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Research paper

Physical activity mediates the effect of education on mental health trajectories in older age

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ABSTRACT

Objective: Why people with lower levels of educational attainment have poorer mental health than people with higher levels can partly be explained by financial circumstances. However, whether behavioral factors can further explain this association remains unclear. Here, we examined the extent to which physical activity mediates the effect of education on mental health trajectories in later life.

Methods: Data from 54,818 adults 50 years of age or older (55 % women) included in the Survey of Health, Aging and Retirement in Europe (SHARE) were analyzed using longitudinal mediation and growth curve models to estimate the mediating role of physical activity (baseline and change) in the association between education and mental health trajectories. Education and physical activity were self-reported. Mental health was derived from depressive symptoms and well-being, which were measured by validated scales.

Results: Lower education was associated with lower levels and steeper declines in physical activity over time, which predicted greater increases in depressive symptoms and greater decreases in well-being. In other words, education affected mental health through both levels and trajectories of physical activity. Physical activity explained 26.8 % of the variance in depressive symptoms and 24.4 % in well-being, controlling for the socioeconomic path (i.e., wealth and occupation).

Conclusions: These results suggest that physical activity is an important factor in explaining the association between low educational attainment and poor mental health trajectories in adults aged 50 years and older.

1. Introduction

Mental conditions are a leading cause of disability (Lépine and Briley, 2011; WHO, 2017a) with increasing prevalence at older ages (Kok and Reynolds, 2017). Promoting mental health and well-being is thus a public health priority, especially in older adults (WHO, 2017b). Education is an important factor in this promotion, as lower levels of education are robustly associated with poor mental health in middle-aged and older adults (Sperandei et al., 2021; Dalgard et al., 2007; Murrell et al., 2003; Stewart-Brown et al., 2015; Srivastava et al., 2021; Andrade et al., 2003; Bromet et al., 2011; de Graaf et al., 2012). Similarly, a meta-analysis showed a dose-response relationship between education and depression, with the log odds ratio for major depression decreasing by 3 % for each additional year of education (Lorant et al., 2003).

Although empirical evidence remains scarce, social epidemiology often contends that the association between educational attainment and mental health is partly explained by socioeconomic conditions over the life course, such as wealth or occupation (Sperandei et al., 2021; Milner et al., 2018; Oakes and Kaufman, 2017). For example, a recent large-scale prospective cohort study of adults aged 45 years or older suggested that wealth mediated the association between lower educational

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attainment and higher psychological distress (Sperandei et al., 2021). This result was consistent with those observed in younger adults (Milner et al., 2018). However, in both studies, nearly half of the association between lower education and poorer mental health remained unexplained. These findings highlight that, although socioeconomic factors are important mediators of the association between education and mental health, a substantial amount of variance remains to be explained. Thus, other pathways through which education could influence mental health should be investigated.

The literature suggests that physical activity is associated with both education and mental health, and could thus be one of these alternative pathways. First, higher levels of education have been shown to be associated with higher levels of physical activity across the lifespan (Droomers et al., 2001; Clouston et al., 2015; Cheval et al., 2018; Beenackers et al., 2012; O'Donoghue et al., 2018; Kari et al., 2020). Second, numerous studies have shown that higher levels of physical activity are associated with better mental health across aging (Chekroud et al., 2018; Schuch et al., 2018; Boisgontier et al., 2020; Choi et al., 2019), with several psychosocial and biological mechanisms explaining this association (De Sousa et al., 2021; Kandola et al., 2019). However, formal testing of this mediation effect of physical activity is lacking.

The objective of the present study was to examine whether baseline levels and changes in physical activity mediate the association between educational attainment and mental health trajectories in adults 50 years of age or older. Additionally, we aimed to extend the existing literature based exclusively on indicators of poor mental health (e.g., depressive symptoms) by including an indicator of good mental health in the outcomes (i.e., well-being) (Read et al., 2016; Pinquart and Sörensen, 2000). We hypothesized that both baseline level and change in physical activity explain the association between lower educational attainment and steeper increases in depressive symptoms as well as steeper decreases in well-being over time, independent of socioeconomic pathways (i.e., household wealth and occupation).

2. Methods

2.1. Participants and study design

Data are from the Survey of Health, Aging and Retirement in Europe (SHARE), a longitudinal, cross-national population-based study of adults 50 years of age or older (Börsch-Supan et al., 2013). In SHARE, data were collected approximately every two years between 2004 and 2019, with a total of eight measurement waves, using computer-assisted personal interviews (CAPI) in participants' homes. Educational attainment was measured when participants were first included in the study. Physical activity and mental health were assessed at all waves except wave 3 (2008–2009). Here, educational attainment and at least one measure of physical activity and one measure of depressive symptoms were required for a participant to be included. Participants with suspected dementia at baseline, as indicated by a score above two on the time orientation question (Aartsen et al., 2019), and participants who reported more than two limitations in activities of daily living (ADL) at baseline, were excluded. SHARE is approved by the relevant research ethics committees in the participating countries. All participants provided written informed consent.

2.2. Measures

2.2.1. Outcome variables

Depressive symptoms were assessed using the Depression Symptoms Scale of the EURO-DEP consortium (EURO-D scale) (Copeland et al., 2004; Prince et al., 1999). The EURO-D scale consists of 12 items: Depressed mood, pessimism, death wish, guilt, sleep, interest, irritability, appetite, fatigue, concentration, enjoyment, and tearfulness. Each item was scored 0 (symptom absent) or 1 (symptom present), resulting in a score ranging from 0 to 12, with higher scores indicating greater depressive symptoms. The reliability of this scale was acceptable, with Cronbach's alpha ranging from 0.71 to 0.72 across waves.

Quality of life and well-being were assessed using a short version of the Control, Autonomy, Satisfaction, Pleasure – 12 items scale (CASP-12) (Hyde et al., 2003; Siegrist et al., 2007) that includes 12 items assessing 4 conceptual domains of individuals' needs: Control, autonomy, self-realization, and pleasure. Each item was scored 0 (often) to 3 (Never), resulting in a score ranging from 0 to 36, with higher scores indicating greater well-being. The reliability of this scale was low, with Cronbach's alpha ranging from 0.34 to.38 across waves.

2.2.2. Exposure variable

Educational attainment was based on the International Standard Classification of Education (ISCED) (United Nations Educational, 2006) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and included three levels: Primary (ISCED levels 0 and 1), secondary (ISCED levels 2 to 4), or tertiary (ISCED levels 5 and 6) (Cullati et al., 2018). This measure was treated as continuous.

2.2.3. Mediators

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., 2020; Cheval et al., 2019; de Souto et al., 2017). Participants responded on a four-point scale: 1 = more than once a week; 2 = once a week; 3 = one to three times a month; 4 = hardly ever or never. This measure was treated as continuous.

Wealth was derived from the equivalized net wealth of the household, which is the financial, physical, and housing wealth after deducting all debt, divided by the square root of benefiting members. The individuals were then categorized into quartiles (i.e., low, below median, above median, high wealth) computed separately for each country (Baranyi et al., 2020; Jürges, 2010). This equivalized wealth indicator is widely used, including by the Eurostat and the Organization for Economic Cooperation and Development (OECD), as it has the advantage of taking into account and adjusting for the actual size of the household. Occupation was defined based on the skill classification of the participants' main job over the life course according to the International Standard Classification of Occupations (ISCO). ISCO's 10 main occupational groups were reclassified according to their skill levels, whereby skill levels 1 and 2 were grouped into “low” and skill levels 3 and 4 were grouped into “high” main occupational position. Participants who never had a paid work were included in a third category (“never worked”).

2.2.4. Covariates

Lack of health behaviors was computed using an index that combines binary indicators of unhealthy eating, smoking, and alcohol consumption across waves, resulting in a continuous variable ranging from 0 (none of the three indicators) to 1 (all unhealthy indicators) (Sieber et al., 2019). The three behaviors were chosen because they, along with physical activity, have been identified by the World Health Organization as the main behavioral risk factors for the development of non-communicable diseases and death (WHO, 2020). This variable allowed the association between physical activity and mental health to be captured, while accounting for the effect of other health behaviors (Breeze et al., 2005). This variable was not included in the baseline model testing the mediating role of socioeconomic indicators only.

2.2.5. Confounders

Potential confounders were identified using directed acyclic graphs to clarify the identification of causal pathways between the exposure, mediators, and outcomes. The selected confounders were consistent with those used in the existing literature (Milner et al., 2018; Cheval et al., in press). The following potential confounders were identified: Parental employment (i.e., low vs. high skill level), chronic conditions (i.

e., < 2 vs. ≥ 2), age group (50–64, 65–79, 80–96 years), sex (male, female), household structure (single vs. couple), and country of residence. All confounders were time-invariant.

2.3. Statistical analyses

We used a longitudinal mediation approach combined with growth curve models to estimate how the initial status (i.e., intercept) and change (i.e., slope) in physical activity (i.e., mediator) could mediate the associations between education (i.e., exposure variable) and the change over time in depressive symptoms and quality of life (outcomes) (von Soest and Hagtvet, 2011). Specifically, the following mediation paths were defined and simultaneously entered into the model. A first path tested baseline physical activity as a mediator. In this path, education predicted baseline physical activity (*path 1a*), which predicted the change in mental health (*path 1b*). A second path tested the change in physical activity as mediator. Education predicted the change in physical activity (*path 2a*), which predicted the change in mental health (*path 2b*). Moreover, a direct effect of education on change in mental health was included (c'). To ensure that the estimation of the mediation was not confounded by differences between subjects in the baseline status of the dependent variable (von Soest and Hagtvet, 2011; Littlefield et al., 2010; Seltzer et al., 2003), we included a path from baseline mental health status to change in mental health. Finally, the models were adjusted for the covariates and confounders.

The baseline models included only the socioeconomic indicators (i.e., wealth and occupation) as mediators. Because wealth and occupation were time-invariant mediators, mediation could only be estimated at the intercept level. Models 2 added physical activity (i.e., level and change) as an independent mediator (Figs. 1 and 2). Missing data were visually inspected to detect potential patterns of missingness, which were not found. Thus, indirect effects were estimated using the maximum

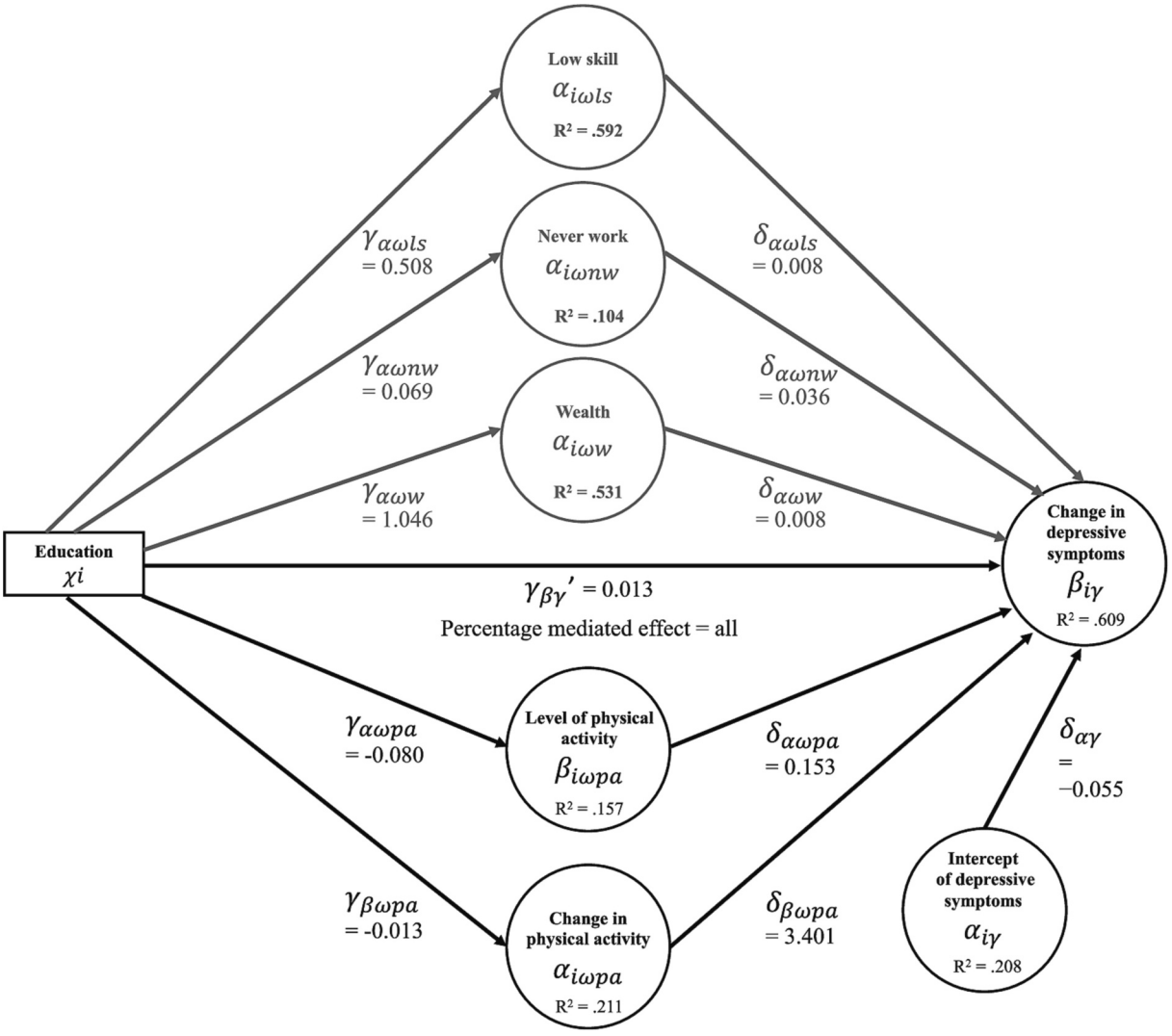

Fig. 1. Longitudinal mediation model combined with growth curve models testing the mediating role of socioeconomic factors on the association between education and depressive symptoms trajectories in old age.

Notes. Education (primary, secondary, tertiary, treated as continuous variable) is the independent variable. Wealth (low, below median, above median, high wealth, treated as continuous variable), occupation (low skilled vs. high skilled vs. never worked), and physical activity (more than once a week, once a week, one to three times a month, hardly ever or never, treated as continuous variable) are the mediating variables. Depressive symptoms are the outcome and were assessed using the EURO-D scale. This figure is a simplification of the tested models that illustrates the main findings. The actual models included additional paths, variance and covariance estimates, as well as covariates and confounders. These paths are not shown for clarity. The model equations are provided in the Supplemental Material. The paths and estimates from the socioeconomic factors are shown in gray. The paths and estimates of physical activity level and change are in black. All the coefficients described here are significant ($p < .001$), except for the association between low (vs. high) skill on the trajectories of depressive symptoms ($p = .013$), and for the direct effect of education on the trajectories of depressive symptoms ($p = .184$).

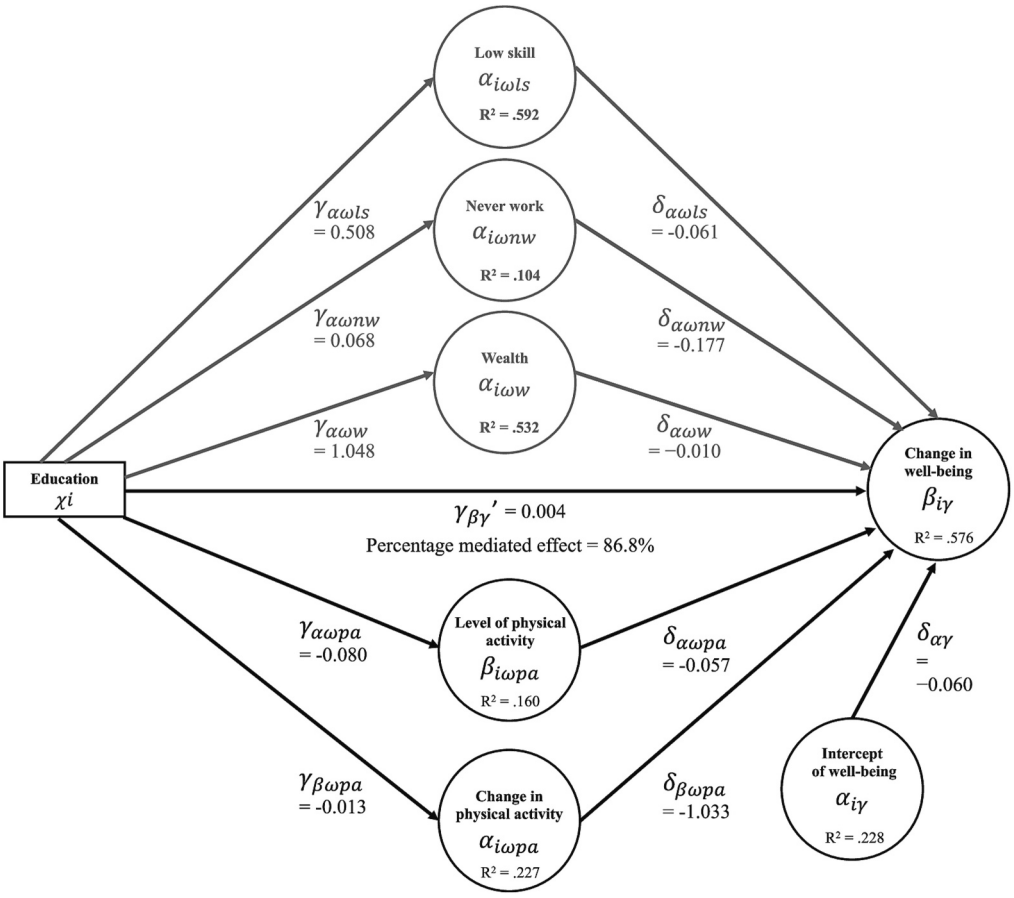

Fig. 2. Longitudinal mediation model combined with growth curve models testing the mediating role of physical activity on the association between education and mental health, accounting for the socioeconomic pathway (i.e., wealth and occupation).
Notes. Education (primary, secondary, tertiary, treated as continuous variable) is the independent variable. Wealth (low, below median, above median, high wealth, treated as continuous variable), occupation (low skilled vs. high skilled vs. never worked), and physical activity (more than once a week, once a week, one to three times a month, hardly ever or never, treated as continuous variable) are the mediating variables. Well-being is the outcome and was assessed using the CASP-12 scale. This figure is a simplification of the tested models that illustrates the main findings. The actual models included additional paths, variance and covariance estimates, as well as covariates and confounders. These paths are not shown for clarity. The model equations are provided in the Supplemental Material. The paths and estimates from the socioeconomic factors are shown in gray. The paths and estimates from physical activity level and change are in black. All the coefficients described here are significant ($p < .001$), except for the association between wealth and the trajectories of depressive symptoms ($p = .070$), and for the direct effect of education on the trajectories of depressive symptoms ($p = .160$).

likelihood estimator and with full information maximum likelihood estimation for the missing values (Maydeu-Olivares, 2017). The proportion of the total effects explained by the mediating variables were calculated as follows: $\frac{\text{indirect effects}}{\text{total effects}}$. Analyses were performed with the lavaan R package (Rosseel, 2012). The lavaan code, formal equations of the longitudinal mediation models, and detailed results are provided in the Supplemental Material.

2.4. Sensitivity analyses

To satisfy the temporal precedence between the slope of physical activity and the slope of mental health, we created a time lag between physical activity (i.e., the mediator) and depressive symptoms and well-being (i.e., the outcomes). Accordingly, the slope of physical activity was estimated before the slope of mental health, thus satisfying the causal condition of temporal precedence between the mediator and the outcomes (Cheong et al., 2003; MacKinnon, 2012).

3. Results

3.1. Descriptive results and growth curves models

A total of 54,818 participants (55 % women) were included in the sample. Table 1 describes the sample stratified by educational level.

Results from the growth curve models showed a positive latent slope for depressive symptoms over time that was steeper in the older age categories (b = 0.011, 95 % confidence interval [95 % CI] = 0.005–0.016, $p < .001$, for age 50–64; b = 0.153, 95 % CI = 0.144–0.161, $p < .001$, for age 65–79; b = 0.173, 95 % CI = 0.148–0.199, $p < .001$, for age 80–96). In addition, results showed a positive slope for well-being over time in the youngest age category (b = 0.047, 95 % CI = 0.032–0.062, $p < .001$, for age 50–64), but a negative slope in the middle age category (b = −0.284, 95 % CI = −0.306 to −0.262, $p < .001$, for age 65–79), which was more pronounced in the oldest age category (b = −0.460, 95 % CI = −0.532 to −0.387 $p < .001$, for age 80–96). These results suggest that mental health deteriorates with age, but that the decline in well-being occurs later than the increase in depressive symptoms. Finally, we observed a negative latent slope for physical activity over time, which was stronger in the older age categories (b = −0.014, 95 % CI = −0.017 to −0.011, $p < .001$, for age 50–64; b = −0.068, 95 % CI = −0.072 to −0.064, $p < .001$, for age 65–79; b = −0.117, 95 % CI = −0.129 to −0.106, $p < .001$, for age 80–96).

3.2. Longitudinal mediation analyses

Tables 2 and 3 present the results of the longitudinal mediation analyses combined with growth curve models for testing wealth and physical activity as mediators of the association between education and mental health. Figs. 1 and 2 illustrate the results.

3.2.1. Depressive symptoms

Baseline model. Low (vs. high) education was associated with lower wealth ($y\alpha\omega w = 1.046$, 95 % CI = 1.038–1.055, $p < .001$), which was associated with a steeper increase in depressive symptoms ($\delta\alpha\omega w = 0.014$, 95 % CI = 0.011–0.017, $p < .001$). In other words, wealth level mediated the association between education and changes in depressive symptoms, as confirmed by a significant indirect effect (0.015, 95 % CI = 0.011–0.018, $p < .001$). Moreover, low (vs. high) education was

Table 1
Baseline characteristics of the participants across education levels.

N = 54,818	Primary level of education (N = 12,026)	Secondary level of education (N = 30,619)	Tertiary level of education (N = 12,173)
Outcomes			
Depressive symptoms, mean ± SD	2.6 ± 2.3	2.2 ± 2.1	1.8 ± 1.8
Well-being, mean ± SD	35.3 ± 6.3	37.8 ± 5.6	39.5 ± 5.1
Mediators			
Wealth, n (%)			
Q1	3359 (27.9)	5714 (18.6)	1271 (10.4)
Q2	3611 (30.1)	7720 (25.2)	2124 (17.5)
Q3	3108 (25.8)	8976 (29.3)	3185 (26.2)
Q4	1948 (16.2)	8209 (26.8)	5593 (45.9)
Physical activity, mean ± SD	2.3 ± 1.06	2.5 ± 0.9	2.6 ± 0.8
Covariates			
Age, n (%)			
50–64	5053 (42.0)	19,907 (65.1)	8197 (67.3)
65–79	5921 (49.2)	9604 (31.4)	3604 (29.6)
80–96	1052 (8.8)	1108 (3.6)	372 (3.1)
Gender			
Women, n (%)	7216 (60.0)	16,846 (55.0)	6129 (50.3)
Men, n (%)	4810 (40.0)	13,773 (45.0)	6044 (49.7)
Marital status			
Alone, n (%)	3268 (27.2)	7539 (24.6)	2854 (23.4)
In couple, n (%)	8758 (72.8)	23,080 (75.4)	9319 (76.6)
Main occupational position			
Low skill level, n (%)	11,210 (93.2)	25,369 (82.8)	7675 (63.0)
High skill level, n (%)	816 (6.8)	5250 (17.2)	4498 (37.0)
Lack of health behaviors	0.24 ± 0.29	0.30 ± 0.30	0.27 ± 0.27
Chronic conditions			
≥2, n (%)	6442 (53.6)	12,318 (40.2)	4153 (34.1)
<2, n (%)	5584 (46.4)	18,301 (59.8)	8020 (65.9)

Notes. Baseline = first measurement for each participant; SD = standard deviation. The descriptive statistics (except for the descriptive statistics of well-being) are estimated using the larger sample (i.e., from depressive symptoms). Depressive symptoms were assessed using the EURO-D scale. Well-being was assessed using the CASP-12 scale. Wealth was derived from the household equalized net wealth and categorized into quartiles – Q1 (low) = 0–25 %; Q2 (below median) ≤25 %–50 %, Q3 (above median) ≤50 %–75 %; Q4 (high wealth) ≤75 %–100 %. Physical activity was self-reported and ranged from 1 (more than once a week) to 4 (hardly ever or never). The Lack of Health Behavior Index includes smoking, alcohol consumption and unhealthy diet and ranged from 0 (none of the 3 healthy behaviors) to 3 (all unhealthy behaviors). Chronic conditions distinguish between participants with two or more chronic conditions from those with less than two chronic conditions.

associated with a higher likelihood of having a low-skilled job ($y\alpha\omega ls$ = 0.508, 95 % CI = 0.504–0.512, $p < .001$) or never having worked ($y\alpha\omega nw$ = 0.069, 95 % CI = 0.067–0.070, $p < .001$) than having a high-skilled job. Relative to having a high-skilled job, having a low-skilled job ($\delta\alpha\omega ls$ = 0.011, 95 % CI = 0.004 to −0.017, $p = .002$) or having never worked ($\delta\alpha\omega nw$ = 0.053, 95 % CI = 0.040 to −0.067, $p < .001$) was associated with a steeper increase in depressive symptoms. Thus, the main occupational position mediated the association between education and changes in depressive symptoms, as confirmed by a significant indirect effect (indirect effect = 0.009, 95 % CI = 0.005–0.013, $p < .001$). 60 % of the total effect of education on depressive symptoms was mediated by wealth (37.5 %) and occupation (22.5 %). The direct effect of education on depressive symptoms remained significant ($\gamma\beta y'$ = 0.016, 95 % CI = 0.010–0.022, $p < .001$) (Table 2).

Model 2. Compared with the baseline model, the indirect effect of education on changes in depressive symptoms through the socioeconomic indicators was reduced by approximately half for wealth (indirect effect = 0.008, 95 % CI = 0.004–0.012, $p < .001$) and by approximately one fifth for occupation (indirect effect = 0.007, 95 % CI = 0.003–0.011, $p = .001$) when physical activity was included as a potential mediator. Low (vs. high) education was associated with a lower baseline levels of physical activity ($y\alpha\omega pa$ = −0.080, 95 % CI = −0.097–0.063, $p < .001$), which was associated with a steeper increase in depressive symptoms ($\delta\alpha\omega pa$ = −0.057, 95 % CI = −0.071–0.043, $p < .001$). In addition, low (vs. high) education was associated with a steeper decline in physical activity ($y\beta\omega pa$ = −0.013, 95 % CI = −0.017 to −0.010, $p < .001$), which was associated with a steeper increase in depressive symptoms ($\delta\beta\omega pa$ = −1.033, 95 % CI = −1.112 to −0.954, $p < .001$). In other words, both baseline levels and changes in physical activity mediated the association between education and changes in depressive symptoms, as confirmed by indirect effects (intercept level = 0.005, 95 % CI = 0.003–0.006, $p < .001$; slope level = 0.014, 95 % CI = 0.010–0.018, $p < .001$). The direct effect of education on depressive symptoms was no longer significant when physical activity was included as a potential mediator ($\gamma\beta y'$ = 0.004, 95 % CI = −0.002–0.011, $p = .184$). 86.8 % of the total effect of education on depressive symptoms was explained (21.0 % by wealth, 18.4 % by occupation, and 47.4 % by physical activity). The addition of physical activity explained 26.8 % of the additional variance in depressive symptom changes relative to the model including wealth as the only mediator (Table 2 and Fig. 2).

3.2.2. Well-being

Baseline model. Low (vs. high) education was associated with a lower wealth ($y\alpha\omega w$ = 1.048, 95 % CI = 1.040–1.057, $p < .001$), which was associated with a steeper decrease in well-being ($\delta\alpha\omega w$ = −0.035, 95 % CI = −0.045 to −0.025, $p < .001$). In other words, wealth level mediated the association between education and changes in well-being, as confirmed by a significant indirect effect (−0.036, 95 % CI = −0.047 to −0.026, $p < .001$). Moreover, low (vs. high) education was associated with a higher likelihood of having a low-skilled job ($y\alpha\omega ls$ = 0.508, 95 % CI = 0.505–0.512, $p < .001$) or never having worked ($y\alpha\omega nw$ = 0.068, 95 % CI = 0.067–0.070, $p < .001$) than to having a high-skilled job. In turn, relative to high-skilled job, having a low-skilled job ($\delta\alpha\omega ls$ = −0.069, 95 % CI = −0.087 to −0.051, $p < .001$) and having never worked ($\delta\alpha\omega nw$ = −0.229, 95 % CI = −0.265 to −0.193, $p < .001$) were associated with a steeper decrease in well-being. Thus, the main occupational position mediated the association between education and changes in depressive symptoms, as confirmed by a significant indirect effect (indirect effect = −0.051, 95 % CI = −0.061–0.040, $p < .001$). 75.6 % of the total effect of education on depressive symptoms was mediated by wealth (31.3 %) and occupation (44.3 %). The direct effect of education on well-being remained significant ($\gamma\beta y'$ = −0.027, 95 %

Table 2
Results of the longitudinal mediation analyses combined with the growth curve models examining the mediating role of physical activity on the association between education and depressive symptoms trajectories in old age.

Depressive symptoms	Baseline model: Socioeconomic pathway only		Model 2: Socioeconomic and physical activity pathways	
	b (95 % CI)	*p*	b (95 % CI)	*p*
Slope depressive symptoms (βiy)				
Education ($\gamma\beta y'$)	0.016 (0.010; 0.022)	<0.001	0.004 (−0.002; 0.011)	0.184
Wealth ($\delta\alpha\omega w$)	0.014 (0.011; 0.017)	<0.001	0.008 (0.004; 0.011)	<0.001
Occupation (ref. High skill)				
Low skill ($\delta\alpha\omega ls$)	0.011 (0.004; 0.017)	0.002	0.008 (0.002; 0.015)	0.013
Never work ($\delta\alpha\omega ls$)	0.053 (0.040; 0.067)	<0.001	0.036 (0.023; 0.050)	<0.001
Intercept physical activity ($\delta\alpha\omega pa$)			−0.057 (−0.071; −0.043)	<0.001
Slope physical activity ($\delta\beta\omega_{pa}$)			−1.033 (−1.112; −0.954)	<0.001
Intercept depressive symptoms	−0.065 (−0.069; −0.060)	<0.001	−0.060 (−0.066; −0.055)	<0.001
Wealth ($\alpha i\omega w$)				
Education ($\gamma\alpha\omega w$)	1.046 (1.038; 1.055)	<0.001	1.046 (1.038; 1.055)	<0.001
Occupation (ref. Low skill) ($\alpha i\omega ls$)				
Education ($\gamma\alpha\omega ls$)	0.508 (0.504; 0.512)	<0.001	0.508 (0.504; 0.512)	<0.001
Occupation (ref. Never work) ($\alpha i\omega nw$)				
Education ($\gamma\alpha\omega nw$)	0.069 (0.067; 0.070)	<0.001	0.069 (0.067; 0.070)	<0.001
Intercept physical activity ($\alpha i\omega pa$)				
Education ($\gamma\alpha\omega pa$)			−0.080 (−0.097; −0.063)	<0.001
Slope physical activity ($\beta i\omega pa$)				
Education ($\gamma\beta\omega pa_)$			−0.013 (−0.017; −0.010)	<0.001
Total effect	0.040 (0.033; 0.046)	<0.001	0.038 (0.031; 0.044)	<0.001
Indirect effects				
Wealth				
Indirect effect (intercept) ($\gamma\alpha\omega w\times\ \delta\alpha\omega w$)	0.015 (0.011; 0.018)	<0.001	0.008 (0.004; 0.012)	<0.001
Occupation				
Indirect effect (intercept) ($\gamma\alpha\omega ls\times\ \delta\alpha\omega ls$) + ($\gamma\alpha\omega nw\times\ \delta\alpha\omega nw$)	0.009 (0.005; 0.013)	<0.001	0.007 (0.003; 0.011)	0.001
Physical activity				
Indirect effect (intercept) ($\gamma\alpha\omega pa\times\ \delta\alpha\omega pa$)			0.005 (0.003; 0.006)	<0.001
Indirect effect (slope) ($\gamma\beta\omega pa\times\ \delta\beta\omega pa$)			0.014 (0.010; 0.018)	<0.001
Total indirect effect	0.024 (0.018; 0.029)	<0.001	0.033 (0.027; 0.039)	<0.001
Percentage of mediated effect				
By wealth only	37.5 %		21.0 %	
By occupation only	22.5 %		18.4 %	
By physical activity			47.4 %	
By all mediators	60 %		86.8 %	

Notes. 95% CI = 95 % confidence interval. All models were adjusted for parental employment (i.e., low vs. high skill level), chronic conditions (i.e., < 2 vs. ≥ 2), age group (50–64, 65–79, 80–96 years), sex (male, female), household structure (single vs. in couple), and main occupational position (low skill level vs. high skill level vs. never worked). Lack of health behaviors (smoking, alcohol consumption, and unhealthy eating, treated as continuous variables ranging from 0 "no unhealthy behavior" to 3 "all the unhealthy behaviors"), and country of residence were adjusted in model 2. Depressive symptoms are the outcome and were assessed using the EURO-D scale. Wealth (low, below median, above median, high wealth, treated as continuous variable), occupation (low skilled vs. high skilled vs. never worked), and physical activity (more than once a week, once a week, one to three times a month, hardly ever or never, treated as continuous variable) are the mediating variables.

CI = −0.044 to −0.011, p = .001) (Table 2 and Fig. 1).

Model 2. Compared with the baseline model, the indirect effect of education on change in well-being through the socioeconomic indicators was reduced by about three times for wealth (indirect effect = −0.011, 95 % CI = −0.022–0.001, p = .070) and by about one fifth for occupation (indirect effect = −0.043, 95 % CI = −0.053 to −0.033, p < .001) when physical activity was included as a potential mediator. Low (vs. high) education was associated with lower initial levels of physical activity ($\gamma\alpha\omega_{pa}$ = −0.080, 95 % CI = −0.098 to −0.062, p < .001), which was associated with a steeper decrease in well-being over time ($\delta\alpha\omega pa$ = 0.153, 95 % CI = 0.109–0.197, p < .001). In addition, low (vs. high) education was associated with a steeper decline in physical activity ($\gamma\beta\omega pa$ = −0.013, 95 % CI = −0.017 to −0.009, p < .001), which was associated with a steeper decrease in well-being ($\delta\beta\omega pa$ = 3.401, 95 % CI = 3.162–3.641, p < .001). In other words, both initial levels and changes in physical activity mediated the association between education and changes in well-being, as confirmed by indirect effects (at the intercept level = −0.012, 95 % CI = −0.017 to −0.008, p < .001; at the slope level = −0.044, 95 % CI = −0.058 to −0.030, p < .001). The direct effect of education on well-being was no longer significant when physical activity was included as a potential mediator ($\gamma\beta y'$ = 0.013, 95 % CI = −0.005–0.032, p = .160). The total effect of education on well-being was fully explained (10 % by wealth, 39.1 % by occupation, and 50.9 % by physical activity). The addition of physical activity explained 24.4 % of the additional variance in well-being changes relative to the model including wealth as the only mediator (Table 2 and Fig. 2).

3.3. Sensitivity analyses

Results of the sensitivity analyses (N = 39,467 for depressive symptoms and N = 39,089 for well-being) were consistent with those of the main analyses (see Supplemental Material). Specifically, for both mental health indicators, the baseline models showed significant indirect effects of education on mental health trajectories through wealth and occupation. The socioeconomic factors explained 48.7 % (28.2 % for wealth and 20.1 % for occupation) of the association between education and changes in depressive symptoms and 76.6 % (34.5 % for wealth and 43.1 % for occupation) of the association between education and changes in well-being. Moreover, results of models 2 showed significant indirect effects of education on changes in mental health through changes in physical activity, while the indirect effects through the socioeconomic pathways were reduced. Models 2 explained 68.4 % of the

Table 3
Results of the longitudinal mediation analyses combined with the growth curve models examining the mediating role of physical activity on the association between education and well-being trajectories in old age.

Well-being	Baseline 1: Socioeconomic pathway only		Model 2: Socioeconomic and physical activity pathways	
	b (95 % CI)	*p*	b (95 % CI)	*p*
Slope well-being (βiy)				
Education ($\gamma\beta y'$)	−0.027 (−0.044; −0.011)	0.001	0.013 (−0.005; 0.032)	0.160
Wealth ($\delta\alpha\omega w$)	−0.035 (−0.045; −0.025)	<0.001	-0.010 (−0.021; 0.001)	0.070
Occupation (ref. High skill)				
Low skill ($\delta\alpha\omega ls$)	−0.069 (−0.087; −0.051)	<0.001	−0.061 (−0.078; −0.044)	<0.001
Never work ($\delta\alpha\omega ls$)	−0.229 (−0.265; −0.193)	<0.001	−0.177 (−0.211; −0.142)	<0.001
Intercept physical activity ($\delta\alpha\omega pa$)			0.153 (0.109; 0.197)	<0.001
Slope physical activity ($\delta\beta\omega_{pa}$)			3.401 (3.162; 3.641)	<0.001
Intercept depressive symptoms	−0.062 (−0.066; −0.058)	<0.001	−0.055 (−0.061; −0.049)	<0.001
Wealth ($\alpha i\omega w$)				
Education ($\gamma\alpha\omega w$)	1.048 (1.040; 1.057)	<0.001	1.048 (1.040; 1.057)	<0.001
Occupation (ref. Low skill) ($\alpha i\omega ls$)				
Education ($\gamma\alpha\omega ls$)	0.508 (0.505; 0.512)	<0.001	0.508 (0.505; 0.512)	<0.001
Occupation (ref. Never work) ($\alpha i\omega nw$)				
Education ($\gamma\alpha\omega nw$)	0.068 (0.067; 0.070)	<0.001	0.068 (0.067; 0.070)	<0.001
Intercept physical activity ($\alpha i\omega oa$)				
Education ($\gamma\alpha\omega pa$)			−0.080 (−0.098; −0.062)	<0.001
Slope physical activity ($\beta i\omega pa$)				
Education ($\gamma\beta\omega pa_)$			−0.013 (−0.017; −0.009)	<0.001
Total effect	−0.115 (−0.133; −0.096)	<0.001	−0.097 (−0.117; −0.077)	<0.001
Indirect effects				
Wealth				
Indirect effect (intercept) ($\gamma\alpha\omega w \times \delta\alpha\omega w$)	−0.036 (−0.047; −0.026)	<0.001	-0.011 (−0.022; 0.001)	0.070
Occupation				
Indirect effect (intercept) ($\gamma\alpha\omega ls \times \delta\alpha\omega ls$) + ($\gamma\alpha\omega nw \times \delta\alpha\omega nw$)	−0.051 (−0.061; −0.040)	<0.001	−0.043 (−0.053; −0.033)	<0.001
Physical activity				
Indirect effect (intercept) ($\gamma\alpha\omega pa \times \delta\alpha\omega pa$)			−0.012 (−0.017; −0.008)	<0.001
Indirect effect (slope) ($\gamma\beta\omega pa \times \delta\beta\omega pa$)			−0.044 (−0.058; −0.030)	<0.001
Total indirect effect			−0.060 (−0.076; −0.044)	<0.001
Percentage of mediated effect				
By wealth	31.3 %		10.0 %	
By occupation only	44.3 %		39.1 %	
By physical activity			50.9 %	
By both wealth and physical activity	75.6 %		All effect explained	

Notes. 95% CI = 95 % confidence interval. All models were adjusted for parental employment (low vs. high skill level), long-term health conditions (< 2 vs. ≥ 2), age group (50–64, 65–79, 80–96 years), sex (male, female), household structure (single vs. couple), and main occupational position (low skill level vs. high skill level vs. never worked). Lack of health behaviors (smoking, alcohol consumption, and unhealthy eating, treated as continuous variables ranging from 0 "no unhealthy behavior" to 3 "all the unhealthy behaviors"), and country of residence were adjusted in model 2. Well-being is the outcome and was assessed using the CASP-12 scale. Wealth (low, below median, above median, high wealth, treated as continuous variable), occupation (low skilled vs. high skilled vs. never worked), and physical activity (more than once a week, once a week, one to three times a month, hardly ever or never, treated as continuous variable) are the mediating variables.

association between education and changes in depressive symptoms and all of the association between education and changes in well-being.

4. Discussion

4.1. Main findings

The results of this large cross-national longitudinal study suggest that physical activity further explains the association between educational attainment and mental health trajectories in older age, above and beyond the effects of the socioeconomic pathway (i.e., wealth and occupation). Specifically, low educational attainment was associated with a lower initial level and a steeper decline in physical activity over time, which were associated with a steeper decline in mental health and well-being. These results were obtained while adjusting for the socioeconomic pathway as well as covariates and potential confounders (i.e., parental employment, chronic conditions, age group, sex, household structure, health behaviors, and country of residence). Adding physical activity level as a mediator explained one quarter of the additional variance in depressive symptoms and in well-being compared with the model with socioeconomic factors as sole mediators. Finally, education was no longer significantly associated with mental health outcomes when physical activity was added to the model.

4.2. Comparison with previous studies

We found that the associations between education and change in mental health or well-being were explained not only by the initial level of physical activity, but also by its change over time: Low education was associated with a lower initial levels and steeper declines in physical activity, which was associated with steeper increases in depressive symptoms and steeper declines in well-being. These findings are in line with the existing literature showing that, on the one hand, low education is associated with lower physical activity across the lifespan (Droomers et al., 2001; Clouston et al., 2015; Cheval et al., 2018; Beenackers et al., 2012; O'Donoghue et al., 2018; Kari et al., 2020) and, on the other hand, that lower physical activity is associated with poorer mental health across aging (Chekroud et al., 2018; Schuch et al., 2018; Boisgontier et al., 2020; Choi et al., 2019).

Our results showed that the socioeconomic indicators (i.e., wealth and occupation) mediated more than half of the association between education and mental health: 60.0 % and 75.6 % for depressive

symptoms and well-being, respectively. These results are fairly consistent with the existing literature, which shows that approximately half of the detrimental effect of low education on mental health is explained by socioeconomic factors (Sperandei et al., 2021; Milner et al., 2018). Our study complements the literature by examining mental health trajectories, whereas previous studies focused on the level of mental health. In addition, while previous studies focused on indicators of poor mental health, our study is the first to also investigate an indicator of good mental health. Interestingly, we found that the results based on depressive symptoms and well-being were consistent overall, suggesting that the mechanisms linking education to mental health are similar for indicators of poor and good mental health.

Regarding the extent to which physical activity reduced the association between low education and mental health, we observed that the addition of physical activity explained 26.8 % of the additional variance in depressive symptoms and 24.4 % in well-being relative to the baseline models that included only the socioeconomic pathway. Overall, the model explained 86.8 % of the detrimental association between education and depressive symptoms and all of the association for well-being. Crucially, for both indicators of mental health, the direct effect of education was no longer significant when physical activity was included as a potential mediator. Thus, these findings suggest that most of the detrimental effect of low education resulting on poor mental health in later life may be explained by a combination of socioeconomic (i.e., wealth and occupation) and behavioral (i.e., physical activity) factors.

When physical activity was included as a potential mediator, the indirect effect of education on mental health through the socioeconomic factors was reduced for both depressive symptoms and well-being. Overall, these findings suggest that a substantial part of the mediating role previously attributed to socioeconomic factors in the association between education and mental health may have been overestimated in previous studies that did not account for the behavioral pathway.

4.3. Limitations and strengths

The study includes features that limit the conclusions that can be drawn. First, although the data are longitudinal, their correlational nature cannot rule out reverse causation, thus preventing the inference of causal relationships between education, wealth, occupation, physical activity, and mental health trajectories. However, to minimize the risk of reverse causation bias, we introduced a time lag between physical activity and mental health to account for the temporal precedence in the sensitivity analyses. Results of these analyses are similar to those of the main analysis. Second, the usual level of physical activity was measured using a self-reported questionnaire, which may not accurately reflect actual levels of physical activity (Prince et al., 2008). Similarly, because our main outcomes were also measured using self-reported scales, a common method variance bias cannot be excluded. Accordingly, the high percentage of education effects on mental health outcomes mediated by physical activity needs to be interpreted in this context. Moreover, the scale used focuses only on physical activity of moderate intensity and includes examples that may prime participants' response toward leisure activities related to household chores (Chalabaev et al., 2022). Future studies should assess physical activity using device-based measures. Third, the socioeconomic pathway was assessed using only two indicators, wealth and occupation. These two variables do not represent a comprehensive measure of socioeconomic advantages and disadvantages (Hällsten and Thaning, 2022). Assessing additional socioeconomic indicators is therefore warranted to better estimate the weight of the socioeconomic pathway in explaining the adverse effects of education on mental health. Fourth, additional mediators of the association between education and health could be considered, such as stress, social support, and cognitive functioning (Cheval et al., in press; Lochner, 2011; Brunello et al., 2016; Ross and Wu, 1995; Henriques et al., 2020). Future studies controlling for these potential mediators are needed to examine their contribution to explaining the association between low education and poor mental health. Fifth, although validated, the CASP-12 demonstrated low reliability, raising concerns about the validity of the observed results. Finally, some of the ordinal variables used in the models were treated as continuous (e.g., education and physical activity). Although this strategy simplified the model estimations, especially for the percentage of mediated effect, it should be acknowledged that it may bias the results. For example, for education, a change from tertiary to secondary education (i.e., from 2 to 1) is considered equivalent to a change from secondary to primary education (i.e., from 1 to 0), which is clearly not the case.

However, these limitations are outweighed by several strengths. First, we use a large-scale (> 50′000), longitudinal (15-year follow-up), and multinational cohort. Second, this is the first study to directly examine whether physical activity can explain the effect of low education on mental health trajectories in adults aged 50 years or older, controlling for the socioeconomic pathway. Third, the statistical approach allowed us to test not only the mediating role of the level of physical activity but also its change over the years. Finally, unlike previous literature, which mostly focused on indicators of poor mental health (e.g., depression), we also used an indicator of good mental health.

5. Conclusion

This study provides the first empirical support for the hypothesized indirect pathway between education and mental health trajectories in older age through physical activity. Both the initial level of physical activity and its change over the years explained a large part of the association between education and mental health trajectories, above and beyond the part explained by the socioeconomic pathway (i.e., wealth and occupation) in adults 50 years of age or older. These findings suggest that increasing physical activity in later life could contribute to reduce the differences in mental health resulting from differences in educational attainment. Several interventions can be implemented to promote physical activity, such as community-based walking sport programs, which are a low-cost, appropriate, and feasible opportunity to engage middle-aged and older adults in physical activity (Sivaramakrishnan et al., 2021; Sivaramakrishnan et al., 2023).

Ethical approval

This study was part of the SHARE study, approved by the relevant research ethics committees in the participating countries.

Informed consent

All participants provided written informed consent.

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Data sharing

This SHARE dataset is available at http://www.share-project.org/data-access.html.

Code sharing

The analytic code is available in the supplemental materials.

CRediT authorship contribution statement

Boris Cheval: Conceptualization, Writing – original draft. **Silvio Maltagliati:** Writing – review & editing. **Ilyes Saoudi:** Writing – review & editing. **Layan Fessler:** Writing – review & editing. **Ata Farajzadeh:** Writing – review & editing. **Stefan Sieber:** Data curation, Writing – review & editing. **Stéphane Cullati:** Writing – review & editing. **Matthieu P. Boisgontier:** Conceptualization, Supervision, Writing – original draft.

Declaration of competing interest

All authors declare that they have no conflict of interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jad.2023.05.052.

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