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Initial Status and Change in Cognitive Function Mediate the Association Between Academic Education and Physical Activity in Adults Over 50 Years of Age

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Higher levels of academic education are associated with higher levels of physical activity throughout the lifespan. However, the mechanisms underlying this association are unclear. Cognitive functioning is a potential mediator of this association because higher levels of education are associated with better cognitive function, which is related to greater engagement in physical activity. Here, we used large-scale longitudinal data from 105,939 adults 50 years of age or older (55% women) from the Survey of Health, Ageing, and Retirement in Europe to investigate whether initial status and change in cognitive function mediate the relationship between education and change in physical activity. Education and physical activity were self-reported. Cognitive function was assessed based on delayed recall and verbal fluency. Academic education was assessed at the first measurement occasion. The other measures were collected seven times between 2004 and 2019. The mediating role of cognitive function was tested using longitudinal mediation analyses combined with growth curve models. We found that higher levels of education were associated with higher levels and slower decreases in cognitive function, which in turn predicted a lower decrease in physical activity across time. These results support the presence of an indirect effect of education on physical activity trajectories by affecting the intercept and slope of cognitive function. Specifically, these findings suggest that both the initial status and change in cognitive function mediate the association between academic education and change in physical activity. In addition, results revealed that, across the aging process, differences in cognitive function and physical activity widen between the low and high educated. In other words, this study demonstrates the long-lasting effect of education on cognitive function and physical activity.

Public Significance Statement
The beneficial effects of education on cognition and physical activity are well-replicated. Yet, little is known about the mechanisms underlying these associations. Based on a large-scale longitudinal European study in adults aged 50 years or older, we show that both the initial status of cognitive function and its change underpin the relationship between education and physical activity across time. Our results shed light on education that engenders positive trajectories of cognition that in turn impact physical activity. These findings highlight the long-run effect of education on cognitive function and physical activity.

Keywords: educational status, cognition, exercise, aging, longitudinal studies

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continued

Academic educational attainment plays a crucial role in promoting the engagement in multiple health behaviors (Conti et al., 2010; Eide & Showalter, 2011; Silles, 2009; Zajacova & Lawrence, 2018), such as physical activity (Chalabaev et al., 2022; Cheval, Sieber, et al., 2018; Droomers et al., 2001; Kari et al., 2020). Less educated people exhibit a higher risk of physical inactivity, a risk that increases with age (Beenackers et al., 2012; Cheval, Sieber, et al., 2018; Droomers et al., 2001; O'Donoghue et al., 2018). Moreover, a recent Mendelian randomization study conducted on middle-age Finnish adults revealed that a higher level of education was associated with more time spent on physical activity (Kari et al., 2020). Overall, these findings support the role of education in determining physical activity levels and their maintenance across the life course. Still, gaps remain in our understanding of the mechanisms underpinning this association.

Several mechanisms may explain why lower levels of education have been associated with lower physical activity. First, poor health literacy has been suggested to explain the relationship between lower education and lower engagement in protective health behaviors (Friis et al., 2016; Levin-Zamir et al., 2016; Stormacq et al., 2019; Sun et al., 2013; Van Der Heide et al., 2013). Second, less educated people may have developed weaker motivation and self-efficacy toward health-protective behaviors, putting them at higher risk for disengagement from these behaviors (Nettle, 2010; Osborn et al., 2011; Torres & Marks, 2009; Verhoeven & Snow, 2001). Third, because the place of residence is influenced by sociocultural position (Diez Roux & Mair, 2010), less educated people are more likely to live in disadvantaged physical (e.g., poor-maintained facilities, lack of aesthetic, and natural spaces) and social environments (e.g., unsafe and isolated areas), which could contribute to their lack of engagement in physical activity (Cheval et al., 2019; Rees-Punia et al., 2018; Xiao et al., 2018).

In addition to these mechanisms, cognitive function is a potential candidate to mediate the association between education and physical activity. On the one hand, previous studies and meta-analyses showed that higher levels of education were associated with better cognitive function (Aartsen et al., 2019; Anstey & Christensen, 2000; Avila et al., 2009; Lenehan et al., 2015; Opdebeeck et al., 2016; Schneeweis et al., 2014). On the other hand, studies showed that better cognitive function predicted higher engagement in physical activity (Cheval, Boisgontier, et al., 2022; Cheval, Csajbók, et al., 2021; Cheval, Orsholits, et al., 2020; Daly et al., 2015; Sabia et al., 2017). According to the theory of effort minimization in physical activity (TEMPA; Cheval & Boisgontier, 2021), this latter association is explained by the fact that cognitive function is considered necessary to counteract the innate human attraction to effort minimization (Cheval & Boisgontier, 2021; Cheval et al., 2017; Cheval, Radel, et al., 2018; Klein-Flügge et al., 2016; Lieberman, 2015; Prévost et al., 2010). In line with this view and consistent with epidemiological and neurobehavioral evidence, experimental studies have demonstrated that cognitive function is crucial in inhibiting this automatic attraction to physical inactivity and in promoting regular engagement in physical activity (Cheval, Cabral, et al., 2021; Cheval, Daou, et al., 2020; Cheval, Tipura, et al., 2018). In sum, existing literature suggests that cognitive function could underlie the association between education and physical activity. However, to the best of our knowledge, no study has directly investigated this potential mediation.

In addition, studies showed that physical activity enhances cognitive function (Blondell et al., 2014; Cheval, Darrous, et al., 2023; Hamer et al., 2018; Hillman et al., 2008), suggesting a reciprocal relationship between these variables (Cheval, Orsholits, et al., 2020; Csajbók et al., 2022). However, recent studies based on the Survey of Health, Ageing, and Retirement in Europe (SHARE) data set formally tested these bidirectional associations using bivariant latent change score models (Cheval, Orsholits, et al., 2020) and longitudinal mediation models combined with autoregressive cross-lagged models (Csajbók et al., 2022). Results showed that changes in cognitive function mainly preceded changes in physical activity. Yet, the effect from physical activity to cognitive function was also significant, albeit weaker. These results suggest a detrimental circular effect between cognitive decline and physical inactivity, with lower cognitive function increasing physical inactivity, which in turn further increase cognitive decline. Here, we focused on the potential mediating role of cognitive function in the relationship between academic education and physical activity (i.e., education → cognitive function → physical activity). To provide a finer grained understanding of the mechanisms underlying this potential mediation, two aspects of cognitive function were considered (initial status and change). This approach allowed disentangling the mediation effects of baseline level and growth in the cognitive function.

The objective of our study was to examine whether initial status and change in cognitive function mediate the relationship between education and change in physical activity in adults 50 years of age or older. Based on previous literature, we hypothesized that higher levels and slower decline in cognitive function mediate the relationship between academic education and physical activity over time.

Method

Transparency and Openness

The SHARE data set used for this study is publicly available at http://www.share-project.org/data-access.html (Börsch-Supan, 2022a, 2022b, 2022c, 2022d, 2022e, 2022f, 2022g). The code of the analyses is available at https://zenodo.org/deposit/7520036. Please see Author note section for details. The hypotheses and analyses were not

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preregistered but are part of a larger project aiming to understand the life course influences on health trajectories at older age.

Participants and Study Design

Data were drawn from SHARE, a longitudinal population-based study of adults 50 years of age or older living in 27 European countries and one middle east country (Börsch-Supan et al., 2013). Data were collected every 2 years between 2004 and 2019, with a total of eight measurement waves using computer-assisted personal interviews in participants' homes. Physical activity and cognitive function (delayed recall and verbal fluency) were assessed in all measurement waves except Wave 3 (2008–2009). Academic education level was measured when participants were first included in the study. The SHARE study was approved by the relevant research ethics committees in the participating countries, and all participants provided written informed consent. To be included in the analyses, at least one measure of physical activity, one measure of cognitive function, and indicated their education level was required. We excluded individuals with suspected dementia at baseline ($N = 3{,}089$), as indicated by a score above two on the time-orientation question (Aartsen et al., 2019), and individuals who reported more than two limitations in activities of daily living at baseline ($N = 10{,}546$).

Measures

Outcome: Physical Activity

Physical activity was derived from the following question: "How often do you engage in activities that require a low or moderate level of energy such as gardening, cleaning the car, or going for a walk?" (Boisgontier et al., 2020; Cheval et al., 2019; Cheval, Orsholits, et al., 2020; de Souto Barreto et al., 2017). Participants responded using a 4-point scale: 1 = *more than once a week*; 2 = *once a week*; 3 = *one to three times a month*; 4 = *hardly ever or never*. In the models, this measure was treated as continuous and ranged from 0 to 3.

Predictor Variable: Education

The level of education was based on the United Nations Educational, Scientific and Cultural Organization's International Standard Classification of Education (ISCED; United Nations Educational, 2006) differentiating primary (ISCED Levels 0 and 1), secondary (ISCED Levels 2 to 4), and tertiary level of education (ISCED Levels 5 and 6; Cullati et al., 2018). In the models, this measure was treated as continuous and ranged from 0 to 2.

Mediating Variables: Cognitive Function

Cognitive function was assessed using two indicators including delayed recall and verbal fluency. Delayed recall is a reliable predictive measure of the development of dementia (Sano et al., 2011; Zhao et al., 2012) and was extracted from an adapted 10-word delayed recall test (Harris & Dowson, 1982). First, participants listened to a list of 10 words that were read out loud by the interviewer. Then, they were immediately asked to recall as many words as possible. At the end of the cognitive testing session, the participants were asked to recall the words from the list a second time, which captured a delayed recall score. This score ranged from 0 to 10, with higher scores indicating a better cognitive function. In the verbal fluency test (Rosen, 1980), the interviewer asked participants to name as many different animals as they could think of in 1 min. The score was the total number of correctly named animals, with a higher score indicating better performance.

Covariates

All the models were adjusted for age group (50–64, 65–79, 80–96 years) and sex (male, female). Note that health-related variables (e.g., depressive symptoms, self-rated health) were not included because they could reasonably be considered colliders based on causal graphs.

Statistical Analysis

First, growth curve models were used to estimate the evolution of the indicators of cognitive function and physical activity across the waves of measurement. These models were adjusted for age group (50–64, 65–79, 80–96 years), sex (male, female), and the level of education. Then, the mediating role of cognitive function on the association between education and physical activity was analyzed using longitudinal mediation analyses combined with growth curve models (von Soest & Hagtvet, 2011). The mediating paths were defined as follows: Academic education (time-invariant exogenous variable) predicted the initial status (intercept) of cognitive function (*Path a1*), which predicted the change (slope) in physical activity (*Path b1*). In addition, academic education predicted the change in cognitive function (*Path a2*), which predicted the change in physical activity (*Path b2*). A direct effect from education to change in physical activity was included (c'). Since the initial status of physical activity was likely to be correlated with its subsequent change in physical activity, a path from initial status of physical activity to change in physical activity was included. This path allowed estimating differences in physical activity changes as a function of education while adjusting for differences in initial status (Seltzer et al., 2003; von Soest & Hagtvet, 2011). In other words, this path allowed us to obtain a mediation analysis that was not confounded by differences in the initial status of the dependent variable (Littlefield et al., 2010). The equations of the models using the terminology of von Soest and Hagtvet (2011) are as follows:

$$\gamma_{it} = \alpha_{iy} + \beta_{iy}\lambda_t + \varepsilon_{yit}, \tag{1}$$

$$\alpha_{i\omega} = \mu_{\alpha\omega} + y_{\alpha\omega}\chi_i + \zeta_{\alpha\omega i}, \tag{2}$$

$$\beta_{i\omega} = \mu_{\beta\omega} + y_{\beta\omega}\chi_i + \zeta_{\beta\omega i}, \tag{3}$$

$$\beta_{iy} = \mu_{\beta y} + \delta_{\alpha y}\alpha_{iy} + \delta_{\alpha\omega}\alpha_{i\omega} + \delta_{\beta\omega}\beta_{i\omega} + \gamma_{\beta y'}\chi_i + \zeta_{\beta y i}. \tag{4}$$

In Equation 1, γ identifies all parameters predicting, γ_{it} i represents the individual, and t represents the time points. Thus, γ_{it} is the value of the trajectory of the outcome variable (i.e., physical activity) for individual i at Time t. α_{iy} is the random intercept for every individual i. β_{iy} is the random slope for every individual i. λ_t is a parameter used to identify time. ε_{yit} is the error term at each time point for each individual.

In Equation 2, $\mu_{\alpha\varepsilon}$ is the intercept of the equation that predicts the random intercept $\alpha_{i\omega}$ of the mediating variable (i.e., cognitive function), $y_{\alpha\omega}$ is the coefficient of regression of the predictor variable (i.e., education), $\zeta_{\alpha\omega}$ is the error term, χ_i is the predictor variable (i.e., education), and i identifies individuals' data points.

In Equation 3, $\mu_{\beta\omega}$ is the intercept of the equation that predict the random slope of the mediating variable $\beta_{i\omega}$, $y_{\beta\omega}$ is the regression coefficient of the predictor variable, $\zeta_{\beta\omega i}$ is the error term.

In Equation 4, $\mu_{\beta y}$ is the intercept of the equation that predicts the random slope β_{iy} of the dependent variable (i.e., physical activity). The slope of the dependent variable is predicted by the predictor variable (i.e., education) χ_i and the random intercept of the mediating variable $\alpha_{i\omega}$. $\gamma_{\beta y'}$ is the regression coefficient for the predictor variable. δαω is the regression coefficient for the intercept of the mediating variable. $\delta_{\beta\omega}$ is the regression coefficient from the slope of the mediating variable to the slope of the dependent variable. $\delta_{\alpha y}$ is the coefficient for the regression of the slope of the dependent variable on its own intercept $\alpha_{iy.}$ $\zeta_{\beta yi}$ represents the error term. Thus, in Model 3, $\gamma_{\beta y'}$ represents the expected difference in physical activity growth rates as a function of the level of education and adjusted for differences in initial physical activity levels. The longitudinal mediation model is illustrated in Figure 1.

Indirect effects at the intercept levels (indirect $L = y_{\alpha\omega} \times \delta_{\alpha\omega}$) and slope levels (indirect $S = y_{\beta\omega} \times \delta_{\beta\omega}$), as well as the total effect ($\gamma_{\beta\gamma} = \gamma_{\beta y'} + y_{\alpha\omega} \times \delta_{\alpha\omega} + y_{\beta\omega} \times \delta_{\beta\omega}$) were estimated using maximum likelihood estimator and full information maximum likelihood estimation for the missing values (Maydeu-Olivares, 2017). The proportions of the total effects explained by the mediating variable at the intercept and slope levels were calculated by subtracting the direct effect ($\gamma_{\beta y'}$) from the total effect ($\gamma_{\beta y}$), and then dividing the result by the total effect (i.e., [total effect −direct effect]/total effect). The analyses were performed with the lavaan R package (Rosseel, 2012). The percentage of variance explained in the slope of physical activity were computed in lavaan.

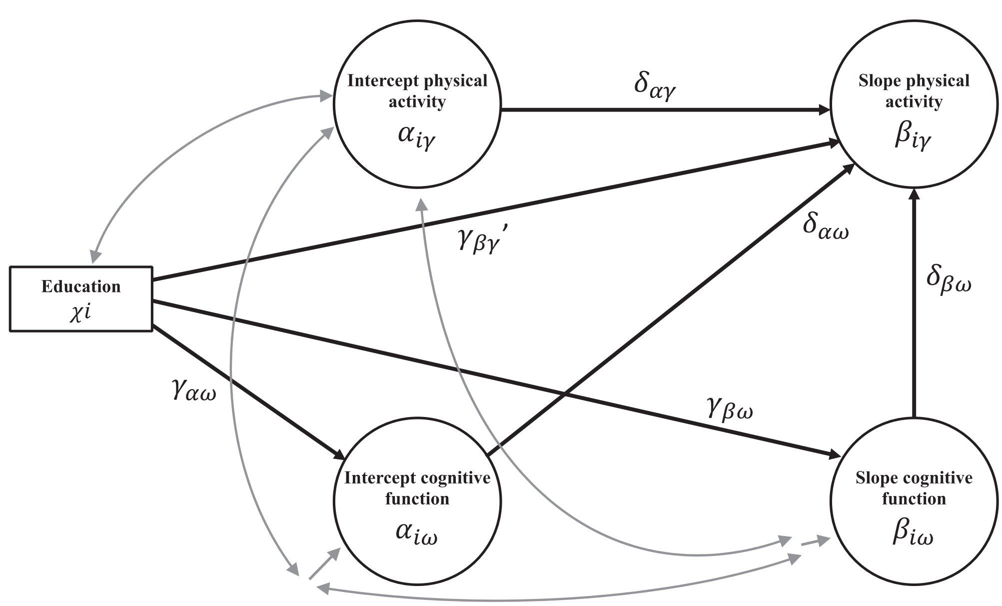
Sensitivity Analyses

Two sensitivity analyses were conducted. In the first sensitivity analysis, two additional paths were specified in the model (i.e., from education to the intercept of physical activity and from the intercept of cognitive function to the slope of cognitive function). These paths were added to check that the main findings were not biased by the absence of these direct paths. Second, to satisfy the temporal precedence between the slope of cognitive function and the slope of physical activity, we created a time lag between cognitive function (i.e., the mediator) and physical activity (i.e., the outcome). Accordingly, the slope of the cognitive function was estimated before the slope of physical activity, thereby satisfying the causal condition of temporal precedence between the mediator and the dependent variable (Cheong et al., 2003; MacKinnon, 2012).

Results

The scripts for data management (i.e., from raw data to data used in the analyses) and for the models tested are available at https://zenodo.org/deposit/7520036. In addition, the complete results of the models are included in the Supplemental Material.

Figure 1
Tested Longitudinal Mediation Model Combined With Growth Curve Models



Note. Education is the predictor variable. Cognitive function (i.e., delayed recall or verbal fluency) is the mediating variable. Physical activity is the dependent variable. This model tests whether the intercept and the slope of cognitive function mediate the association between education and change in physical activity.

Descriptive Results

A total of 105,939 participants (55% women) were included in the sample. Table 1 presents the characteristics of the participants stratified by education level. Simple association tests showed that participants with higher levels of education had better cognitive function, higher levels of physical activity, were younger, and more likely to be a man ($p < .001$). Moreover, during follow-up, 10,043 (9.5%) participants died, 35,179 (33.2%) dropped out (i.e., did not respond to Wave 7 or 8), and 60,717 (57.3%) continued to participate in the study. On average, participants had 2–3 repeated measures of cognitive function and physical activity. More specifically, 37,434, 25,293, 19,032, 12,417, 4,678, 4,213, and 2,872, responded to one, two, three, four, five, six, and seven waves of measurement, respectively.

Growth Curves Models

Physical Activity

Results of the growth curves model adjusted for age group (ref. 50–64 years), gender (ref. women), and the level of education (ref. primary) showed a significant latent intercept (b = 2.459, 95% confidence interval [95% CI 2.442, 2.476], $p < .001$) and a significant negative latent slope (b = −0.030, 95% CI [−0.034, 0.026], $p < .001$), indicating a decrease in the level of physical activity over time. The negative latent slope was more than twice higher in adults 65–79 years of age (b = −0.069, 95% CI [−0.073, −0.065], $p < .001$) and was more than thrice higher in adults 80–96 years of age (b = −0.100, 95% CI [−0.109, 0.091], $p < .001$).

Delayed Recall

Results of the growth curves model adjusted for age group (ref. 50–64 years), gender (ref. women), and the level of education (ref. primary) showed a significant latent intercept (b = 3.491, 95% CI [3.458, 3.525], $p < .001$) and a significant positive latent slope (b = 0.011, 95% CI [0.004, 0.0019], $p = .002$), indicating an increase in the level of delayed recall across time in adults 50–64 years of age. However, a significant negative latent slope was observed in adults 65–79 (b = −0.069, 95% CI [−0.076, −0.061], $p < .001$) and 80–96 years of age (b = −0.086, 95% CI [−0.104, −0.068], $p < .001$).

Verbal Fluency

Results of the growth curves model adjusted for age group (ref. 50–64 years), gender (ref. women), and the level of education (ref. primary) showed a significant latent intercept (b = 1.727, 95% CI [1.715, 1.738], $p < .001$), but a nonsignificant latent slope (b = 0.001, 95% CI [−0.001, 0.003], $p < .001$), indicating no significant change in the level of verbal fluency across time in adults 50–64 years of age. However, a significant negative latent slope was observed in adults 65–79 (b = −0.029, 95% CI [−0.031, −0.026], $p < .001$) and 80–96 years of age (b = −0.043, 95% CI [−0.049, −0.037], $p < .001$).

Longitudinal Mediation Analyses

Table 2 and Figure 2 show the results of the longitudinal mediation analyses combined with growth curve models.

Delayed Recall

We observed a significant association of education with the intercept of delayed recall ($y_{\alpha\omega}$ = 0.809, 95% CI [0.786, 0.832], $p < .001$) and a significant association of the intercept of delayed recall with the slope of physical activity ($\delta_{\alpha\omega}$ = 0.010, 95% CI [0.008, 0.012], $p < .001$). Thus, the intercept of delayed recall mediated the association between education and the slope in physical activity, as confirmed by a significant indirect effect at this intercept level (indirect effect L = 0.008, 95% CI [0.007, 0.010], $p < .001$). In addition, results showed a significant association of education with the slope of delayed recall ($y_{\beta\omega}$ = 0.023, 95% CI [0.018, 0.028], $p < .001$), as well as a significant association of the slope of delayed recall with the slope of physical activity ($\delta_{\beta\omega}$ = 0.159, 95% CI [0.140, 0.178], $p < .001$). Thus, the slope of delayed recall mediated the association between education and the slope in physical activity, as confirmed by a significant indirect effect at this slope level (indirect effect S = 0.004, 95% CI [0.003, 0.005], $p < .001$). The total effect was significant (b = 0.023, 95% CI [0.023,

Table 1
Baseline Characteristics of the Participants Across Levels of Education

N = 105,939	Primary level of education (N = 22,526)	Secondary level of education (N = 59,883)	Tertiary level of education (N = 23,530)	p value
Outcome: physical activity	2.3 ± 1.1	2.5 ± 0.9	2.6 ± 0.8	<.001
Mediator: cognitive function				
Delayed recall, $M \pm SD$	2.7 ± 1.8	3.8 ± 2.0	4.7 ± 2.0	<.001
Verbal fluency, $M \pm SD$	15.4 ± 5.9	20.2 ± 6.9	23.4 ± 7.4	<.001
Covariates				
Age, n (%)				
50–64	9,042 (40.1)	37,852 (63.2)	15,565 (66.2)	
65–79	10,949 (48.6)	19,221 (32.1)	7,038 (29.9)	
80–96	2,535 (11.3)	2,810 (4.7)	927 (3.9)	<.001
Gender				
Women, n (%)	13,179 (58.5)	32,369 (54.1)	11,669 (49.6)	
Men, n (%)	9,347 (41.5)	27,514 (45.9)	11,831 (50.4)	<.001

Note. Baseline = first measurement for each participant; p values are based on the analysis of variance and chi-square tests for continuous and categorical variables, respectively, testing the effect of education.

Table 2
Results of Longitudinal Mediation Analyses Combined With Growth Curve Models

N = 105,939	Model: delayed recall		Model: verbal fluency	
	b [95% CI]	p	b [95% CI]	p
Slope physical activity (β_{iy})				
Intercept physical activity ($\delta_{\alpha y}$)	−0.087 [−0.093, −0.081]	<.001	−0.080 [−0.087, −0.074]	<.001
Education ($\gamma_{\beta y'}$)	0.013 [0.011, 0.015]	<.001	0.010 [0.007, 0.012]	<.001
Intercept mediator ($\delta_{\alpha\omega}$)	0.010 [0.008, 0.012]	<.001	0.032 [0.018, 0.037]	<.001
Slope mediator ($\delta_{\beta\omega}$)	0.159 [0.140, 0.178]	<.001	0.782 [0.719, 0.844]	<.001
Age (ref. 50–64)				
65–79	−0.021 [−0.024, −0.018]	<.001	−0.014 [−0.017, −0.012]	<.001
80–96	−0.067 [−0.075, −0.060]	<.001	−0.051 [−0.059, −0.043]	<.001
Sex (ref. women)				
Men	0.009 [0.007, 0.012]	<.001	0.006 [0.004, 0.009]	<.001
Intercept mediator ($\alpha_{i\omega}$)				
Education ($y_{\alpha\omega}$)	0.809 [0.786, 0.832]	<.001	0.365 [0.357, 0.373]	<.001
Age (ref. 50–64)				
65–79	−0.596 [−0.629, −0.563]	<.001	−0.125 [−0.137, −0.113]	<.001
80–96	−1.458 [−1.533, −1.382]	<.001	−0.318 [−0.345, −0.292]	<.001
Sex (ref. women)				
Men	−0.415 [−0.446, −0.384]	<.001	−0.016 [−0.027, −0.006]	.003
Slope mediator ($\beta_{i\omega}$)				
Education ($y_{\beta\omega}$)	0.023 [0.018, 0.028]	<.001	0.002 [0.001, 0.004]	.005
Age (ref. 50–64)				
65–79	−0.085 [−0.092, −0.078]	<.001	−0.031 [−0.033, −0.028]	<.001
80–96	−0.115 [−0.133, −0.097]	<.001	−0.050 [−0.056, −0.044]	<.001
Sex (ref. women)				
Men	0.002 [−0.004, 0.009]	.511	−0.001 [−0.003, 0.002]	.609
Intercept physical activity (α_{iy})				
Age (ref. 50–64)				
65–79	−0.006 [−0.023, 0.012]	.523	−0.001 [−0.018, 0.017]	.970
80–96	−0.304 [−0.342, −0.265]	<.001	−0.295 [−0.333, −0.256]	<.001
Sex (ref. women)				
Men	0.038 [0.022, 0.054]	<.001	0.036 [0.020, 0.052]	<.001
Indirect effects				
Indirect effect 1 (intercept) ($y_{\alpha\omega} \times \delta_{\alpha\omega}$)	0.008 [0.007, 0.010]	<.001	0.012 [0.010, 0.013]	<.001
Indirect effect 2 (slope) ($y_{\beta\omega} \times \delta_{\beta\omega}$)	0.004 [0.003, 0.005]	<.001	0.002 [0.001, 0.003]	.005
Total effect				
$\gamma_{\beta\gamma}$ ($\gamma_{\beta y'} + y_{\alpha\omega} \times \delta_{\alpha\omega} + y_{\beta\omega} \times \delta_{\beta\omega}$)	0.025 [0.023, 0.027]	<.001	0.024 [0.021, 0.026]	<.001

Note. 95% CI = confidence interval at 95%. The score of verbal fluency was divided by ten to facilitate the convergence of the models.

0.027], $p < .001$). Academic education remained significantly associated with change in physical activity after adjustment for delayed recall ($\gamma_{\beta y'} = 0.013$, 95% CI [0.011, 0.015], $p < .001$), suggesting a partial mediation. Specifically, the percentage of the total effect of education on the slope in physical activity that was mediated by the intercept and the slope of delayed recall was 48% (32% at was mediated at the intercept level, and 16% at the slope level). The model explained 33.5% of the variance in the slope in physical activity.

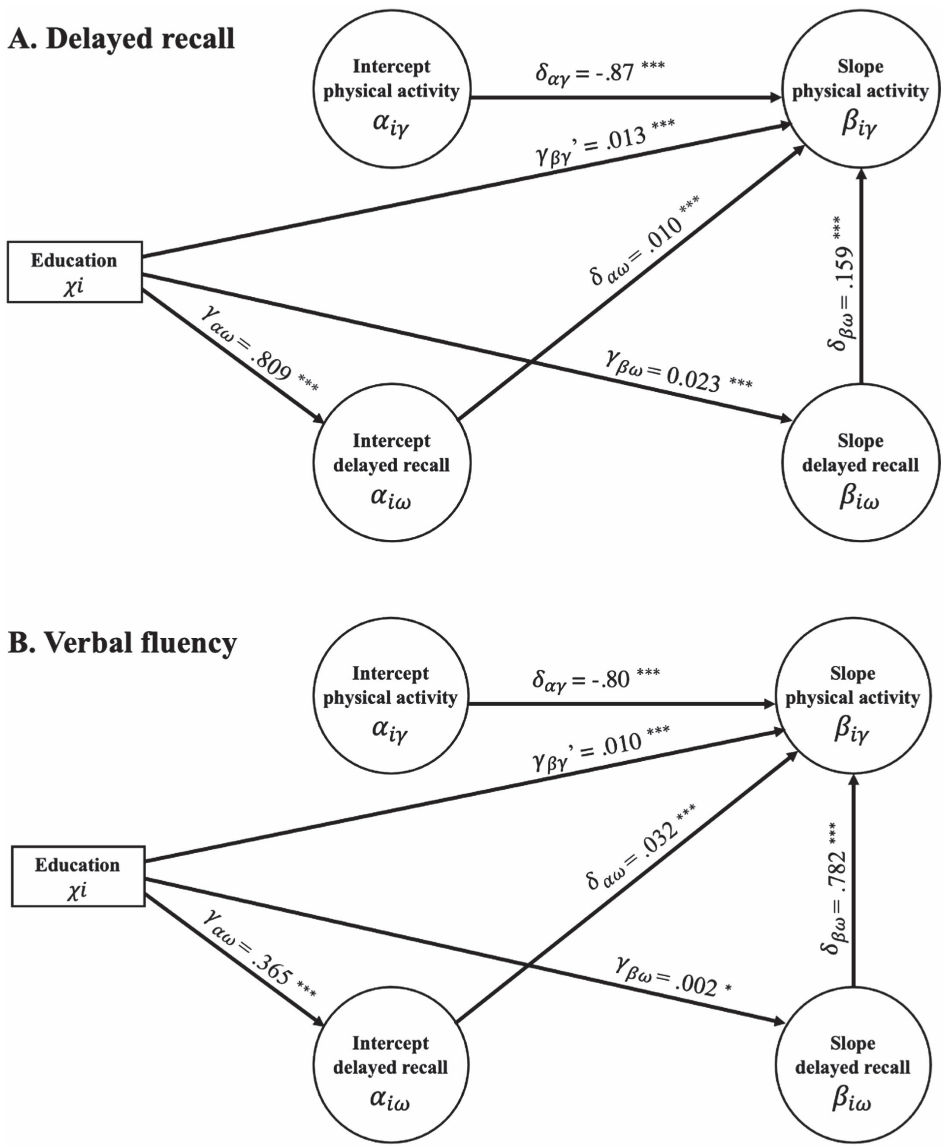
Verbal Fluency

We observed a significant association of education with the intercept of verbal fluency ($y_{\alpha\omega} = 0.365$, 95% CI [0.357, 0.373], $p < .001$) and a significant association of the intercept of verbal fluency with the slope of physical activity ($\delta_{\alpha\omega} = 0.032$, 95% CI [0.018, 0.037], $p < .001$). Thus, the intercept of verbal fluency mediated the association between education and the slope in physical activity, as confirmed by a significant indirect effect at this intercept level (Indirect Effect 1 = 0.012, 95% CI [0.010, 0.013], $p < .001$). In addition, results showed a significant association of education with the slope of verbal fluency ($y_{\beta\omega} = 0.002$, 95% CI [0.001, 0.004], $p = .005$), as well as a significant association of the slope of verbal fluency with the slope of physical activity ($\delta_{\beta\omega} = 0.782$, 95% CI [0.719, 0.844], $p < .001$). Thus, the slope of verbal fluency mediated the association between education and the slope in physical activity, as confirmed by a significant indirect effect at this slope level (Indirect Effect 2 = 0.002, 95% CI [0.001, 0.003], $p = .005$). The total effect was significant ($b = 0.024$, 95% CI [0.021, 0.026], $p < .001$). Education remained significantly associated with change in physical activity after adjustment for verbal fluency ($\gamma_{\beta y'} = 0.010$, 95% CI [0.007, 0.012], $p < .001$), suggesting a partial mediation. Specifically, the percentage of the total effect of education on the slope in physical activity that was mediated by the intercept and the slope of verbal was 58.3% (50% at was mediated at the intercept level, and 8.3% at the slope level). The model explained 43.9% of the variance in the slope in physical activity.

Sensitivity Analyses

Table 3 shows the results of the sensitivity analysis in which two additional paths were included in the model (i.e., from education to

Figure 2
Results of the Longitudinal Mediation Models Combined With Growth Curve Models



* $p = .05$. *** $p < .001$.

the intercept of physical activity and from the intercept of cognitive function to the slope of cognitive function). Results were consistent with the main analyses. Specifically, the indirect effects of education on change in physical activity through both the intercept and the slope of delayed recall were significant. Education remained significantly associated with change in physical activity after adjusting for delayed recall ($\gamma_{\beta y'} = 0.010$, 95% CI [0.007, 0.012], $p < .001$), suggesting a partial mediation. Specifically, the percentage of the total effect of education on the slope in physical activity that was mediated by the intercept and the slope of delayed recall was 68.7%. For verbal fluency, education remained significantly associated with change in physical activity after adjustment for verbal fluency ($\gamma_{\beta y'} = 0.013$, 95% CI [0.011, 0.015], $p < .001$), suggesting a partial mediation. Specifically, the percentage of the total effect of education on the slope in physical activity that was mediated by the intercept and the slope of verbal fluency was 53.3%.

Table 4 shows the results of the sensitivity analysis in which a time lag was introduced between cognitive function and physical activity.

The sensitivity analyses yielded results that were consistent with the main analyses. Specifically, the indirect effects of education on change in physical activity through both the intercept and the slope of delayed recall were significant. Education remained significantly associated with change in physical activity after adjusting for delayed recall ($\gamma_{\beta y'} = 0.017$, 95% CI [0.012, 0.022], $p < .001$), suggesting a partial mediation. Specifically, the percentage of the total effect of education on the slope in physical activity that was mediated by the intercept and the slope of delayed recall was 39.3%.

Table 3

Results of Longitudinal Mediation Analyses Combined With Growth Curve Models With Two Additional Paths Added in the Models

N = 105,939	Model: delayed recall		Model: verbal fluency	
	b [95% CI]	p	b [95% CI]	p
Slope physical activity (β_{iy})				
Intercept physical activity ($\delta_{\alpha y}$)	−0.087 [−0.093, −0.081]	<.001	−0.080 [−0.087, −0.074]	<.001
Education ($\gamma_{\beta y'}$)	0.013 [0.011, 0.015]	<.001	0.010 [0.007, 0.012]	<.001
Intercept mediator ($\delta_{\alpha\omega}$)	0.010 [0.008, 0.012]	<.001	0.032 [0.028, 0.037]	<.001
Slope mediator ($\delta_{\beta\omega}$)	0.159 [0.140, 0.178]	<.001	0.782 [0.719, 0.844]	<.001
Age (ref. 50–64)				
65–79	−0.021 [−0.024, −0.018]	<.001	−0.014 [−0.017, −0.010]	<.001
80–96	−0.067 [−0.075, −0.060]	<.001	−0.051 [−0.059, −0.043]	<.001
Sex (ref. women)				
Men	0.009 [0.007, 0.012]	<.001	0.006 [0.004, 0.009]	<.001
Intercept mediator ($\alpha_{i\omega}$)				
Education ($y_{\alpha\omega}$)	0.809 [0.786, 0.832]	<.001	0.365 [0.357, 0.373]	<.001
Age (ref. 50–64)				
65–79	−0.596 [−0.630, −0.563]	<.001	−0.125 [−0.137, −0.113]	<.001
80–96	−1.458 [−1.533, −1.382]	<.001	−0.318 [−0.345, −0.292]	<.001
Sex (ref. women)				
Men	−0.415 [−0.446, −0.384]	<.001	−0.016 [−0.027, −0.006]	.003
Slope mediator ($\beta_{i\omega}$)				
Intercept mediator	−0.036 [−0.041, −0.032]	<.001	−0.029 [−0.032, −0.026]	<.001
Education ($y_{\beta\omega}$)	0.053 [0.047, 0.059]	<.001	0.013 [0.011, 0.015]	<.001
Age (ref. 50–64)				
65–79	−0.106 [−0.113, −0.099]	<.001	−0.034 [−0.036, −0.032]	<.001
80–96	−0.168 [−0.185, −0.151]	<.001	−0.059 [−0.064, −0.053]	<.001
Sex (ref. women)				
Men	−0.013 [−0.019, −0.007]	<.001	−0.001 [−0.003, 0.001]	.301
Intercept physical activity (α_{iy})				
Education	0.101 [0.089, 0.113]	<.001	0.105 [0.093, 0.117]	<.001
Age (ref. 50–64)				
65–79	−0.006 [−0.023, 0.012]	.524	−0.001 [−0.018, 0.017]	.972
80–96	−0.304 [−0.342, −0.265]	<.001	−0.295 [−0.333, −0.256]	<.001
Sex (ref. women)				
Men	0.038 [0.022, 0.054]	<.001	0.036 [0.020, 0.052]	<.001
Indirect effects				
Indirect effect 1 (intercept) ($y_{\alpha\omega} \times \delta_{\alpha\omega}$)	0.008 [0.007, 0.010]	<.001	0.012 [0.010, 0.013]	<.001
Indirect effect 2 (slope) ($y_{\beta\omega} \times \delta_{\beta\omega}$)	0.008 [0.007, 0.010]	<.001	0.010 [0.009, 0.012]	<.001
Total effects				
$\gamma_{\beta\gamma}$ ($\gamma_{\beta y'} + y_{\alpha\omega} \times \delta_{\alpha\omega} + y_{\beta\omega} \times \delta_{\beta\omega}$)	0.030 [0.027, 0.032]	<.001	0.032 [0.030, 0.034]	<.001

Note. 95% CI = confidence interval at 95%. The score of verbal fluency was divided by ten to facilitate the convergence of the models.

For verbal fluency, the result patterns were identical to the main results, although the indirect effect of education through the intercept of verbal fluency did not reach significance (p = .053) because the initial status of verbal fluency was not significantly associated with the change in physical activity ($\delta_{\alpha\omega}$ = 0.009, 95% CI [−0.001, 0.018], p = .053). Consistent with the main analysis, education remained significantly associated with change in physical activity after adjustment for verbal fluency ($\gamma_{\beta y'}$ = 0.020, 95% CI [0.015, 0.025], p < .001), suggesting a partial mediation. Specifically, the percentage of the total effect of education on the slope in physical activity that was mediated by the intercept and the slope of verbal fluency was 28.6%.

Discussion

Main Findings

This large-scale study of European adults aged 50 years or older revealed that the association between education level and change in physical activity behavior was explained not only by the initial status of cognitive function, but also its change across time. Higher educational level was associated with a higher initial status and a slower decline of cognitive function, which in turn slowed down the decline in physical activity. Education level remained significantly associated with physical activity after adjustment for cognitive function, suggesting that additional mechanisms may explain the relationship between academic education and physical activity. Hence, our study lends support for the long-lasting effect of education on cognitive function and, consequently, on physical activity. In this section, we discuss our results in the context of previous literature, elaborate on the mechanisms likely to explain the observed associations, and provide some limiting conditions to our findings.

Comparison With Previous Studies

Our results revealed an association between education and physical activity that is consistent with earlier evidence indicating that

Table 4

Results of Longitudinal Mediation Analyses Combined With Growth Curve Models With a Temporal Lag Between Cognitive Function and Physical Activity

N = 59,194	Model: delayed recall b [95% CI]	p	Model: verbal fluency b [95% CI]	p
Slope physical activity (β_{iy})				
Intercept physical activity ($\delta_{\alpha y}$)	−0.073 [−0.084, −0.062]	<.001	−0.078 [−0.089, −0.067]	<.001
Education ($\gamma_{\beta y'}$)	0.017 [0.012, 0.022]	<.001	0.020 [0.015, 0.025]	<.001
Intercept mediator ($\delta_{\alpha\omega}$)	0.005 [0.001, 0.009]	.007	0.009 [−0.001, 0.018]	.053
Slope mediator ($\delta_{\beta\omega}$)	0.172 [0.137, 0.207]	<.001	0.786 [0.639, 0.932]	<.001
Age (ref. 50–64)				
65–79	−0.032 [−0.039, −0.025]	<.001	−0.031 [−0.038, −0.024]	<.001
80–96	−0.064 [−0.081, −0.047]	<.001	−0.063 [−0.081, −0.045]	<.001
Sex (ref. women)				
Men	0.008 [0.002, 0.014]	.006	0.009 [0.003, 0.015]	.002
Intercept mediator ($\alpha_{i\omega}$)				
Education ($y_{\alpha\omega}$)	0.789 [0.757, 0.821]	<.001	0.373 [0.362, 0.384]	<.001
Age (ref. 50–64)				
65–79	−0.550 [−0.598, −0.503]	<.001	−0.127 [−0.143, −0.111]	<.001
80–96	−1.353 [−1.471, −1.235]	<.001	−0.308 [−0.348, −0.268]	<.001
Sex (ref. women)				
Men	−0.438 [−0.482, −0.393]	<.001	−0.018 [−0.032, −0.003]	.019
Slope mediator ($\beta_{i\omega}$)				
Education ($y_{\beta\omega}$)	0.040 [0.032, 0.049]	<.001	0.006 [0.003, 0.009]	<.001
Age (ref. 50–64)				
65–79	−0.101 [−0.114, −0.088]	<.001	−0.026 [−0.030, −0.022]	<.001
80–96	−0.146 [−0.181, −0.110]	<.001	−0.042 [−0.054, −0.031]	<.001
Sex (ref. women)				
Men	−0.002 [−0.014, 0.010]	.726	−0.004 [−0.007, 0.001]	.064
Intercept physical activity (α_{iy})				
Age (ref. 50–64)				
65–79	−0.070 [−0.096, −0.045]	<.001	−0.068 [−0.094, −0.043]	<.001
80–96	−0.546 [−0.609, −0.783]	<.001	−0.545 [−0.608, −0.483]	<.001
Sex (ref. women)				
Men	0.040 [0.017, 0.064]	.001	0.038 [0.014, 0.062]	.002
Indirect effects				
Indirect effect 1 (intercept) ($y_{\alpha\omega} \times \delta_{\alpha\omega}$)	0.004 [0.001, 0.007]	.007	0.003 [−0.001, 0.007]	.053
Indirect effect 2 (slope) ($y_{\beta\omega} \times \delta_{\beta\omega}$)	0.007 [0.005, 0.009]	<.001	0.005 [0.002, 0.007]	<.001
Total effects				
$\gamma_{\beta\gamma}$ ($\gamma_{\beta y'} + y_{\alpha\omega} \times \delta_{\alpha\omega} + y_{\beta\omega} \times \delta_{\beta\omega}$)	0.028 [0.024, 0.032]	<.001	0.028 [0.024, 0.032]	<.001

Note. 95% CI = confidence interval at 95%. The score of verbal fluency was divided by ten to facilitate the convergence of the models.

individuals with a higher level of education are more likely to engage in a wide range of health-protective behaviors (Conti et al., 2010; Eide & Showalter, 2011; Silles, 2009; Zajacova & Lawrence, 2018), including physical activity (Chalabaev et al., 2022; Cheval, Sieber, et al., 2018; Droomers et al., 2001; Kari et al., 2020). The link between education and a sustained engagement in health behaviors can be explained by several mechanisms, including, but not limited to, increased knowledge of the health recommendations (i.e., health literacy; Friis et al., 2016; Levin-Zamir et al., 2016; Sun et al., 2013; Van Der Heide et al., 2013), a greater motivation or ability to engage in protective health behaviors (Osborn et al., 2011; Torres & Marks, 2009; Verhoeven & Snow, 2001), and better physical and social conditions (Cheval et al., 2019; Diez Roux & Mair, 2010; Rees-Punia et al., 2018; Xiao et al., 2018). Here, we demonstrate, for the first time, that this association could be underpinned by improved cognitive function. Importantly, the implementation of longitudinal mediation analyses combined with growth curve models revealed that both a higher initial status and a slower decline in cognitive function could explain the positive association between higher academic education and a slower decline in physical activity.

These findings contrast with existing literature that failed to robustly demonstrate an association between education and the rate of change in cognitive function in old age (Lövdén et al., 2020). Specifically, the previous literature suggests positive effects of educational attainment on cognitive function level, but also shows weak evidence, at best, of an association between education and cognitive decline in old age. These findings suggest that educational attainment may primarily affect late-life cognitive function through its influence on the level of cognitive function during early adulthood. Note, however, that according to the Strachan-Sheikh model of life course functioning (Vineis et al., 2016), while early life exposures (such as education) are expected to strongly impact the highest level of health functioning, they are also expected to influence aging trajectories. To explain our results suggesting an association between educational attainment and cognitive decline in old age, some features of our methods could be put forth as they increased the statistical power of our study compared to the previous literature. Specifically, Hertzog et al. (2006) argued that a lower statistical power to detect individual differences in change (vs. to detect individuals differences in the levels of cognitive function) could result from a combination of a rather limited change in cognitive function during adulthood until older age and a small number of longitudinal waves covering a relatively short time period (Brandmaier et al., 2018; Ghisletta et al., 2020). Noteworthy, our study combines a large-sample size (i.e., $n > 100{,}000$), a high number of measurements with a short time intervals (up to eight measurements with an average 2-year interval between waves), and a long follow-up (i.e., up to 15 year). These methodological features contributed to increase statistical power and our ability to detect significant associations. In addition, we used two indicators of cognitive function (i.e., delayed recall and verbal fluency), representing tow cognitive domains (Harvey, 2019), that yield consistent results. Note, however, that word-fluency tasks typically require a mixture of fluid (e.g., processing speed) and crystalized (e.g., word knowledge) cognitive abilities (Salthouse, 2005). With aging, fluid cognitive abilities typically become slower and less efficient (Baltes, 1997), but the rate at which this decline occurs greatly varies across individuals (Hartshorne & Germine, 2015). Although these features make the investigations of these abilities, and of their decline in old age, particularly relevant, the current results cannot be generalized to other cognitive abilities. In other words, it cannot be excluded that the significant association observed between education and cognitive decline could be specific to the type of tasks used in the study. In any case, since previous literature suggests a negligible effect of education on the rate of change of cognitive function in older age, our current findings should be interpreted cautiously. Additional large-scale studies with long-term follow-ups and testing multiple indicators of cognitive functioning are thus needed to replicate our findings.

Potential Mechanisms

How can this mediating effect of cognitive function on the relationship between education and physical activity be explained? Our results showing that higher educational level is associated with better cognitive function align with the previous literature (Aartsen et al., 2019; Anstey & Christensen, 2000; Avila et al., 2009; Lenehan et al., 2015; Schneeweis et al., 2014). The mechanism of cognitive reserve can be put forward to explain how education enhances cognitive function (Cullati et al., 2018; Lenehan et al., 2015; Stern, 2002, 2009). Originally, cognitive reserve was developed to explain the gap between biological damage in the brain (or brain pathology) and patients' clinical presentation (Stern, 2002). Recently, the relevance of cognitive reserve has been extended to physiological cognitive aging (Stern, 2009). Cognitive reserve is the brain's ability to optimize its performance through differential recruitment of brain networks, which may be associated with different cognitive strategies (Stern, 2002). The construction of cognitive reserve is based on cognitively stimulating situations, such as academic, occupational, and leisure activities (Opdebeeck et al., 2016; Stern, 2009). Particularly, Lenehan et al. (2015) contended that empirical data support the proposition that more educated individuals maintain a higher level of cognitive functioning compared with less educated individuals. Our findings are consistent with this proposition as they demonstrate that higher levels of education are associated with a higher initial status in cognitive function and its slower decline across time. In other words, individuals with higher levels of education may exhibit a higher cognitive reserve that is better maintained over time compared to less educated individuals. Consequently, our results suggest that gaps in cognitive function and physical activity between the least and most educated widen over the course of aging.

We found that higher cognitive function was associated with higher physical activity. This result is consistent with previous studies suggesting that cognitive function is important to engage in physical activity (Cheval, Boisgontier, et al., 2022; Cheval, Csajbók, et al., 2021; Cheval, Orsholits, et al., 2020; Daly et al., 2015; Sabia et al., 2017). The recent TEMPA allows to account for these findings (Cheval & Boisgontier, 2021). Anchored in an evolutionary perspective, TEMPA posits that humans have an innate attraction to physical effort minimization (Cheval, Daou, et al., 2020; Cheval & Boisgontier, 2021; Cheval et al., 2017; Klein-Flügge et al., 2016; Prévost et al., 2010) and that engaging in physically active behaviors is associated with higher levels of cognitive function to overcome this attraction (Cheval, Daou, et al., 2020; Cheval, Cabral, et al., 2021; Cheval, Orsholits, et al., 2020; Cheval, Tipura, et al., 2018). This hypothesis is supported by the current results showing that education has an indirect effect on the change in physical activity across time through effects on the initial status and change in cognitive function. Although education remained significantly associated with change in physical activity after adjusting for cognitive function, these findings suggest that, among the multiple potential mechanisms that have been shown to underpin the association between education level and physical activity (i.e., health knowledge, motivation, environmental/neighborhood conditions), cognitive function may also be involved.

Limitations and Strengths

The study includes at least four limitations. First, we relied on a self-reported measure of physical activity. This measure may have reduced measurement validity and could have generated a misclassification bias (Prince et al., 2008). Likewise, this measure was used in its raw metric and treated as continuous. Yet, the transition from 1 (i.e., more than once a week) to 2 (i.e., once a week) is not equivalent to the transition from 2 to 3 (i.e., one to three times a month) or from 3 to 4 (i.e., hardly ever or never). Accelerometer-measured physical activity should be included in future studies. The same critique can be used for the education variable, which was also treated as continuous. Second, our measure of cognitive function was based on two tests intended to capture two dimensions of cognitive function, namely cognitive impairment and early signs of dementia (Harris & Dowson, 1982; Rosen, 1980; Zhao et al., 2012). Yet, general cognitive function is underpinned by many other cognitive domains such as problem solving, reasoning, processing speed, and inhibition (Davies et al., 2018; Fawns-Ritchie & Deary, 2020). Since both the effect of education and cognitive function could differ by cognitive dimension (Cheval & Boisgontier, 2021; Cheval, Cabral, et al., 2021; Cheval, Daou, et al., 2020; Cheval et al., 2019; Cheval, Radel, et al., 2018; Cheval, Tipura, et al., 2018), future studies should investigate the relationships between education, other specific cognitive functions, and physical activity. Third, our study was based on correlational data. Accordingly, we cannot exclude reverse causality and cannot infer a true causal relationship from education to physical activity through cognitive function. Yet, it should be noted that results of the sensitivity analysis, in which a time lag was introduced between the change in cognitive function and the change in physical activity to respect the temporal precedence, revealed consistent results with those observed in the main analyses. Fourth, several additional mechanisms (e.g., health literacy, motivation, environmental conditions) may explain why education is related to physical activity. Yet, these variables were not available in SHARE, which prevented us from assessing the unique association of cognitive function with physical activity after adjustment for these additional variables. As such, the proportions of the total effect of education on physical activity explained by cognitive function could have been overestimated.

The study includes at least four strengths. First, it was based on a large sample of noninstitutionalized older adults 50 years of age or older from 28 countries. Second, this is the first study to directly test and support the hypothesized mediating role of cognitive function on the association between educational attainment and physical activity. Third, we relied on a statistical approach suited to formally test mediation processes both at the baseline level and growth across time. Finally, the results of the sensitivity analyses including a time lag between the predictors and the outcome in order to minimize the risk of reverse causation bias were consistent with the main results.

Conclusion

Our findings reveal that initial status and change in cognitive function explain the positive association between educational attainment and a physical activity maintenance over the years. These results shed light on the long-lasting effect of education on the trajectories of cognitive function across aging that in turn impacts physical activity. Education, via its self-perpetuating effect in supporting cognitive function, thus plays an essential role in promoting an active lifestyle.

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