Preserved Differentiation Between Physical Activity and Cognitive Performance Across Young, Middle, and Older Adulthood Over 8 Years

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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 aged 20–24, 40–44, and 60–64 years at baseline (n = 6,869) completed physical activity (PA; 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 PA 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 PA and cognitive score. PA 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. PA appears to be unique in showing differences across young, middle, and older adulthood in predicting cognition.

Key Words: Activity engagement—Adulthood—Cognitive change—Longitudinal—Physical activity.

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 with the relative risk ratios of various modifiable factors including diabetes, midlife obesity, depression, and smoking, physical inactivity contributed to the largest proportion of Alzheimer’s disease cases in the United States and was the third largest contributor worldwide (Barnes & Yaffe, 2011). Randomized controlled trials and interventions introducing physical activity (PA) 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).

PA 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 among 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 PA 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. Interventions that introduce PA 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.

One method of investigation is to assess both the link between level of PA and baseline cognitive score, and level of PA 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 that 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.

Few studies have evaluated the issue of preserved differentiation and differential preservation in regards to PA and cognition. Gow, Mortensen, and Avlund (2012) found that PA 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 PA predicting cognitive change, specifically change in verbal fluency (Lindwall et al., 2012). However, fluctuations in the amount of PA 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 PA were found to be dynamically linked to changes in verbal speed and episodic memory over 12 years in sample aged 55–94 years at baseline, where both PA influenced cognitive change and cognitive ability influenced PA 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 PA 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 PA. Sturman and coworkers (2005) found PA no longer predicted 6-year cognitive decline following the addition of cognitive activity to the model. Similarly, the effect of PA 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 PA 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 PA 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 PA and cognitive function have the same association throughout the life span is among 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 PA and cognition across adulthood.

Compared with younger cohorts (i.e., 15–39 years; 18–27 years), cross-sectional comparisons have found PA to be a stronger predictor of executive function (Hillman et al., 2006) and visual imagery performance (Newson & Kemps, 2006) for those aged 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 among those aged 66–70 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 with self-reported retrospective reports of PA 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 that higher levels of PA at age 36 were associated with a reduced rate of memory decline from ages 43 to 53, but PA level at age 43 attenuated the association (Richards et al., 2003). Overall, the conclusions regarding PA participation and cognitive functioning across adulthood remain equivocal.

The present study aimed to investigate two research questions in a population-based longitudinal data set...
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 PA 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 PA was related to cognitive ability: being more physically active compared with others or showing greater individualized change in PA 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 PA level. Further, this evaluation allowed examination of the type of association between PA 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 PA 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 PA 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, PA 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 and living in the community in the year of registration. There was an attrition rate of 10% over the study period, with 6,680 participants returning for Wave 2 and 6,996 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**

**PA participation.**—Participants were asked in an open-ended format to report the average weekly number of hours spent engaging in PA 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). Immediately prior to these questions, three additional questions asked participants to rate their weekly PA level on a 4-point scale (i.e., from 3 times/week to never/hardly ever). These questions provided further examples regarding what is classified as mildly, moderately, and vigorously energetic activity. The data were first trimmed for PA outliers due to the extensive range in reported activity (e.g., 10 participants reported 70 hr of mild PA each week, when the overall average was <7 hr). 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 PA 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 PA 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 metabolic equivalent values (MET; milliliters of used oxygen/minute) that corresponded to each PA type to calculate the combined value. On average, light intensity is less than 3 METs, moderate intensity is 3–6 METs, and vigorous intensity is greater than or equal to 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 1/2 the intensity of moderate activity. Following this scale, PA for the present analyses was calculated for each individual as Mild sessions + (2 × Moderate sessions) + (3 × Vigorous sessions) to produce a value on the same scale. 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.

The PA scores were converted into T scores \((M = 50, SD = 10)\) using the baseline means and standard deviations across age groups. PA was then divided into two components: (a) PA-between represented the between-person effect of PA and was obtained by calculating each individual’s average combined PA score across the waves and (b) PA-within represented the within-person effect of PA and was obtained by subtracting each individual’s combined PA score for that wave from their average level of combined PA 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 Symbol Digit Modalities Test (Smith, 1982), which presented participants with a coding key pairing numbers 1 through 9 with 9 symbols. Participants were given 90 s 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 four 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, they were 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 and coworkers (2012).

**Covariates**

As cognitive ability and PA 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 RIAS 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 [MS: mental and social activity]) and within-person (mental and activity score at each minus 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 was 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 examination of age group differences in cognitive change. Verification of significant variation in PA across time was also conducted using a similar model (due to the close association between activity types, mental and social activity were not included in
this model) with total PA as the dependent variable. Next, the PA 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 PA and fluid performance existed. Finally, the interaction between the PA measures and age group was added to the model. All models were also run with PA in raw scores to permit easy conversion of results to hours per week of PA. Results were identical to those conducted with PA 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 post hoc tests. Of note, all three groups were different from one another in mild activity participation (ps < .001), with the oldest group engaging in the most activity. In contrast, the 20s group engaged in the most moderate PA compared with 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 PA, next followed by the middle-aged cohort, and finally the oldest cohort (all ps < .001). The overall total of combined PA 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), whereas 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 PA 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 (γ00–20s = 44.49), followed by the 40s cohort (γ00–40s = 42.86), and finally the 60s cohort (γ00–60s = 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 (γ10s: ps < .001). Only the 60s group experienced average decline in performance across the 8 years (γ10–60s = −0.26), whereas the 20s showed an increase (γ10–20s = 0.29) and the 40s did not significantly change over time (γ10–40s = 0.05). All group comparisons for slope were significant (γ11s: ps < .001).

Table 1: Descriptive Information for Sample at Baseline (n = 6,869)

<table>
<thead>
<tr>
<th>Age cohort</th>
<th>Significance test</th>
</tr>
</thead>
<tbody>
<tr>
<td>20: n = 2,289</td>
<td>40: n = 2,426</td>
</tr>
<tr>
<td>Time in study</td>
<td>M (SD)</td>
</tr>
<tr>
<td>% Female</td>
<td>52.8</td>
</tr>
<tr>
<td>Years of education</td>
<td>14.22 (1.50)</td>
</tr>
<tr>
<td>% Full-time employment</td>
<td>56.8</td>
</tr>
<tr>
<td>Physical health</td>
<td>51.54 (6.94)</td>
</tr>
<tr>
<td>Mental health</td>
<td>47.34 (9.55)</td>
</tr>
<tr>
<td>Anxiety symptoms</td>
<td>3.84 (2.70)</td>
</tr>
<tr>
<td>Depressive symptoms</td>
<td>2.89 (2.37)</td>
</tr>
<tr>
<td>% Hypertension ever</td>
<td>22.0</td>
</tr>
<tr>
<td>% Diabetes ever</td>
<td>0.9</td>
</tr>
<tr>
<td>Mental and social activity-between</td>
<td>51.13 (8.76)</td>
</tr>
<tr>
<td>Mental and social activity-within</td>
<td>−0.63 (4.80)</td>
</tr>
<tr>
<td>Mild physical activity</td>
<td>4.25 (5.36)</td>
</tr>
<tr>
<td>Moderate physical activity</td>
<td>2.30 (2.82)</td>
</tr>
<tr>
<td>Vigorous physical activity</td>
<td>1.29 (1.89)</td>
</tr>
<tr>
<td>Combined physical activity</td>
<td>11.51 (12.74)</td>
</tr>
</tbody>
</table>

**Notes.** 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 × moderate) + (3 × vigorous). **p < .01. ***p < .001.
Change in PA Composite

An unconditional model predicting total PA had an intraclass correlation of 38.8%, indicating primarily within-person variation in PA participation. A conditional model found that the youngest cohort participated in more hours of weekly PA ($\gamma_{00-20h} = 50.82$) compared with the oldest cohort ($\gamma_{00-60s} = 49.84; p_{diff} < .01$), but neither group was significantly different from the middle-aged group ($\gamma_{00-40s} = 50.34$). Both the youngest and oldest cohorts also increased their frequency of participation over time ($\gamma_{10-20h} = 0.36; \gamma_{10-40s} = 0.24$), but this change was greater among the 20s cohort ($p_{diff} < .05$). The middle age group did not significantly change their exercise frequency ($\gamma_{10-40h} = 0.02$) in contrast to the two other groups ($\gamma_{11h}; p < .001$).

Relationship Between PA and Fluid Cognitive Composite

The addition of the PA variables significantly improved model fit ($p < .001$; see Table 2). The between-person effect of PA was significant over and above mental and social activity. An additional hour in average weekly PA participation was associated with 0.5 higher initial score on the fluid cognitive composite. Within-person variation in participation in PA across the waves also covaried with cognitive performance. On occasions where the average individual engaged in an additional hour of PA, they scored 0.1 higher on the cognitive composite for that wave. Average PA 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 PA. 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 PA and the cognitive composite by age cohort. Given the lack of a significant effect of PA-between × Time, and to provide a parsimonious model, age contrasts for the PA-between × Time effect were not included in the final model. Additional analyses including these contrasts found all Age × PA-between × Time contrasts were indeed not significant. The addition of age group by the PA measures significantly improved model fit ($p < .05$). Variation between-persons in PA 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 ($\gamma_{00-20} = 0.08, SE = 0.01, p < .001$), followed by the 60s ($\gamma_{00-60s} = 0.04, SE = 0.02, p < .05$) and 40s cohorts ($\gamma_{00-40s} = 0.03, SE = 0.02, p < .05$), 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 PA participation was only associated with baseline cognitive performance, as it did not significantly predict the cognitive slope. Within-individual changes in PA engagement were associated with changes in the fluid cognitive composite across the 8 years. However, this association was only apparent for the youngest age group ($\gamma_{20-20s} = 0.03, SE = 0.01, p < .001$), which was significantly different from the 40s ($\gamma_{20-40s} = -0.004, SE = 0.01, ns$), but not the 60s cohort ($\gamma_{20-60s} = 0.01, SE = 0.01, ns$). Therefore, on occasions where the average person in the 20s age group exercised 1 hr more than their typical exercise level, their cognitive score tended to be 0.3 higher.

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

<table>
<thead>
<tr>
<th></th>
<th>Adding physical activity</th>
<th>Adding physical activity × Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate (SE)</td>
<td>Estimate (SE)</td>
</tr>
<tr>
<td><strong>Fixed effects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PA-within</td>
<td>0.01 (0.005)**</td>
<td>0.009 (0.009)</td>
</tr>
<tr>
<td>60 vs. 20</td>
<td>0.02 (0.01)</td>
<td></td>
</tr>
<tr>
<td>60 vs. 40</td>
<td>-0.01 (0.01)</td>
<td></td>
</tr>
<tr>
<td>40 vs. 20p</td>
<td>0.03 (0.01)*</td>
<td>0.04 (0.02)*</td>
</tr>
<tr>
<td>PA-between (× Age group)</td>
<td>0.05 (0.01)**</td>
<td>0.04 (0.02)*</td>
</tr>
<tr>
<td>60 vs. 20</td>
<td>0.04 (0.02)*</td>
<td></td>
</tr>
<tr>
<td>60 vs. 40</td>
<td>-0.004 (0.02)</td>
<td></td>
</tr>
<tr>
<td>40 vs. 20p</td>
<td>0.05 (0.02)*</td>
<td></td>
</tr>
<tr>
<td>PA-between × Time</td>
<td>-0.001 (0.001)</td>
<td>-0.001 (0.001)</td>
</tr>
<tr>
<td>MS-within</td>
<td>0.001 (0.001)</td>
<td>0.002 (0.007)</td>
</tr>
<tr>
<td>MS-between</td>
<td>0.11 (0.01)**</td>
<td>0.11 (0.01)**</td>
</tr>
<tr>
<td>MS-between × Time</td>
<td>0.001 (0.001)</td>
<td>0.001 (0.001)</td>
</tr>
<tr>
<td><strong>Random effects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual</td>
<td>12.37 (0.28)**</td>
<td>12.34 (0.27)**</td>
</tr>
<tr>
<td>Intercept</td>
<td>29.21 (0.77)**</td>
<td>29.18 (0.77)**</td>
</tr>
<tr>
<td>Time</td>
<td>0.07 (0.01)**</td>
<td>0.08 (0.01)**</td>
</tr>
<tr>
<td>Change in model fit, −2LL</td>
<td>37.07***</td>
<td>12.93*</td>
</tr>
<tr>
<td>$df_k$</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Notes. The 60s cohort served as reference group in models. LL = log likelihood; MS = mental and social activity; PA = physical activity.

Contrast with 40s as reference group tested in another analysis but different coding for age group.

*p < .05. **p < .01. ***p < .001.

DISCUSSION

Using a population-based sample spanning young, middle, and older adulthood, the present study investigated the associations of within-individual and between-person PA 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 PA 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 PA 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 PA 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 and coworkers (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 PA is more informative. Cognitive change was not associated with the between-person effect of PA 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 PA 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 Mortensen, et al. (2012) did find PA 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 PA predicting change in verbal memory even among 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 life span.

The present findings of support for preserved differentiation reiterate the possibility that finding a midlife PA 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 PA 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 1 hr 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 and coworkers (2012) also found evidence of within-person covariation across four longitudinal studies, but the samples were limited to those aged 55 and older. The 20s cohort showed the greatest fluctuation in their frequency of PA 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 PA 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 among middle-aged and young-old adults. Further, studies of individuals from birth that measure the development of cognitive ability and PA patterns are also required to fully understand the complex interrelationship.

The result that the youngest adults demonstrated the strongest relation between PA and baseline cognitive score is in contrast to studies that found a greater association for older compared with younger cohorts (e.g., Hillman et al., 2006; Newson & Kems, 2006). Others, however, have found a superior association among 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 PA. However, the measurement of two activity types in the present paper differed. Participation in moderate and vigorous exercise was also significantly lower among the middle and older cohorts compared with 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 PA 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 PA was linked to cognitive ability regardless of age group, reiterating the importance of staying active throughout life.

PA 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 PA. 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 PA into its within- and between-person components in a population-based sample of young, middle-aged, and older adults. Our measure of PA 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 PA composite was only a general approximation of how to account for differences in physical effort. It was necessary to investigate an overall total of PA 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 PA 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 PA and higher cognitive performance. We do not know if adults who engaged in more PA 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, et al. (2012) found that PA remained a significant predictor of concurrent cognitive ability at age 70 even after age 11 intelligence was accounted for. Similarly, Gow, Mortensen, et al. (2012) demonstrated that after accounting for cognitive ability at age 50, greater PA at ages 60 and 70 was still associated with less cognitive decline by age 80, indicating that the impact of later PA 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 PA were initiated by better baseline cognitive ability.

Further, although the present sample included data from adults aged 20–32, 40–52, and 60–72 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 adult population.

The present analyses support the hypothesis that PA 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 PA 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 PA and cognitive performance suggests that “the earlier, the better” may indeed be true.

Supplementary Material

Supplementary material can be found at: http://psychsocgerontology.oxfordjournals.org/

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