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Research Report

Bidirectional Within- and Between-Person Relations Between Physical Activity and Cognitive Function

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Abstract

Objectives: To examine bidirectional within- and between-person relations between physical activity and cognitive function across 15 years.
Methods: Participants (*N* = 1,722, age range 40–85 years, 55% women) were drawn from the Betula prospective cohort study. We included 4 waves of data. Bivariate latent curve models with structured residuals were estimated to examine bidirectional within- and between-person relations between physical activity and cognitive function (episodic memory recall, verbal fluency, visuospatial ability).
Results: We observed no statistically significant bidirectional within-person relations over time. Higher levels of physical activity at baseline were related to less decline in episodic memory recall. Positive occasion-specific within- and between-person relations were observed, with the most consistent being between physical activity and episodic memory recall.
Discussion: The lack of bidirectional within-person relations indicates that shorter time lags may be needed to capture time-ordered within-person relations. The link between higher physical activity at baseline and less decline in episodic memory recall over time may indicate a protective effect of physical activity on episodic memory recall.

Keywords: Adults, Cognition, Exercise, Reciprocal relations

Numerous studies show that physical activity can play a vital role in the improvement or maintenance of cognitive function across the life course (Engeroff et al., 2018). Reviews and meta-analyses show a consistent pattern suggesting that engaging in more physical activity is related to reduced risk of cognitive decline (Blondell et al., 2014; Northey et al., 2018). The hippocampus and prefrontal cortex, which are involved in executive and memory-related cognitive functions, have been suggested as important brain regions linking physical activity to cognitive function (Stillman & Erickson, 2018). Although most studies have been unidirectional and focused on the effect of physical activity on cognitive function, recent research suggests that cognitive function might also be a potent predictor of physical activity (Cheval et al., 2020).

In a prospective study in older adults, the effect of cognitive function on physical activity was 50% stronger than the effect of physical activity on cognition (Daly et al., 2015).

Lower cognitive resources have also been associated with lower levels and a steeper decrease in physical activity over time in people over 50 years of age (Cheval et al., 2020). The results further showed that the time-ordered effect of cognitive resources on physical activity was stronger than the opposite. Effective cognitive functioning is important to initiate and maintain physical activity, which requires self-regulatory skills, the ability to create exercise regimes, and managing pain and discomfort that comes with physical activity engagement (Stillman & Erickson, 2018). Cognitive resources are needed to overcome the natural inclination to conserve energy and instead undertake physical activity, and the frontal lobe and medial prefrontal cortex, which are important for self-control, are likely involved (Cheval et al., 2020).

Most studies on the relation between physical activity and cognitive function have focused on between-person effects, that is, whether higher (or lower) levels of physical activity compared to other people are related to stronger (or weaker) cognitive ability compared to other people (Kowalski et al., 2018). Within-person effects, on the other hand, reflect how variation relative to a person's own mean is related across variables and require that each person is measured more than once. Decomposing between-person and within-person effects is important because results often differ between these levels of analysis (Bielak et al., 2014).

The primary purpose of the present study was to examine bidirectional within-person relations between physical activity and cognitive function. Three cognitive domains (episodic memory recall, verbal fluency, visuospatial ability) known to be age-sensitive and related to physical activity were targeted in the current study (see Stenling et al., 2021). These domains represent executive and memory-related cognitive functions that have been shown to benefit from physical activity (Engeroff et al., 2018), and appear to be important for the initiation and maintenance of health behaviors, such as physical activity (Cheval et al., 2020).

We extended previous findings (e.g., Bielak et al., 2014; Cheval et al., 2020; Daly et al., 2015; Kowalski et al., 2018; Stenling et al., 2021) by examining time-ordered bidirectional within-person relations across 15 years. A secondary purpose was to examine bidirectional between-person relations between physical activity and cognitive function. Due to the scarcity of previous research on time-ordered bidirectional physical activity-cognition relations, no hypotheses were specified a priori.

Method

Study Population

The data used in the present study were collected within the Betula prospective cohort study (Nyberg et al., 2020). Participants were tested at 5-year intervals, and six test waves (T) and six samples (S1–S6) have been included between 1988 and 2014. The samples are representative of the target population with regard to demographic factors such as education, sex, income, and marital status. We included S1 and S3 because these are the only two samples with comprehensive longitudinal data on physical activity and cognitive variables. T2 was used as baseline because physical activity questions were introduced at T2. We included four measurement points (T2–T5) across 15 years. All participants provided written informed consent at study inclusion.

Participants

Of the 1,966 available participants, 244 participants were excluded due to missing data on the control variables (*n* = 241) or dementia diagnosis at baseline (*n* = 3; see Author Note 1). The analyses included 1,722 participants (47% from S1 and 53% from S3). The sample at baseline had a mean age of 61.5 years (*SD* = 14.0, range 40–85 years), an average of 10.3 years of education (*SD* = 4.4, range 2–31 years), and consisted of 55% women (see Author Note 2).

Measures

Physical activity

Participants responded to a single-item question asking how often they had done *Sports/Exercise/Walking in the forest* during the last 3 months. Frequency of physical activity was rated as *never* (1), *occasionally* (2), *a few times a month* (3), *sometime per week* (4), or *every day* (5).

Episodic memory recall

Five measures were used to assess *episodic memory recall*. These were: (a) action recall after completion of 16 verb–noun actions; (b) sentence recall of 16 verb–noun sentences; (c) category-cued recall of nouns from actions performed; (d) category-cued recall of nouns from the sentences studied; and (e) free recall of 12 nouns that were read aloud by the test leader. Performance in each task was used to create a composite score of *episodic memory recall*, which could range from 0 to 76, with higher scores indicating better episodic memory recall. Omega reliability estimates ranged from 0.863 to 0.890 across T2–T5.

Verbal fluency

Three tasks were used to assess *verbal fluency*. In each task, the goal is to verbally generate within 1 min as many words as possible (except person names). These were: (a) Fluency A: recall words with initial letter A. (b) Fluency M: generate words that contain exactly five letters and have initial letter M. (c) Fluency B: recall occupations with initial letter B. We summed the three scores into a composite score with higher scores indicating better *verbal fluency*. Omega reliability estimates ranged from 0.764 to 0.789 across T2–T5.

Visuospatial ability

Visuospatial ability was assessed using the Wechsler adult intelligence scale-Revised Block Design Test (Weschler, 1981).

The participant must arrange a number of bicolored blocks (red–white) into patterns that correspond to targets presented on sheets. Targets are presented with ascending difficulty and they require either a set of four or nine blocks to be solved. The time limit is either 1 or 2 min, depending on task difficulty. The raw score, calculated from the number of patterns solved and the time taken to solve them, was used in the analyses. Higher scores indicate better performance.

Control variables

Age at baseline, apolipoprotein (APOE) ε4 status (72% noncarriers and 28% carriers), years of education, and sex were included as time-invariant covariates in the analyses. We also included sample (S1 or S3) to account for potential practice effects.

Statistical Analysis

We used Mplus version 8.6 (Muthén & Muthén, 1998–2017) and the robust full information maximum likelihood estimator to estimate latent curve models with structured residuals (LCM-SR; Curran et al., 2014). Univariate and bivariate LCM-SR (see Figure 1) were estimated to examine: (a) the rate of change over time in physical activity and cognitive function; (b) within-person autoregressive effects (i.e., how within-person deviations from the person-specific curve predict themselves at the next ordered measurement occasion); (c) bidirectional within-person relations over time; and (d) bidirectional between-person relations over time where the slope factor of one variable (e.g., cognitive function) is regressed on the intercept factor of the other variable (e.g., physical activity). The three cognitive variables were examined in separate models. After the shape of the trajectories had been determined in univariate models, we compared four nested bivariate LCM-SR (Curran et al., 2014). Model 1 only included autoregressive effects within variables over time (i.e., later residual regressed on prior residual). In Model 2, we regressed the residuals of cognitive function on the residuals of physical activity. In Model 3, we regressed the residuals of physical activity on the residuals of cognitive function. Model 4 was a full bidirectional model including within-person effects in both directions. Model fit was assessed using the comparative fit index (CFI), Tucker–Lewis index, root mean square error of approximation (RMSEA), and standardized root mean squared residual (SRMR). Traditional cutoff criteria (CFI > 0.90, SRMR and RMSEA < 0.08) were used to indicate acceptable fit (Marsh, 2007). Nested models were compared with the Bayesian Information Criterion (BIC; Bollen et al., 2014), with lower values indicating better fit. The significance level was set to 0.05.

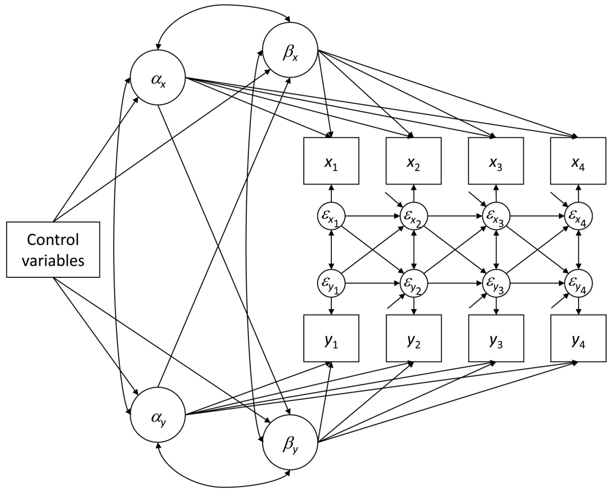

Figure 1. Graphical description of the latent curve model with structured residuals.

Results

Univariate LCM-SR indicated that episodic memory recall ($\beta_{\text{linear}} = -0.167$, $\beta_{\text{quadratic}} = -0.017$) and visuospatial ability ($\beta_{\text{linear}} = -0.210$, $\beta_{\text{quadratic}} = -0.008$) had an accelerated decline, verbal fluency a linear decline ($\beta_{\text{linear}} = -0.112$), and physical activity ($\beta_{\text{linear}} = 0.012$) a small increase over time. Physical activity had a statistically significant within-person autoregressive effect ($\beta_{\text{ar}} = 0.237$, $p < .001$). None of the cognitive variables had statistically significant within-person autoregressive effects (see Author Note 3).

Model 1 (only autoregressive effects) had the lowest BIC for all three cognitive variables (Table 1), which suggests that there were no bidirectional within-person effects over time. Occasion-specific within-person relations between physical activity and episodic memory recall were positive and statistically significant ($\sigma = 0.347$, $p = .002$), whereas relations with verbal fluency ($\sigma = 0.153$, $p = .071$) and visuospatial ability ($\sigma = 0.104$, $p = .188$) were weaker in magnitude and not statistically significant.

Positive between-person relations were found at baseline between the intercept of physical activity and the intercept of all three cognitive variables (episodic memory recall, $r = 0.204$, $p < .001$; verbal fluency, $r = 0.226$, $p < .001$; visuospatial ability, $r = 0.120$, $p = .005$), linking higher levels of physical activity to better performance on the cognitive tests at baseline. Higher levels of physical activity at baseline also predicted less decline in episodic memory recall ($\beta = 0.074$, $p = .023$) and, although not statistically significant, verbal fluency ($\beta = 0.022$, $p = .326$). Baseline physical activity did not show a positive relation with change in visuospatial ability ($\beta = -0.022$, $p = .367$). Baseline levels of episodic memory recall ($\beta = 0.000$, $p = .871$), verbal fluency ($\beta = 0.000$, $p = .838$), and visuospatial ability ($\beta = -0.001$, $p = .064$) were not statistically significant predictors of subsequent changes in physical activity (see Author Note 4).

Discussion

In the current study, we examined bidirectional within- and between-person relations between physical activity and

Table 1. Model Fit Indices of the Bivariate LCM-SR Models (*N* = 1,722)

	χ^2	*df*	*p*	CFI	TLI	RMSEA	90% CI	SRMR	BIC
Episodic memory recall (EM)									
Autoregressive effects	49.904	36	.0616	0.997	0.995	0.015	[0.000, 0.024]	0.028	48,956
Physical activity → EM	48.036	35	.0700	0.998	0.995	0.015	[0.000, 0.024]	0.028	48,962
EM → Physical activity	49.772	35	.0503	0.997	0.995	0.016	[0.000, 0.025]	0.028	48,963
Bidirectional model	47.824	34	.0582	0.997	0.995	0.015	[0.000, 0.025]	0.028	48,969
Verbal fluency (VF)									
Autoregressive effects	78.383	42	<.001	0.992	0.987	0.022	[0.015, 0.030]	0.028	47,170
Physical activity → VF	77.793	41	<.001	0.992	0.987	0.023	[0.015, 0.031]	0.028	47,177
VF → Physical activity	77.386	41	<.001	0.992	0.987	0.023	[0.015, 0.030]	0.028	47,177
Bidirectional model	75.898	40	<.001	0.992	0.987	0.023	[0.015, 0.031]	0.028	47,183
Visuospatial ability (VA)									
Autoregressive effects	59.677	36	.0078	0.996	0.992	0.020	[0.010, 0.028]	0.029	46,803
Physical activity → VA	58.502	35	.0076	0.996	0.992	0.020	[0.010, 0.028]	0.029	46,810
VA → Physical activity	55.310	35	.0158	0.996	0.993	0.018	[0.008, 0.027]	0.029	46,806
Bidirectional model	55.085	34	.0125	0.996	0.992	0.019	[0.009, 0.028]	0.029	46,813

Notes: BIC = Bayesian Information Criterion; CFI = comparative fit index; CI = confidence interval; LCM-SR = latent curve model with structured residuals; RMSEA = root mean square error of approximation; SRMR = standardized root mean squared residual; TLI = Tucker–Lewis index. Autoregressive effects estimated and set equal for all variables. The slope variance of physical activity was set to zero. Sample, sex, age, APOE ε4 carrier, and years of education were included as control variables.

cognitive function across 15 years. No statistically significant bidirectional within-person relations between physical activity and cognitive function were found. A statistically significant within-person autoregressive effect was observed for physical activity, but not for the cognitive variables. Higher than usual physical activity was related to higher than usual episodic memory recall at each time point (i.e., within-person correlation). Higher levels of physical activity were related to better cognitive function at baseline and to less decline in episodic memory recall.

The within-person autoregressive effects showed that higher than usual physical activity at one time point was related to higher than usual physical activity at a subsequent time point while controlling for the general time trend. This suggests that habitual physical activity to some extent persists over time within individuals. The lack of significant within-person autoregressive effects for the cognitive variables indicates that higher (or lower) than usual cognitive performance at a specific measurement occasion was not enduring over time. Instead, individuals seem to fall back on their person-specific cognitive trajectory quite quickly (Mund et al., 2021).

The nonsignificant bidirectional relations contrast with previous findings showing larger effects of cognition on subsequent physical activity than vice versa (Cheval et al., 2020; Daly et al., 2015). However, two major differences between the current study and these previous studies might explain the differences in results. First, we used a different data analytic approach (i.e., LCM-SR) to examine time-ordered within-person relations. Cheval et al. (2020) used a bivariate latent change score model, which assesses whether previous levels of one variable predict subsequent change in another variable. Daly et al. (2015) used multilevel models, but each direction was specified in separate models. Although all of these statistical models are considered acceptable, results can vary as a function of the model used (cf. Bainter & Howard, 2016). Second, 5 years intervened between waves in the current study compared to 2 years in Cheval et al. (2020) and Daly et al. (2015).

The cross-sectional relations (between- and within-person) are in line with previous findings (Bielak et al., 2014; Stenling et al., 2021), and suggest that occasion-specific levels of physical activity and cognitive function generally follow a similar pattern. Finally, people engaging in more physical activity at baseline exhibited less decline in episodic memory recall. These findings suggest a potential long-term protective effect of physical activity engagement on episodic memory recall (cf. Nyberg & Pudas, 2019).

There are a number of limitations in the current study. First, we used a single-item self-report measure that captures frequency of physical activity but not duration or intensity, and was restricted to certain activities. Future research collecting physical activity data via accelerometers (or a more detailed questionnaire) is warranted. Second, the 5-year measurement intervals may have been too long to capture bidirectional within-person relations between physical activity and cognitive function, although this conjecture requires confirmation. Third, we focused on three cognitive domains only; future research should investigate other cognitive domains that have been suggested as potent predictors of physical activity (e.g., specific domains of executive functions; Cheval et al., 2020). Fourth, although we controlled for important time-invariant covariates established in the literature (Nyberg et al., 2020), there may have been other covariates, particularly time-varying covariates, not accounted for (cf. Mund et al., 2021). Future studies should explore the role of time-invariant and time-varying covariates in more detail. Fifth, early-life factors, such as birth weight and parental education (Walhovd et al., 2016), have been found to influence life-span changes in cognition; the impact of such factors in the current study is unknown.

In conclusion, our findings did not indicate bidirectional within- or between-person relations between physical activity and cognitive function across 5 years. The most consistent finding was the link between physical activity and episodic memory recall, which was observed across levels of analyses, in cross-sectional analyses (within- and between-person), and in longitudinal analyses (between-person only). Our findings indicate both short-term links between higher than usual levels of physical activity and better than usual episodic memory recall at each measurement occasion, and that higher levels of physical activity may facilitate maintenance of episodic memory across 15 years. These findings are of particular interest given that impairment of episodic memory constitutes a marker for dementia up to 10 years prior to diagnosis (Boraxbekk et al., 2015).

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences* online.

Author Note

1. Excluded participants had fewer years of education and performed worse on the cognitive tests at baseline compared to included participants (see Supplementary Table S1).
2. An attrition analysis using logistic regression showed that older age and poorer performance on the cognitive tests at baseline were statistically significant predictors of having missing data at one or more measurement points across T3–T5 (see Supplementary Table S2).
3. See Supplementary Table S3 for more information about the univariate LCM-SR.
4. The effects of the time-invariant covariates are presented in Supplementary Tables S4–S6.

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Conflict of Interest

None declared.

Acknowledgments

Collaborations on data from the Betula Project are available for external researchers as far as the proposed projects are assessed by the Steering Committee as scientifically sound, and the issues to be studied are not already highlighted in ongoing Betula studies. Thus, access to the Betula data requires approval by the Steering Committee and we are not allowed to share the data publically. This study was not preregistered in an independent, institutional registry. The Mplus syntax for the latent curve models with structured residuals is provided as Supplementary Material.

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