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Activity Engagement Is Related to Level, but Not Change in Cognitive Ability Across Adulthood

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It is unclear whether the longitudinal relation between activity participation and cognitive ability is due to *preserved differentiation* (active individuals have higher initial levels of cognitive ability), or *differential preservation* (active individuals show less negative change across time). This distinction has never been evaluated after dividing time-varying activity into its two sources of variation: between-person and within-person variability. Further, few studies have investigated how the association between activity participation and cognitive ability may differ from early to older adulthood. Using the PATH Through Life Project, we evaluated whether between- and within-person variation in activity participation was associated with cognitive ability and change within cohorts aged 20–24 years, 40–44 years, and 60–64 years at baseline (n = 7,152) assessed on three occasions over an 8-year interval. Multilevel models indicated that between-person differences in activity significantly predicted baseline cognitive ability for all age cohorts and for each assessed cognitive domain (perceptual speed, short-term memory, working memory, episodic memory, and vocabulary), even after accounting for sex, education, occupational status, and physical and mental health. In each case, greater average participation was associated with higher baseline cognitive ability. However, the size of the relationship involving average activity participation and baseline cognitive ability did not differ across adulthood. Between-person activity and within-person variation in activity level were both not significantly associated with change in cognitive test performance. Results suggest that activity participation is indeed related to cognitive ability across adulthood, but only in relation to the starting value of cognitive ability, and not change over time.

Keywords: activity engagement, cognitive change, life span, adulthood, longitudinal

Most older adults will likely agree that one of the best ways to maintain a high level of cognitive functioning as they age is to stay physically, socially, and intellectually active. Although we still do not have definitive proof of this positive relationship (Salthouse, 2006, 2007; but see Hertzog, 2009), some have concluded that "the available evidence favors the hypothesis that maintaining an intellectually engaged and physically active lifestyle promotes successful cognitive aging" (Hertzog, Kramer, Wilson, & Lindenberger, 2009, p. 1; also see Schooler, 2007). For example, research studies have found those who participate in more activities such as reading the newspaper, frequently interacting with others, and physical activities ranging from walking to strenuous exercise have been found to perform better on cognitive tests (e.g., Hillman et al., 2006; Holtzman et al., 2004; Hultsch, Hammer, & Small, 1993), show less decline in age-related cognitive functioning over time (e.g., Béland, Zunzunegui, Alvarado, Otero, & del Ser, 2005; Ghisletta, Bickel, & Lövdén, 2006; Weuve et al., 2004), and have a reduced likelihood of developing neurodegenerative disorders (e.g., Alzheimer's disease; AD) compared to inactive individuals (e.g., Crowe, Andel, Pedersen, Johansson, & Gatz, 2003; Laurin, Verreault, Lindsay, MacPherson, & Rockwood, 2001; Ravaglia et al., 2008; Verghese et al., 2003; Wang, Karp, Winblad, & Fratiglioni, 2002). However, recent reviews and commentaries have highlighted that a number of essential questions remain to be investigated about the relationship between activity engagement and cognition (e.g., Bielak, 2010; Salthouse, 2006). We focus on two such issues in the present paper.

First, it is important to acknowledge the possibility that active older adults may score higher on cognitive tests not because they are currently active, but because they always have had superior cognitive functioning. A conundrum was introduced by Salthouse, Babcock, Skovronek, Mitchell, and Palmon (1990), and differentiates change or aging from differences that were present well before older adulthood. The first hypothesis, termed *differential-preservation*, predicts that active individuals benefit from various types of mental stimulation, and this stimulation continually pos-

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itively impacts their trajectory of cognitive change as they age, where they show less cognitive decline over time compared to inactive individuals. Alternatively, active individuals may have always outperformed their inactive peers on cognitive tests, and this difference is maintained into older adulthood. Importantly though, this second hypothesis predicts active and inactive individuals will show the same trajectory of cognitive change across time, hence only showing *preserved-differentiation* (also see Salthouse, 2006). Although there have been studies demonstrating active older adults showed less cognitive decline over time (e.g., Béland et al., 2005), Hoffman and Stawski (2009) noted that failure to divide a time-varying predictor into its two components, between-person variation and within-person variation across time, can lead to misleading conclusions about the results. For example, is the association of time-varying activity with cognition due to between-person differences (e.g., the effect of having a high activity level on cognitive ability) or due to within-person change (e.g., the effect of increasing or decreasing one's activity level on cognitive change)? It remains to be seen whether the between- and within-person components of activity participation differ in predicting cognitive ability and change across time, with the between-person effect in particular being able to directly address the preservation conundrum. Differential-preservation would be supported if average activity level significantly predicted the rate of cognitive change, whereas preserved-differentiation would be supported if the variable was not significant.

A second unanswered question about the association between activity participation and cognitive performance concerns whether the benefits of being cognitively, socially, and physically active differ across the life span. There is some evidence to suggest that the relationship may be stronger in the latter half of older age (i.e., 75 years and up), compared to those in the younger-old age range (i.e., 60–74 years; see Bielak, 2010 for a review). However, the strength of the relationship may remain constant after the seventies, as those 70 to 84 years and 85 to 103 years had the same 2-year positive relationship between social participation and perceptual speed (Lövdén, Ghisletta, & Lindenberger, 2005). Because nearly all of the research regarding the activity-cognition relationship has concentrated on those aged 60 and older, few studies have investigated the differences throughout adulthood. In a comparison of cohorts in their early twenties, forties, and sixties, Parslow, Jorm, Christensen, and Mackinnon (2006) showed that positive relationships between mental speed and the social, enterprising, conventional, and investigative activity domains were only found among the oldest age group. Similarly, Hillman and colleagues (2006) found a greater effect of physical activity for older (40–71 years) compared to younger adults (15–39 years). Not all studies have found a more powerful effect in older adulthood though; nonsignificant cognitive activity effects were found for those both under and over 50 years of age (Salthouse, Berish, & Miles, 2002), and although the relationship between physical activity and cognitive performance was greater in older age in another study (i.e., 18–27 years vs. 65–92 years), no age differences were apparent for cognitive activity effects (Newson & Kemps, 2006). Answering the question of whether the effects of activity in older age are significantly different from how activity may or may not benefit cognition in the rest of adulthood is important because for some cognitive domains, a substantial amount of decline has already occurred by age 60 (Salthouse, 2009). Therefore, the optimal point to introduce an intervention that promotes cognitive health is likely to be much earlier in the life span (Salthouse, 2008), thus requiring an understanding of how the activity-cognition relationship might work differently at younger ages.

The present study enhanced the current literature by focusing on the link between activity participation and cognitive ability across the life span. We evaluated the 8-year relationship between activity participation and cognition across three different age cohorts: young (20–32 years), middle (40–52 years) and old (60–72 years) adulthood. This unique longitudinal study provided an excellent design through which to examine the activity–cognition relationship throughout the adult life span. The present study also included five indicators of cognitive ability, each assessing a different cognitive domain. Given the wide variation regarding which cognitive domains are examined across research studies, no one cognitive domain has emerged as showing the strongest link with activity participation in older adulthood (Bielak, 2010). Further, it is also possible that the relationship may differ according to age, and this study provided the context to evaluate this.

We focused on two specific research questions. First, we investigated whether between-person differences and within-person changes in activity participation significantly predicted ability in various domains of cognitive performance across 8 years. We hypothesized that the between-person effects (i.e., average activity level) would have a stronger relation with cognition compared to the within-person effects (i.e., changes in activity level), because the link between changes in activity and changes in cognition tend to be modest in comparison to those seen concurrently (e.g., 6 years, Bielak, Hughes, Small, & Dixon, 2007). However, because time-varying activity engagement has never been separated from its between-person effects, we did not have a specific expectation about whether the between-person activity effect would significantly predict differences in cognitive change and demonstrate differential preservation of cognitive ability over time. Second, we investigated whether there were age differences in the associations between activity and cognition. In keeping with the finding that the effects of activity appear to be stronger in old-old age compared to young-old age (e.g., Hultsch et al., 1993), we hypothesized that the association with activity would follow a linear relationship, being strongest among those in their sixties, relatively weaker among those in their forties, and weakest among those in their twenties. Finally, because the level of activity engagement may differ according to physical and mental health (RAND-12 assessment; Hays, 1988), sex, years of education, and employment status (i.e., full-time, part-time, or unemployed), we also evaluated whether activity participation was a significant predictor of cognition controlling for these variables.

Method

Data were drawn from the PATH Through Life Project (PATH), which follows a cohort-sequential design in which participants are repeatedly tested every 4 years (see Anstey et al., 2011). In these analyses, we use three waves of testing (i.e., over 8 years) of all three cohorts (i.e., 20s, 40s, and 60s).

Participants

PATH participants are community-dwelling adults residing in the city of Canberra or the neighboring town of Queanbeyan, Australia. Potential participants were drawn from three age groups: 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. Participants were recruited through the electoral rolls, for which registration is compulsory for Australian citizens. The number of participants who returned the survey totaled 7,485, of whom 2,404 were in the 20s; 2,530 in the 40s; and 2,551 in the oldest cohort. Approximately half of each age cohort was female.

There was limited sample attrition 4 and 8 years later, as 6,680 and 5,996 participants completed Waves 2 and 3, respectively. Although the multilevel modeling (MLM) framework permitted the inclusion of all participants regardless of attrition, only participants with available baseline data for all outcome variables were included, resulting in 7,152 participants. There was a mean length of follow-up of 7.00 years (*SD* = 2.43). Further information on attrition and scores by each cohort across the waves are presented in Table 1.

Measures and Procedure

The procedure of testing for PATH has been previously described in detail (Anstey et al., 2011). At each testing wave, participants completed a questionnaire that assessed their sociodemographic characteristics, and included measures of well-being, mental and physical health, cognitive function, and activity participation. The majority of the questionnaire was administered on a hand-held or laptop computer, and was completed under the supervision and with the assistance of an interviewer.

Activity Participation

We used the RIASEC Activity List (Parslow et al., 2006) to assess whether participants engaged in 54 different activities over the past 6 months. This list was derived from Holland's theory (1973) that six primary interest categories (Realistic, Investigative, Artistic, Social, Enterprising, and Conventional; RIASEC) could be used to help individuals identify their primary interests and thus potential career options, and has been empirically shown to be a reasonable method to categorize the lifestyle activities engaged in by older adults (Kerby & Ragan, 2002). The shortened RIASEC activity list designed for career testing (Lokan, 1994), which asked about individuals' interest in participating in various activities, was modified for use in the PATH study by focusing on whether participants had engaged in the activity in the past 6 months.

However, to reduce the burden on participants, the questionnaire was shortened in Wave 3 to only include 16 items. The items in the realistic and conventional categories were excluded as they were deemed too work-specific, and four items from each of the remaining subscales were chosen based on the following criteria: (a) general accessibility of the activity, (b) nonage specificity of the activity, (c) nonemployment specificity of the activity, (d) cultural appropriateness of wording, and (e) low ambiguity of what it means to undertake the activity. These items are listed in Table 2. The total score was recorded.

Cognitive Ability

Perceptual speed. Perceptual speed was assessed using the Symbol Digit Modalities Test (SDMT; Smith, 1982). Participants were presented with a coding key pairing numbers 1 through 9 with nine symbols. Participants were given 90 seconds to transcribe as many randomly ordered numbers to corresponding symbols as possible. The number of correct responses was recorded.

Short-term memory. This was measured by immediate recall of the California Verbal Learning Test (CVLT-Immediate; Delis, Kramer, Kaplan, & Ober, 1987). The list contained 16 words, from four taxonomic categories (e.g., fruits, tools) presented in unblocked order. Participants were read the list, and asked to immediately recall as many words as possible. The number of correctly recalled words was recorded.

Working memory. Working memory was assessed using digit span backward 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 numbers backward (e.g., 7 – 1 – 9, would be repeated as 9 – 1 – 7). The number of correctly recalled sets was recorded.

Episodic memory. This was measured by the CVLT-Delayed (Delis et al., 1987). Participants were read a list of 16 words from four taxonomic categories (e.g., fruits, tools) presented in unblocked order. Following a short interval (i.e., grip strength), participants were asked to recall as many words as possible. The number of correctly recalled words was recorded.

Vocabulary. Vocabulary was measured by the Spot-the-Word Test (Baddeley, Emslie, & Nimmo-Smith, 1992). Participants were presented with 60 word pairs, each containing a real word and a nonword. Participants were asked to identify the real word. The number of correctly identified real words was recorded.

Data Preparation and Statistical Analysis

To permit comparison across tasks, all cognitive and activity scores across the three waves were converted into *T* scores (*M* = 50, *SD* = 10) using the baseline means and standard deviations (*n* = 7,152) across age groups. The between-person effect for activity was obtained by calculating each individual's average activity score across the waves (activity-between). The within-person effect was obtained by subtracting each individual's activity score for that wave from their average level of activity participation (activity-within; see Table 1).

The data were analyzed using MLM in PASW Statistics version 18.01 (SPSS, 2009). Change in cognition was modeled across a time in study metric because not all participants were tested at precise 4-year intervals and this metric provides additional information and variation for the models. The following model was used:

$$\text{Level 1: Cognitive Measure}_{ij} = \beta_{0j} + \beta_{1j}(\text{Time in Study}) + e_{ij}$$

$$\text{Level 2: } \beta_{0j} = \gamma_{00} + \gamma_{01}(\text{Age 60 vs. 20}) + \gamma_{02}(\text{Age 60 vs. 40}) + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}(\text{Age 60 vs. 20}) + \gamma_{12}(\text{Age 60 vs. 40}) + u_{1j}$$

where, the Level 1 equation examined individual rates of change across each individual's time in study. Specifically, the change in cognitive performance for a given individual (i) at a given occasion (j) was a function of that individual's cognitive performance

Table 1
Descriptive Statistics for Measures Entered Into the Multilevel Models

		Measure							
		Symbol Digit Modalities Test	CVLT-Immediate	Digit Span Backward	CVLT-Delayed	Spot-the-word	Activity total	Activity (Between)	Activity (Within)
Age group	*n*	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
20									
Wave 1	2346	55.45 (8.87)	51.71 (9.57)	50.95 (10.01)	51.97 (9.42)	46.03 (8.97)	50.48 (9.91)	51.09 (8.80)	−.61 (4.75)
Wave 2	2082	56.95 (8.79)	53.71 (10.28)	53.06 (9.73)	54.33 (10.29)	48.25 (8.36)	49.99 (9.86)	—	−1.29 (4.82)
Wave 3	1927	57.30 (8.53)	55.29 (10.08)	53.77 (10.01)	55.57 (9.79)	49.76 (7.62)	53.85 (9.77)	—	2.13 (5.26)
40									
Wave 1	2470	52.05 (8.10)	50.91 (9.82)	50.39 (10.08)	50.93 (9.87)	50.88 (9.62)	50.90 (10.07)	50.86 (9.24)	.04 (4.42)
Wave 2	2294	52.22 (7.70)	51.31 (10.03)	51.93 (9.93)	51.76 (9.88)	52.16 (8.76)	50.44 (10.19)	—	−.52 (4.26)
Wave 3	2128	51.59 (7.68)	52.28 (9.71)	52.45 (10.16)	52.21 (9.66)	52.90 (8..48)	51.86 (10.26)	—	.52 (4.93)
60									
Wave 1	2336	43.32 (8.20)	48.00 (9.83)	49.08 (9.77)	47.80 (9.82)	53.24 (9.84)	49.06 (9.76)	48.45 (9.20)	.61 (3.96)
Wave 2	2023	42.96 (7.99)	47.05 (9.71)	49.89 (9.61)	47.40 (9.53)	55.12 (8.86)	47.69 (9.77)	—	−1.05 (3.87)
Wave 3	1805	41.39 (7.93)	45.65 (9.92)	49.58 (9.51)	46.44 (9.30)	55.65 (8.44)	49.59 (10.32)	—	.38 (4.71)

Covariates	Education (years)	Employment status (% not-working)	RAND physical health	RAND mental health
20	14.20 (1.50)	14.8%	51.54 (6.99)	47.38 (9.57)
40	14.45 (2.27)	9.8%	51.02 (8.07)	49.02 (9.44)
60	13.88 (2.59)	58.6%	48.87 (9.89)	53.23 (8.48)

Note. Cognitive and activity measures were standardized to the T metric ($M = 50$, $SD = 10$) using the baseline sample ($n = 7{,}152$) across age groups. CVLT = California Verbal Learning Test.

Table 2
Activity Questions

1. Read scientific books or magazines
2. Read about special subjects on my own
3. Solved math or chess puzzles
4. Done troubleshooting of software packages on a PC
5. Sketched, drawn, or painted
6. Practiced a musical instrument
7. Gone to recitals, concerts, or musicals
8. Read literature
9. Attended religious services
10. Participated in club activities
11. Helped others with their personal problems
12. Worked as a volunteer
13. Discussed politics
14. Influenced others
15. Been on a committee of a group
16. Led a group in accomplishing some goal

at the first wave of testing (β_{0j}; intercept), plus that individual's average rate of change in cognitive performance across time in study (β_{1j}; 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_{0j}) for each individual was modeled as a function of the starting point for the average participant in the oldest cohort (γ_{00}), plus the average difference in intercept between the 60s and 20s cohort (γ_{01}), plus the average difference in intercept between the 60s and 40s cohorts (γ_{02}), plus variation between individuals in intercept (u_{0j}). Correspondingly, each individual's slope estimate (β_{1j}) was now a function of change for the average member of the 60s cohort per year increase of being in the study (γ_{10}), plus the average difference in slope between the 60s and 20s (γ_{11}), plus the average difference in slope between the 60s and 40s (γ_{12}), plus variation between persons in slope (u_{1j}). The same model with activity participation as the dependent variable was used to evaluate if significant change occurred in activity participation.

Next, activity was added to the model predicting cognitive change as two distinct variables: activity within-person and activity between-person. Activity within-person varied over time and was consequently added as a Level 1 predictor. Activity between-person was stable across time (i.e., each individual's mean activity level) and was added as a predictor of β_{0j}, the cognitive intercept, and β_{1j}, the cognitive slope.

$$\text{Level 1: Cognitive Measure}_{ij} = \beta_{0j} + \beta_{1j}(\text{Time in Study}) + \beta_{2j}(\text{Activity-Within}) + e_{ij}$$

$$\text{Level 2: } \beta_{0j} = \gamma_{00} + \gamma_{01}(\text{Age 60 vs. 20}) + \gamma_{02}(\text{Age 60 vs. 40}) + \gamma_{03}(\text{Activity-Between}) + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}(\text{Age 60 vs. 20}) + \gamma_{12}(\text{Age 60 vs. 40}) + \gamma_{13}(\text{Activity-Between}) + u_{1j}$$

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

The age-related interactions with the activity measures in the prediction of cognitive level and change were investigated by adding the age cohort comparisons to the definition of β_{0j}, β_{1j}, and β_{2j}. Finally, the effects of sex, employment status, physical and mental health, and education were added to the definition of all three equations.

The results are presented in four parts. First, each cognitive measure was evaluated to investigate whether significant change occurred across the 8 years, and to examine age group differences in mean levels of change. Next, a corresponding analysis that included activity engagement as the dependent variable was conducted to determine if significant change existed in activity participation and whether this varied by age group. Third, we investigated whether there was significant time-varying covariation between activity and cognition (i.e., activity-within), and if between-person differences in activity were associated with level of cognitive ability (i.e., activity-between predicting the intercept) and the rate of change (i.e., activity-between predicting the slope). Of primary interest was whether the associations of cognition with activity varied by age cohort. Finally, we investigated whether the activity-cognition relationships held when sex, education, occupational status, and physical and mental health were accounted for. Given the large number of models and cognitive abilities being assessed, we only report $p < .001$.

Results

Cognitive Change Over 8 Years

Each cognitive measure was first evaluated using an intercept-only model to provide a baseline index of between- and within-person variation (see Table 3, Model 1). Next, we assessed whether significant change occurred in each of the five measures. We were particularly interested in whether the change varied by age cohort.

There were significant age group differences in both the starting point and slope of the change for all five cognitive tasks (see Table 3, Model 2). The 20s cohort had the highest initial scores for nearly all cognitive domains, followed by the 40s and 60s. However, this pattern was reversed for the spot-the-word task where the oldest cohort had the highest baseline score, followed by the 40s and 20s. Regarding change across time, the average participant in the 60s cohort experienced significant declines in symbol digit, and immediate and delayed recall with each additional year of being in the study, but showed improvement on the spot-the-word task. There was no significant yearly group-based change for digit backward for the 60s. In contrast, the 20s and 40s cohorts significantly improved their scores for immediate and delayed recall, digit backward, and spot-the-word. For every case except digit backward, the 20s cohort showed significantly greater gains than the 40s. In contrast, for symbol digit, the 20s improved across time but the 40s showed a decrease. There were significant differences between all age groups for every change comparison except between the 60s and 40s on spot-the-word, and the 20s and 40s on digit backward.

Overall, there was significant change across the 8 years in each cognitive measure, and significant random variance within- and between-individuals remaining to be explained.

Table 3
Parameter Estimates From Multilevel Models Examining Change

	Task					
	Symbol Digit	CVLT-Immediate	Digit Backward	CVLT-Delayed	Spot-the-word	Activity
	Estimate (*SE*)	Estimate (*SE*)	Estimate (*SE*)	Estimate (*SE*)	Estimate (*SE*)	Estimate (*SE*)
Model 1						
Fixed effect–Intercept	50.19 (.11)*	50.49 (.10)*	50.99 (.10)*	50.74 (.10)*	50.95 (.11)*	50.22 (.11)*
Random effect–Residual	16.63 (.22)*	49.11 (.63)*	36.25 (.47)*	43.20 (.56)*	15.20 (.20)*	34.41 (.44)*
Random effect–Intercept	85.42 (1.55)*	56.79 (1.30)*	63.97 (1.33)*	59.82 (1.30)*	77.11 (1.41)*	68.94 (1.40)*
Model fit, $df = 3$	$\chi^2 = 126662$	$\chi^2 = 139003$	$\chi^2 = 134407$	$\chi^2 = 137503$	$\chi^2 = 123818$	$\chi^2 = 136697$
Model 2						
Fixed Effects (60 = ref)						
Intercept	43.47 (.17)*	48.04 (.20)*	49.23 (.20)*	47.87 (.20)*	53.33 (.19)*	48.61 (.20)*
Time	−0.32 (.02)*	−0.33 (.03)*	0.02 (.02)	−0.21 (.03)*	0.18 (.02)*	−0.02 (.02)
Intercept × Age Group						
60 vs. 20	12.16 (.25)*	3.74 (.28)*	1.93 (.28)*	4.26 (.28)*	−7.22 (.27)*	1.27 (.29)*
60 vs. 40	8.69 (.24)*	2.78 (.27)*	1.31 (.28)*	3.12 (.27)*	−2.39 (.27)*	2.04 (.28)*
40 vs. 20[a]	3.47 (.24)*	0.95 (.27)*	0.62 (.28)	1.14 (.27)*	−4.83 (.27)*	−0.77 (.28)
Time × Age Group						
60 vs. 20	0.50 (.02)*	0.75 (.04)*	0.32 (.03)*	0.63 (.04)*	0.22 (.02)*	0.38 (.03)*
60 vs. 40	0.21 (.01)*	0.46 (.04)*	0.21 (.03)*	0.33 (.04)*	−0.01 (.02)	0.09 (.03)
40 vs. 20[a]	0.28 (.02)*	0.29 (.04)*	0.11 (.03)	0.30 (.04)*	0.23 (.02)*	0.28 (.03)*
Random Effects						
Residual	14.26 (.26)*	44.27 (.81)*	32.81 (.61)*	39.88 (.73)*	13.27 (.25)*	30.48 (.56)*
Intercept	56.05 (1.12)*	52.97 (1.66)*	66.16 (1.66)*	55.91 (1.63)*	75.55 (1.74)*	69.89 (1.67)*
Time	0.10 (.01)*	0.21 (.04)*	0.17 (.03)*	0.13 (.03)*	0.07 (.01)*	0.20 (.03)*
Change in Model fit, $df_\Delta = 7$	$\chi^2_\Delta = 3744$*	$\chi^2_\Delta = 1109$*	$\chi^2_\Delta = 465$*	$\chi^2_\Delta = 1053$*	$\chi^2_\Delta = 1614$*	$\chi^2_\Delta = 436$*

Note. 60s cohort served as reference group in Model 2.
[a] Contrast tested in another analysis using same model but different coding for age group.
* $p < .001$.

Activity Change Over 8 Years

We conducted the same models as shown above (Models 1 and 2) on the activity total score to ensure that significant change also occurred in activity participation across the 8 years. Table 3 shows that there were significant group differences in both baseline activity level and change in activity participation over time. The 20s and 40s cohorts participated in the most activities at baseline, followed by the 60s. In terms of change, the average participant in both the 20s and 40s cohorts showed significant increases in activity level with each additional year of being in the study, with the 20s showing the greatest increase. The average 60s participant did not significantly change in their activity level across the 8 years, but there was significant variation from individual to individual (between-persons) and variation for each individual around their own best-fitting regression line (within-person).

Relationship Between Cognition and Activity

Across all five cognitive tasks, the activity between-person effects were significant in predicting cognitive ability (Model 3), but only in relation to the intercept. For each additional unit of average activity participation (i.e., 0.1 *SD*) across the 8 years, the typical participant had an average starting value of .017 *SD* more points on delayed recall, .016 *SD* more points on symbol digit, .018 *SD* more points on immediate recall, .019 *SD* more points on digit backward, and .033 *SD* more points on spot-the-word. There were no instances of average activity level significantly predicting the rate of cognitive change, or significant associations between changes in activity (activity-within) and changes in cognition. The addition of the activity measures significantly improved model fit for each task.

We next investigated whether there were age-related interactions with the activity measures in the prediction of cognition. As can be seen in Table 4 (Model 4), there were only two significant age differences in the activity-between effect (intercept). Each significant difference was in the expected direction, where older adults showed a greater effect of activity participation than the middle-aged adults. For example, the older adults showed .022 *SD* more points on symbol digit at baseline per 0.1 *SD* higher in mean activity level compared to the 40s (.013 *SD*). Further, although not shown in Table 4, the activity-between intercept effect was significant for both the 20s and 40s cohort for every cognitive task, but the two groups did not significantly differ from one another in this effect. In contrast, average activity level did not significantly predict the cognitive slope, and within-person activity change did not significantly covary with cognitive change across time for any of the age groups or tasks. Therefore, their related interactions with age are not listed in Table 4.

The Role of Covariates

To account for possible differences in the activity-cognition relationship due to other variables, we covaried the effects of sex, employment status, physical and mental health, and education. Activity-between remained a significant predictor of baseline cognitive ability for each age cohort and for every cognitive task.

Table 4
Parameter Estimates From Multilevel Models Examining Age Differences in Activity Predicting Cognitive Performance and Change

	Cognitive test				
	Symbol Digit	CVLT-Immediate	Digit Backwards	CVLT-Delayed	Spot-the-word
	Estimate (*SE*)	Estimate (*SE*)	Estimate (*SE*)	Estimate (*SE*)	Estimate (*SE*)
Model 4					
Activity-within	0.02 (.01)	0.03 (.02)	−0.01 (.02)	0.03 (.02)	0.02 (.01)
Activity-between	0.22 (.02)*	0.24 (.02)*	0.22 (.02)*	0.20 (.02)*	0.37 (.02)*
Activity-between × Time	.003 (.002)	−.004 (.003)	.000 (.002)	−.003 (.003)	−.002 (.002)
Activity-between × Age Group					
60 vs. 20	−0.07 (.03)	−0.08 (.03)	−0.06 (.03)	−0.05 (.03)	−0.04 (.03)
60 vs. 40	−0.09 (.03)*	−0.11 (.03)*	−0.03 (.03)	−0.06 (.03)	−0.07 (.03)
Change in Model fit[a], $df_\Delta = 6$	21.83	21.39	4.91	10.05	12.92
Model 5 (adding covariates)					
Activity-between	0.13 (.02)*	0.16 (.02)*	0.12 (.02)*	0.14 (.02)*	0.20 (.02)*
Activity-between × Age Group					
60 vs. 20	−0.02 (.03)	−0.02 (.03)	0.0002 (.03)	0.0003 (.03)	0.06 (.03)
60 vs. 40	−0.06 (.02)	−0.07 (.03)	−0.002 (.03)	−0.02 (.03)	−0.03 (.03)
Change in Model fit[b], $df_\Delta = 6$	372*	735*	222*	722*	683*

Note. 60s cohort served as reference group in models. Model 4: There were no significant activity-within × age group, or activity-between × time × age group effects. [a] Compared to Model 3 (i.e., activity effects but not age group × activity). [b] Compared to Model 4.
* $p < .001$.

The size of the effects did decrease however compared to Model 4 (see Table 4, Model 5). For example, each additional unit of average activity participation (i.e., 0.1 *SD*) was associated with the average 60s participant scoring .013 *SD* higher on the symbol digit task at Wave 1 with the covariates controlled, compared to .022 *SD* higher without accounting for them. In terms of cohort differences, there were no significant age group contrasts in the activity-between effect for the intercept. Consistent with the results from Model 4, there were no significant effects for activity-between in relation to the cognitive slope, or for activity-within in relation to cognitive change for any age cohort, and as such the predicted values are not included in Table 4.

Discussion

The majority of studies investigating the relationship between activity participation and cognitive ability have involved older adult samples and included activity participation as a single time-varying variable (e.g., Hultsch, Hertzog, Small, & Dixon, 1999; Mackinnon, Christensen, Hofer, Korten, & Jorm, 2003). To our knowledge, this is the first investigation of the association between activity and cognitive change to investigate the distinct contributions of between- and within-person variation in activity participation in the prediction of cognitive ability, and to directly examine these differences over the adult life-course. Surprisingly, we did not find that average activity level or within-person changes in activity levels were associated with cognitive change, nor did we find age differences in the strength of association between activity and cognition. We did however, replicate the established finding of an association between activity level (between-person) and baseline cognitive performance.

Across the entire sample and for each cognitive task, average activity level (activity-between) was significantly associated with baseline cognitive test performance. In each case, the direction of the association was positive, with greater average activity participation linked to a higher cognitive score. For example, an individual in their 60s who had an average activity level that was one standard deviation higher than the typical participant in that age group tended to score .13 *SD* higher on a test of perceptual speed, .16 *SD* higher on a short-term memory test, .12 *SD* higher on a working memory test, .14 *SD* higher on an episodic memory test, and .20 *SD* higher on an index of vocabulary. However, average activity level, and fluctuations in activity participation across the 8 years (activity-within) were not related to the rate of change, or corresponding cognitive change. This pattern of results persisted across age groups, cognitive tasks, and even after accounting for education, physical and mental health, employment status, and sex. Therefore, average activity level (between-person effect) was related to baseline cognitive ability, but was not associated with the rate of cognitive change, and performing more or less activities than usual at each time point (within-person effect) was not associated with cognitive change.

The presence of a significant baseline, but not slope relationship with average activity level suggests that active individuals may have always had superior cognitive functioning, rather than also showing differential change or aging compared to their inactive peers. Therefore, these findings are in accordance with *preserved differentiation*, and not *differential-preservation* over time (see Salthouse, 2006). Other studies using various indicators of cognitive reserve (Stern, 2002) have come to similar conclusions, such as finding that the personality trait of openness (Schoenhofen Sharp, Reynolds, Pedersen, & Gatz, 2010), vocabulary knowledge, and years of education (Tucker-Drob, Johnson, & Jones, 2009) were positively related to higher levels of cognitive ability, but not more gradual cognitive decline across time. Although other papers have indeed found evidence that cognitive change is associated with time-varying activity (Albert et al., 1995; Wilson et al., 2002), the statistical framework used in such work does not completely remove between-person elements from the time-varying predictor

(Hoffman & Stawski, 2009). Another study only involved initial activity, which is consequently not circumspect to the same potential interpretation errors of a time-varying variable, and did in fact find higher initial mental activity was related to higher baseline cognitive score, and more gradual cognitive decline (Wilson et al., 2010). One possible reason for the divergent results compared to the present work is that the Wilson et al. study included a sample of only older adults, and they were substantially older than our baseline cohort of 60–64 year olds. Therefore, it is possible that the differential-preservation explanation is feasible, but more applicable to late life.

It is important to note that the absence of a slope relationship in the present study is not necessarily inconsistent with the "use it or lose it" hypothesis. Rather, Hertzog et al. (2009) argued that activities that raise the level of cognitive functioning are just as important as effects that might slow the rate of cognitive decline, and noted that the amount of engagement needed to stave off age-related decline at a higher level of cognition may be greater than that required to resist decline at lower levels. Additional research is needed to shed further light on the debate over whether activity engagement affects aging per se.

The lack of a within-person change relationship across all three age groups demonstrates that performance on cognitive tests is not particularly sensitive to changes in activity participation. However, our conclusion can only apply to our current analysis using a relatively long time period (i.e., 8 years) with retest intervals of 4 years. Two papers using the bivariate dual change score model found that within-person fluctuations in activity corresponded with changes in cognition over shorter time frames (e.g., 1–2 years, Ghisletta et al., 2006; Lövdén et al., 2005). Therefore, changes in cognition may in fact covary with changes in activity, but possibly only over briefer time periods.

We also expected the strength of the association between activity participation and cognitive ability to differ depending on the stage of adulthood. For activity-between, there were only two significant effects, but each was in the expected direction where older adults showed a stronger association between average activity participation and baseline cognitive ability relative to middle-aged adults. However, these age differences disappeared when the covariates were added to the model. The associations for within-person variations from average activity level and cognition, and between-person activity and cognitive slope, also did not differ across adulthood, but in contrast, were uniformly nonsignificant. The lack of age-related differences were unexpected given suggestions that activity effects may increase with age (Bielak et al., 2007; Hillman et al., 2006; Hultsch et al., 1993), and is in contrast to cross-sectional findings on this same sample at baseline (Parslow et al., 2006). However, not all studies have found a more powerful association with activity in older compared to younger adulthood (Newson & Kemps, 2006; Salthouse et al., 2002), and none have directly compared the components of within- and between-person variation.

Our results suggest that activity participation is indeed associated with baseline cognitive ability regardless of stage of adulthood, and that this effect is uniform across adulthood. Our results were particularly notable for the youngest cohort, for whom activity engagement is not typically regarded as a key predictor of cognitive prowess. The fact that the relation between activity and cognition was just as strong in young adulthood as in older adulthood indicates that the positive association between activity engagement and cognitive performance is likely to be evident across the adult life span. Further, the strength of average activity level in predicting cognitive ability was similar across the five cognitive domains. This is an important finding as no other study has compared age differences across a wide range of cognitive abilities.

Our present findings must be interpreted in conjunction with several study limitations. The activity questionnaire did not assess the frequency of activity engagement, and a more sensitive measure may have revealed more substantial differences between the age groups and increased the size of the within-person variation over time. It was also the case that the number of activity questions contributing to the overall measure was relatively small. However, the fact that average activity level based on such a general measure was related to cognitive ability across all measurement domains and age cohorts points to the likelihood of stronger associations being detectable with more sensitive measures of engagement. It is also important to note that the present results cannot shed light on the causality of the association between activity and cognition. Next, consistent with prior research (Salthouse, 2010), the type of cognitive change being explained differed across adulthood (i.e., gains, declines, stability). Therefore, any investigation into the potential differences of how activity engagement may impact cognitive ability across the life span will be entangled with the fact that the direction and size of cognitive change to explain is also different across age. However, cognitive change in early and middle adulthood is not any less reliable than change in older adulthood (Salthouse, 2010), and our statistical models allowed for the variation in cognitive change both by age cohort and within-person. Finally, it has been suggested that the failure to detect significant correlated change between two variables may in fact be due to limited statistical power (Hertzog, Lindenberger, Ghisletta, & von Oertzen, 2006), a problem which may be compounded when the change effects are expected to be modest (Hertzog et al., 2009). According to the figures in Hertzog and colleagues' paper (2006) illustrating statistical power based on sample size, number of occasions, and growth curve reliability, even the symbol digit task, which had a reliability of .85, would have had limited power to detect change with our large sample. Therefore, even though our statistical methodology differed from that used in the illustrative paper, our capacity to detect within-person activity effects may have been underpowered.

We specifically targeted the need for further study into how the two components of activity participation across time, between-person and within-person variation, predicted cognitive level and long-term change, and if these associations differed across adulthood. Greater average activity engagement was associated with a higher baseline cognitive score across all cognitive domains and age cohorts, and this relationship did not significantly differ across adulthood. However, between-person activity and within-person variation in activity level were both not significantly associated with change in cognitive test performance. Therefore, results support that activity engagement only provides preserved differentiation in cognition, and not differential cognitive aging. Finally, our results suggest that activity participation is indeed associated with cognitive ability before reaching older adulthood, and given the possibility that even the most effective later life cognitive intervention may never match the benefits of getting on the right path earlier in life (Hertzog et al., 2009), greater understanding of how activity may influence cognition across the life span is essential.

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