). Others however, have found a superior association amongst early adulthood (Middleton, et al., 2010). Of interest, we found no age differentiation in the present sample in the effects of mental and social activity on cognitive functioning (Bielak, et al., 2012), suggesting that age variability in activity-based predictive effects across young, middle, and older adulthood are unique to physical activity. However, the measurement of the two activity types in the present paper differed. Participation in moderate and vigorous exercise was also significantly lower amongst the middle and older cohorts compared to the 20s group, despite no age differences in total weekly physical exercise. Therefore, the more vigorous and physically challenging exercise of the 20s cohort may explain the differential results, which has been shown to have unique effects on memory (Roig, Nordbrandt, Geertsen, & Nielsen, 2013). In addition, there is the possibility that there may be an upper age limit after which the benefits of physical activity in relation to cognitive ability are reduced. For example, Bunce and Murden (2006) found the cognitive benefit shown by the most active individuals in their 60s converged with less active individuals by their mid-70s. Nevertheless, mild physical activities such as walking have also been linked to better cognitive status (Andel, et al., 2008), and physical activity was linked to cognitive ability regardless of age group, reiterating the importance of staying active throughout life.

Physical activity was uniquely associated with fluid cognitive ability over and above cognitive and social activity participation, suggesting physical exercise has associations with mental ability that other activity domains cannot duplicate. Research with animals and randomized controlled trials with humans have revealed extensive brain-based changes as a result of introducing physical exercise (Erickson, Gildengers, & Butters, 2013). However, the predictive effect of between-person differences in mental and social activity on cognition was nearly double that found in relation to physical activity. Consequently, all types of engagement appear to be relevant to cognitive functioning across adulthood, a conclusion supported by findings that the total participation (Wang et al., 2013), and variety of activity (Carlson et al., 2012) were particularly predictive of later cognitive status.

The present analysis was unique in dividing physical activity into its within- and between-person components in a population-based sample of young, middle-aged, and older adults. Our measure of physical activity was based on frequency of engagement rather than a count of specific physical activities, providing a more precise indicator of activity level and greater variability. It also included a range of physical intensity, but the calculation of the physical activity composite was only a general approximation of how to account for differences in physical effort. It was necessary to investigate an overall total of physical activity engagement, as analyzing each intensity type separately produced results contrary to expectations and past research (e.g., negative associations). Physically active individuals may have disproportional engagement in different intensities of physical exercise (e.g., a high frequency of running, but little time spent walking), negatively influencing analyses focusing only single intensity types. For this reason, we recommend combining physical activity intensity types in future studies evaluating their link with cognition.

Although our results support the hypothesis of preserved differentiation, our analyses cannot disentangle the directionality or causation of the relation between frequent physical activity and higher cognitive performance. We do not know if adults who engaged in more physical activity always had higher mental functioning, or if the best-performers on the cognitive tests have been physically active their entire lives. It may even be the case that differential preservation is possible later in older age, or once the effects of health and other risk factors are more apparent. Using data from a birth cohort study, Gow, Corley, Starr, and Deary (2012) found physical activity remained a significant predictor of concurrent cognitive ability at age 70 even after age 11 intelligence was accounted for. Similarly, Gow et al. (2012) demonstrated that after accounting for cognitive ability at age 50, greater physical activity at ages 60 and 70 was still associated with less cognitive decline by age 80, indicating that the impact of later physical activity on cognitive performance was genuine. Unfortunately, few studies have the wealth of longitudinal data required to investigate this enigma, and it remains a possibility that the present links with physical activity were initiated by better baseline cognitive ability.

Further, although the present sample included data from adults aged 20 to 32, 40 to 52, and 60 to 72 years, the narrow age bands of recruitment for the young (20-24 years), middle (40-44 years), and older (60-64 years) adults precludes extrapolating the present findings across the entirety of adulthood. Moreover, we analyzed data from relatively young older adults. Future studies would benefit from examining the same associations in an older adults population.

The present analyses support the hypothesis that physical activity across young, middle, and older adulthood is associated with cognitive ability by way of preserved individual differences, rather than differential changes with age. Moreover, these effects were apparent over and above the influence of mental and social activity participation, underscoring the unique attributes of physical exercise. Further, unlike mental and social engagement (Bielak, et al., 2012), the greatest physical activity effects were found for the youngest adults. It has been suggested that far better outcomes may be possible the earlier in life an individual is active (Hertzog, et al., 2009), but there is little evidence to support this. Our explicit examination of how the stage of adulthood may moderate the relationship between physical activity and cognitive performance suggests that "the earlier, the better" may indeed be true.

Table 1. Descriptive information for sample at baseline (*n* = 6869).

	Age Cohort			Significance Test
	20 *n*=2289	40 *n*=2426	60 *n*=2154	
	M (SD)	*M (SD)*	*M (SD)*	*F(df) /χ2 (df, n)*
Time in Study	6.95 (2.52)	7.14 (2.27)	6.90 (2.56)	6.35 (2, 6868)**
% Female	52.8	53.2	48.9	10.45 (2, n=6869)**
Years of education	14.22 (1.50)	14.46 (2.26)	13.94 (2.61)	32.98(2, 6866)***
% Full-time employment	56.8	70.2	22.4	1785.05 (4, n=6869)***
Physical health	51.54 (6.94)	51.04 (8.02)	49.11 (9.73)	52.95 (2, 6866)***
Mental health	47.34 (9.55)	49.03 (9.43)	53.38 (8.38)	255.30 (2, 6866)***
Anxiety symptoms	3.84 (2.70)	3.49 (2.70)	2.17 (2.28)	258.90 (2, 6866)***
Depressive symptoms	2.89 (2.37)	2.40 (2.36)	1.61 (1.83)	189.52 (2, 6866)***
% Hypertension ever	22.0	45.1	81.0	1562.55 (2, n=6869)***
% Diabetes ever	0.9	3.8	12.7	314.72 (2, n=6869)***
Mental and social activity-between	51.13 (8.76)	50.84 (9.24)	48.63 (9.10)	50.49 (2, 6866)***
Mental and social activity-within	-0.63 (4.80)	0.04 (4.46)	0.62 (4.02)	43.74 (2, 6860)***
Mild physical activity	4.25 (5.36)	5.14 (4.52)	6.29 (5.18)	86.72 (2, 6478)***
Moderate physical activity	2.30 (2.82)	2.04 (2.13)	2.00 (2.74)	8.52 (2, 6309)***
Vigorous physical activity	1.29 (1.89)	0.91 (1.49)	0.43 (1.16)	162.02 (2, 6546)***
Combined physical activity	11.51 (12.74)	11.85 (9.35)	11.30 (9.96)	1.35 (2, 5912)

Note. Mental and social activity were standardized to the *T* metric (*M*=50, *SD* =10) using the baseline sample. Combined physical activity refers to the *raw* total number of hours engaged in self-reported physical activity per week, following the calculation of mild + (2 x moderate) + (3 x vigorous). **p*<.05; ***p*<.01; ****p*<.001.

Table 2. Parameter Estimates from Multilevel Models Examining Physical Activity Predicting Cognitive Performance and Change

	Adding Physical Activity	Adding Physical Activity X Age
	Estimate (*SE*)	Estimate (*SE*)
Fixed Effects		
PA-within	0.01 (.005)**	.009 (.009)
60 vs. 20		0.02 (.01)
60 vs. 40		-0.01 (.01)
40 vs. 20[a]		.03 (.01)*
PA-between (X Age Group)	0.05 (.01)***	0.04 (.02)*
60 vs. 20		0.04 (.02)*
60 vs. 40		-.004 (.02)
40 vs. 20[a]		0.05 (.02)*
PA-between X Time	-.001 (.001)	-.001 (.001)
MS-within	.001 (.001)	.002 (.007)
MS-between	.11 (.01)***	.11 (.01)***
MS-between X Time	.001 (.001)	.001 (.001)
Random Effects		
Residual	12.37 (.28)***	12.34 (.27)***
Intercept	29.21 (.77)***	29.18 (.77)***
Time	0.07 (.01)***	0.08 (.01)***
Change in Model fit, -2LL	37.07***	12.93*
df_{Δ}	3	4

Note. **p*<.05; ***p*<.01; ****p*<.001. PA=physical activity; MS=mental and social activity. LL = log likelihood. 60s cohort served as reference group in models. [a]Contrast with 40s as reference group tested in another analysis but different coding for age group.

Funding

The PATH project was supported by the National Health and Medical Research Council (NHMRC) (grant numbers 229936, 179839, 973302, 179805, and 418039). This work was supported by NHMRC (fellowship 1002560 to K. J. A), the Australian Research Council (ARC) (fellowship 120100227 to N.C.), the Dementia Collaborative Research Centres, the ARC Centre of Excellence in Population Ageing Research, and the Leverhulme Trust (UK) Research Fellowship to D. B.

Acknowledgements

The authors are grateful to Tony Jorm, Helen Christensen, Bryan Rodgers, Simon Easteal, Andrew MacKinnon, Peter Butterworth, Patricia Jacomb, Karen Maxwell, and the PATH project interviewers and participants.

References

Ahlskog, E. J., Geda, Y. E., Graff-Radford, N. R., & Petersen, R. C. (2011). Physical exercise as a preventive or disease-modifying treatment of dementia and brain aging. *Mayo Clinic Proceedings, 86*(9), 876-884. doi: 10.4065/mcp.2011.0252

Ainsworth, B. E., Haskell, W. L., Herrmann, S. D., Meckes, N., Bassett, D. R. J., Tudor-Locke, C., . . . Leon, A. S. (2011). 2011 compendium of physical activities: A second update of codes and MET values. *Medicine and Science in Sports and Exercise, 43*, 1575-1581.

Andel, R., Crowe, M., Pedersen, N. L., Fratiglioni, L., Johansson, B., & Gatz, M. (2008). Physical exercise at midlife and risk of dementia three decades later: A population-based study of Swedish twins *Journals of Gerontology: Medical Sciences, 63A*, 62-66.

Anstey, K. J., Christensen, H., Butterworth, P., Easteal, S., Mackinnon, A., Jacomb, T., . . . Jorm, A. F. (2012). Cohort profile: The PATH through life project. *International Journal of Epidemiology, 41*, 951-960. doi: 10.1093/ije/dyr025

Barnes, D. E., & Yaffe, K. (2011). The projected effect of risk factor reduction on Alzheimer's disease prevalence. *Lancet Neurology, 10*, 819-828. doi: 10.1016/51474-4422(11)70072-2

Bielak, A. A. M. (2010). How can we not “Lose It” if we still don’t understand how to “Use It”? Unanswered questions about the influence of activity participation on cognitive performance in older age: A mini-review. *Gerontology, 56*, 507-519.

Bielak, A. A. M., Anstey, K. J., Christensen, H., & Windsor, T. D. (2012). Activity engagement is related to level, but not change in cognitive ability across adulthood. *Psychology and Aging, 27*(1), 219-228. doi: 10.1037/a0024667

Bunce, D., & Murden, F. (2006). Age, aerobic fitness, executive function, and episodic memory. *European Journal of Cognitive Psychology, 18*, 221-233.

Carlson, M. C., Parisi, J. M., Xia, J., Xue, Q.-L., Rebok, G. W., Bandeen-Roche, K., & Fried, L. P. (2012). Lifestyle activities and memory: Variety may be the spice of life. The Women's Health and Aging Study II. *Journal of the International Neuropsychological Society, 18*, 286-294. doi: 10.1017/S135561771100169X

Colcombe, S. J., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychological Science, 14*, 125-130.

Couillard-Després, S. (2013). Hippocampal neurogenesis and ageing. *Current Topics in Behavioral Neurosciences, 15*, 343-355. doi: 10.1007/7854_2012_232

Delis, D., Kramer, J., Kaplan, E., & Ober, B. (1987). *California Verbal Learning Test.* San Antonio, TX: Psychological Corporation/Harcourt Brace Jovanovich.

Dik, M. G., Deeg, D. J. H., Visser, M., & Jonker, C. (2003). Early life physical activity and cognition at old age. *Journal of Clinical and Experimental Neuropsychology, 25*, 643-653.

Erickson, K. I., Gildengers, A. G., & Butters, M. A. (2013). Physical activity and brain plasticity in late adulthood. *Dialogues in Clinical Neuroscience, 15*(1), 99-108.

Etnier, J. L., Salazar, W., Landers, D. M., Petruzzello, S. J., Han, M., & Nowell, P. (1997). The influence of physical fitness and exercise upon cognitive functioning: A meta-analysis. *Journal of Sport and Exercise Psychology, 19*, 249-277.

Flicker, L. (2010). Modifiable lifestyle risk factors for Alzheimer's disease. *Journal of Alzheimer's Disease, 20*, 803-811. doi: 10.3233/JAD-2010-091624

Folstein, M., Folstein, S., & McHugh, P. R. (1975). Mini-Mental State: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189-198.

Goldberg, D., Bridges, K., Duncan-Jones, P., & Grayson, D. (1988). Detecting anxiety and depression in general medical settings. *BMJ, 297*, 897-899.

Gow, A. J., Corley, J., Starr, J. M., & Deary, I. J. (2012). Reverse causation in activity-cognitive ability associations: The Lothian birth cohort 1936. *Psychology and Aging, 27*(1), 250-255. doi: 10.1037/a0024144

Gow, A. J., Mortensen, E. L., & Avlund, K. (2012). Activity participation and cognitive aging from age 50 to 80 in the Glostrup 1914 cohort. *Journal of the American Geriatrics Society, 60*, 1831-1838. doi: 10.1111/j.1532-5415.2012.04168.x

Hays, R. (1988). *RAND-36 Health Status Inventory*. San Antonio, TX: The Psychological Corporation.

Hertzog, C., Kramer, A. F., Wilson, R. S., & Lindenberger, U. (2009). Enrichment effects on adult cognitive development: Can the functional capacity of older adults be preserved and enhanced? *Psychological Science in the Public Interest, 9*, 1-65.

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: Exercise effects on brain and cognition. *Nature Reviews: Neuroscience, 9*, 58-65.

Hillman, C. H., Motl, R. W., Pontifex, M. B., Posthuma, D., Stubbe, J. H., Boomsma, D. I., & de Geus, E. J. C. (2006). Physical activity and cognitive function in a cross-section of younger and older community-dwelling individuals. *Health Psychology, 25*, 678-687.

Hindin, S. B., & Zelinski, E. M. (2012). Extended practice and aerobic exercise interventions benefit untrained cognitive outcomes in older adults: A meta-analysis. *Journal of the American Geriatrics Society, 60*, 136-141.

Hoffman, L., & Stawski, R. S. (2009). Persons as contexts: Evaluating between-person and within-person effects in longitudinal analysis. *Research in Human Development, 6*, 97-120.

Horn, J. L. (1987). A context for understanding information processing studies of human abilities. In P. A. Vernon (Ed.), *Speed of information processing and intelligence* (pp. 201-238). Norwood, NJ: Ablex.

Howley, E. T. (2011). Letter to the editor. *Journal of Physical Activity and Health, 8*, 141-142.

Langlois, F., Vu, T. T. M., Chassé, K., Dupuis, G., Kergoat, M.-J., & Bherer, L. (2012). Benefits of physical exercise training on cognition and quality of life in frail older adults. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 68*, 400-404. doi: 10.1093/geronb/gbs069

Lee, T., Lipnicki, D. M., Crawford, J. D., Henry, J. D., Troller, J. N., Ames, D., . . . OATS Research Team. (2013). Leisure activity, health, and medical correlates of neurocognitive performance among monozygotic twins: The older Australian twins study. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences*. doi: 10.1093/geronb/gbt031

Lindwall, M., Cimino, C. R., Gibbons, L. E., Mitchell, M. B., Benitez, A., Brown, C. L., . . . Piccinin, A. M. (2012). Dynamic associations of change in physical activity and change in cognitive function: Coordinated analyses of four longitudinal studies. *Journal of Aging Research, 2012*. doi: 10.1155/2012/493598

Middleton, L. E., Barnes, D. E., Lui, L.-Y., & Yaffe, K. (2010). Physical activity over the life course and its association with cognitive performance and impairment in old age. *Journal of the American Geriatrics Society, 58*, 1322-1326. doi: 10.1111/j.1532-5415.2010.02903.x

Miller, D. I., Taler, V., Davidson, P. S. R., & Messier, C. (2012). Measuring the impact of exercise on cognitive aging: Methodological issues. *Neurobiology of Aging, 33*, 622.e629-622.e643. doi: 10.1016/j.neurobiolaging.2011.02.020

Newson, R. S., & Kemps, E. B. (2006). The influence of physical and cognitive activities on simple and complex cognitive tasks in older adults. *Experimental Aging Research, 32*, 341-362.

Paillard-Borg, S., Wang, H. X., Winblad, B., & Fratiglioni, L. (2009). Pattern of participation in leisure activities among older people in relation to their health conditions and contextual factors: A survey in a Swedish urban area. *Ageing and Society, 29*, 803-821. doi: 10.1017/S0144686X08008337

Parisi, J. M., Rebok, G. W., Seeman, T. E., Tanner, E. K., Tan, E. J., Fried, L. P., . . . Carlson, M. C. (2012). Lifestyle activities in sociodemographically at-risk urban, older adults prior to participation in the Baltimore Experience Corps trial. *Activities, Adaptation, and Aging, 36*(3), 242-260. doi: 10.1080/01924788.2012.702306

Parslow, R. A., Jorm, A. F., Christensen, H., & Mackinnon, A. (2006). An instrument to measure engagement in life: Factor analysis and associations with sociodemographic, health and cognition measures. *Gerontology, 52*, 188-198.

Physical activity guidelines advisory committee. (2008). *Physical activity guidelines advisory committee report*. Washington, DC: US Department of Health and Human Services.

Pietrelli, A., Lopez-Costa, J., Goni, R., Brusco, A., & Basso, N. (2012). Aerobic exercise prevents age-dependent cognitive decline and reduces anxiety-related behaviors in middle-aged and old rats. *Neuroscience, 202*, 252-266.

Plassman, B. L., Williams, J. W. J., Burke, J. R., Holsinger, T., & Benjamin, S. (2010). Systematic review: Factors associated with risk for and possible prevention of cognitive decline in later life. *Annals of Internal Medicine, 153*(3), 182-193.

Richards, M., Hardy, R., & Wadsworth, M. E. J. (2003). Does active leisure protect cognition? Evidence from a national birth cohort. *Social Science & Medicine, 56*, 785-792.

Roig, M., Nordbrandt, S., Geertsen, S. S., & Nielsen, J. B. (2013). The effects of cardiovascular exercise on human memory: A review with meta-analysis. *Neuroscience and Biobehavioral Reviews, 37*, 1645-1666. doi: 10.1016/j.neurobiorev.2013.06.012

Rovio, S., Kåreholt, I., Helkala, E.-L., Viitanen, M., Windblad, B., Tuomilehto, J., & Kivipelto, M. (2005). Leisure-time physical activity at midlife and the risk of dementia and Alzheimer's disease. *Lancet Neurology, 4*, 705-711. doi: 10.1016/S1474-4422(05)70198-8

Salthouse, T. A. (2006). Mental exercises and mental aging: Evaluating the validity of the “use it or lose it” hypothesis. *Perspectives on Psychological Science, 1*, 68-87.

Salthouse, T. A. (2008). Exercise and mental resources: Methodological problems. In W. W. Spirduso, L. W. Poon & W. Chodzko-Zajko (Eds.), *Exercise and Its Mediating Effects on Cognition* (Vol. 2, pp. 111-116). Champaign, Illinois: Human Kinetics.

Small, B. J., Dixon, R. A., McArdle, J. J., & Grimm, K. J. (2012). Do changes in lifestyle engagement moderate cognitive decline in normal aging? Evidence from the Victoria Longitudinal Study. *Neuropsychology, 26*(2), 144-155. doi: 10.1037/a0026579

Smith, A. (1982). *Symbol Digit Modalities Test* Los Angeles: Western Psychological Services.

Spirduso, W. W., Poon, L. W., & Chodzko-Zajko, W. (2008). Conclusions and future research directions. In W. W. Spirduso, L. W. Poon & W. Chodzko-Zajko (Eds.), *Exercise and Its Mediating Effects on Cognition* (pp. 211-219). Champaign, Illinois: Human Kinetics.

Sturman, M. T., Morris, M. C., Mendes de Leon, C. F., Bienias, J. L., Wilson, R. S., & Evans, D. A. (2005). Physical activity, cognitive activity, and cognitive decline in a biracial community population. *Archives of Neurology, 62*, 1750-1754.

Wang, H. X., Y., J., Hendrie, H. C., Liang, C., Yang, L., Cheng, Y., . . . Gao, S. (2013). Late life leisure activities and risk of cognitive decline. *Journal of Gerontology: Medical Sciences, 68*(2), 205-213. doi: 10.1093/gerona/gls153

Wechsler, D. (1945). A standardized memory scale for clinical use. *Journal of Psychology, 19*, 87-95.

Weuve, J., Kang, J. H., Manson, J. E., Breteler, M. M. B., Ware, J. H., & Grodstein, F. (2004). Physical activity, including walking, and cognitive function in older women. *Journal of the American Medical Association, 292*, 1454-1461.

Supplementary Table 1. Descriptive statistics for physical activity and cognitive measures by age group and wave.

		Measure			
		Fluid Cognitive Composite	Combined Physical Activity	Physical Activity Between	Physical Activity Within
Age Group	*n*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
20					
Wave 1	2289	52.62 (6.70)	49.98 (11.88)	52.40 (9.26)	-1.52 (7.37)
Wave 2	1987	54.55 (7.06)	53.88 (10.14)	-	1.27 (6.37)
Wave 3	1821	55.44 (6.95)	53.04 (10.37)	-	.45 (6.84)
40					
Wave 1	2426	51.18 (6.86)	50.30 (8.72)	50.50 (7.78)	-.07 (5.03)
Wave 2	2249	51.88 (6.80)	50.69 (8.97)	-	.01 (5.01)
Wave 3	2016	52.20 (6.70)	50.42 (9.10)	-	.06 (5.10)
60					
Wave 1	2154	47.33 (6.92)	49.79 (9.29)	50.98 (8.50)	-.70 (5.11)
Wave 2	1884	46.99 (6.66)	51.63 (9.87)	-	.22 (5.42)
Wave 3	1660	45.93 (6.66)	51.99 (10.06)	-	.60 (5.68)

Note. Measures were standardized to the *T* metric (*M*=50, *SD* =10) using the baseline sample.

Supplementary Appendix A

The following models were used. The covariates of sex, employment status, ever having diabetes, ever having hypertension, education, mental and physical health, anxiety and depressive symptoms, and the between and within components of mental and social activity were also included in the models.

Model 1: Cognitive change over time

Level 1: Fluid Cognitive Composite$_{ij}$ = $\beta_{0i} + \beta_{1i}$(Time in Study) + e_{ij}

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}$(Age group contrast$_1$)+ γ_{02}(Age group contrast$_2$)+ u_{0i}

$\beta_{1i} = \gamma_{10} + \gamma_{11}$(Age group contrast$_1$)+ γ_{12}(Age group contrast$_2$) + u_{1i}

The Level 1 equation examined individual rates of change across each individual's time in study. Specifically, the change in fluid cognitive performance for a given individual (i) at a given occasion (j) was a function of that individual's fluid cognitive performance at the first wave of testing (β_{0i}; intercept), plus that individual's average rate of change in cognitive performance across time in study (β_{1i}; slope), plus an error term reflecting within-subject residual variance remaining to be explained after controlling for time in study (e_{ij}; deviation from their individual regression line). At Level 2, or the between-subjects level, the intercept (β_{0i}) for each individual was modeled as a function of the starting point for the average participant in the reference cohort (γ_{00}), plus the average difference in intercept between the reference group and one age cohort (γ_{01}), plus the average difference in intercept between the reference group and the other age cohort (γ_{02}), plus variation between individuals in intercept (u_{0i}). Correspondingly, each individual's slope estimate (β_{1i}) was a function of change for the average member of reference cohort per year increase of being in the study (γ_{10}), plus the average difference in slope between the reference cohort and one age cohort (γ_{11}), plus the average difference in slope between the reference cohort and the other cohort (γ_{12}), plus variation between persons in slope (u_{1i}).

Model 2: Addition of physical activity measures

Level 1: Fluid Cognitive Composite$_{ij}$ = β_{0i} + β_{1i}(Time in Study) + β_{2i}(PA-Within) + e_{ij}

Level 2: β_{0i} = γ_{00} + γ_{01}(Age group contrast$_1$)+ γ_{02}(Age group contrast$_2$)+ γ_{03}(PA-Between) + u_{0i}

β_{1i} = γ_{10} + γ_{11}(Age group contrast$_1$)+ γ_{12}(Age group contrast$_2$) + γ_{13}(PA-Between) + u_{1i}

$\beta_{2i} = \gamma_{20}$

Model 3: Addition of Age X Physical activity interactions[1]

Level 1: Fluid Cognitive Composite$_{ij}$ = β_{0i} + β_{1i}(Time in Study) + β_{2i}(PA-Within) + e_{ij}

Level 2: β_{0i} = γ_{00} + γ_{01}(Age group contrast$_1$)+ γ_{02}(Age group contrast$_2$)+ γ_{03}(PA-Between) + γ_{04}(Age group contrast$_1$ X PA-Between) + γ_{05}(Age group contrast$_2$ X PA-Between) + u_{0i}

β_{1i} = γ_{10} + γ_{11}(Age group contrast$_1$)+ γ_{12}(Age group contrast$_2$) + γ_{13}(PA-Between) + u_{1i}

β_{2i} = γ_{20} + γ_{21}(Age group contrast$_1$ X PA-Within) + γ_{25}(Age group contrast$_2$ X PA-Within) + u_{2i}

Note. PA=Physical activity.[1]Due to the non-significant effect of PA-between X time, age contrasts for the PA-between X time effect were not included.