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Cognitive resources explain the engagement in physical activity and its age-related decline: A longitudinal study of 105,206 people

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Highlights

- Cognitive resources are critical to counteract an automatic attraction to effort minimization
- Lower cognitive resources are associated with lower levels and faster decline of physical activity across aging
- Both inter-individual differences and intra-individual changes in cognitive resources explain the frequency and trajectory of engagement in physical activity
- Cognitive resources are particularly important to engage in moderate physical activity

Significance

Recent findings showed that cognitive resources are required to counteract an automatic attraction to effort minimization, thereby suggesting an important role of cognition for the implementation of intentions to be physically active. We investigate the influence of cognitive resources on the engagement in physical activities and their evolution across aging. Repeated measures data from 105,206 adults aged 50 to 90 years show that lower cognitive resources are associated with lower physical activity and faster decline across aging. These cognitive resources are particularly relevant to explain the engagement in moderate physical activity. These results demonstrate that cognitive resources are required to reach higher levels of engagement in physical activity and slow down its decline across aging.

Abstract

Cognitive resources may be critical to counteract an automatic attraction to effort minimization and increase the engagement in physical activity. Large-scale longitudinal studies are required to assess whether inter-individual differences and intra-individual changes in cognitive resources explain this engagement across aging. Data from 105,206 adults aged 50 to 90 years from the Survey of Health, Ageing and Retirement in Europe (SHARE) were used in adjusted linear mixed models to examine whether the engagement in physical activity and its evolution across aging was dependent on cognitive resources. Cognitive resources and physical activity were measured 5 times over a 12-year period. Delayed recall and verbal fluency were used as indicators of cognitive function and cognitive reserve was assessed based on the level of education. The frequency of engagement in moderate and vigorous physical activity was self-reported. Results showed that lower cognitive resources were associated with lower levels and steeper decreases of physical activity across aging. The associations between inter-individual cognitive differences and the engagement in moderate physical activity increased across aging. These findings suggest that, after 50 years old, the level of engagement in physical activity and its trajectory over the years depend on the level of cognitive resources still available.

Keywords: physical activity, ageing; cognition, health, longitudinal change

Introduction

During evolution, energetic cost minimization provided an advantage for survival by extending the time individuals could chase a pray or search a shelter, thereby increasing the odds of success (1-3). Due to this vital advantage they conferred, brain mechanisms and behaviors supporting this minimization evolved into automatisms (4, 5). In modern societies, these automatisms became a problem and have resulted in a pandemic of physical inactivity (6). Counteracting this automatic attraction to energetic cost minimization has been associated with higher brain activity in the frontal lobe (4). These results suggest that cognitive resources are required and may explain inter-individual differences. Moreover, the age-related decline of these cognitive resources may influence physical activity trajectories.

In healthy aging, observational studies have widely reported the protective effect of physical activity on cognitive functions (7-12). Yet, the evidence stemming from intervention studies was inconclusive. Some studies observed a protective effect of physical activity (13, 14), whereas more recent ones did not observe this protective effect (15-19). One study also suggested that the effect of cognitive functions on physical activity was stronger than the effect in the opposite direction (20). Another study supported the prospective effect of cognition on physical activity (21). This study showed that the level of physical activity declines earlier in individuals with mild cognitive impairments in the preclinical phase of dementia. Taken together, these findings suggest a bidirectional relationship between cognition and physical activity. However, to the best of our knowledge, large-scale longitudinal studies focusing on the effect of cognitive function on physical activity in healthy aging are lacking.

This study aimed to investigate whether cognitive resources explain the frequency of engagement in moderate and vigorous physical activity and their trajectories across aging. We used data from 105,206 adults aged 50 years and older collected over 12 years. Both the effect of inter-individual differences and intra-individual changes in cognitive resources were tested. We hypothesized that lower cognitive resources (both inter- and intra-individual) are associated with less frequent engagement in physical activities (H1) and with a faster decline of these engagements across aging (H2).

Results

Table S1 reports participants' characteristics as a function of their baseline engagement in moderate physical activity, i.e., physically active participants (scored 1 or 2 on the item assessing moderate physical activity) vs. physical inactive participants (scored 3 or 4). Physically active participants showed better delayed recall and verbal fluency, higher education, lower levels of dementia, and were less likely to be older, to be a woman, and to drop out or die during the survey than physically inactive participants.

Cognitive resources, frequency of engagement in physical activity, and trajectories across aging

<u>Moderate physical activity</u>

Table S2 presents the models used to examine the engagement in moderate physical activity as a function of cognitive resources and its evolution across aging.

The models examining the engagement in moderate physical activity were adjusted for a priori covariates (i.e., gender, measurement occasions, birth cohort, attrition, chronic conditions, country of residence, and dementia) and showed that lower levels of delayed recall, verbal fluency, and education were associated with lower engagement in physical activity (Figure 1). For delayed recall and verbal fluency, this association was observed both at the between- and within-participant levels. At the between-person level, participants with lower levels of delayed recall or verbal fluency showed lower engagement in moderate physical activity. At the within-person level, decreases in delayed recall or verbal fluency were associated with lower engagement in moderate physical activity. These associations remained significant in the fully-adjusted model including the three cognitive resources.

The models examining the trajectories of moderate physical activity across aging showed that lower levels of delayed recall, verbal fluency, and education were associated with a faster decline of physical activity across aging (Figure 2). At the between-person level, participants with lower levels of delayed recall, verbal fluency, and education showed an accelerated decline of physical activity across aging. In other words, the influence of cognitive resources on the engagement in moderate physical activity was more pronounced as adults grew older. At the within-person level, decreases in delayed recall or verbal fluency was associated with a faster decline of physical activity, but without acceleration across aging. In the fully-adjusted model including the three cognitive resources, these associations were attenuated but the cognitive resources remained associated with the trajectories of moderate physical activity. In this model, the variables under consideration explained 42.4% of the variance in the engagement in moderate physical activity.

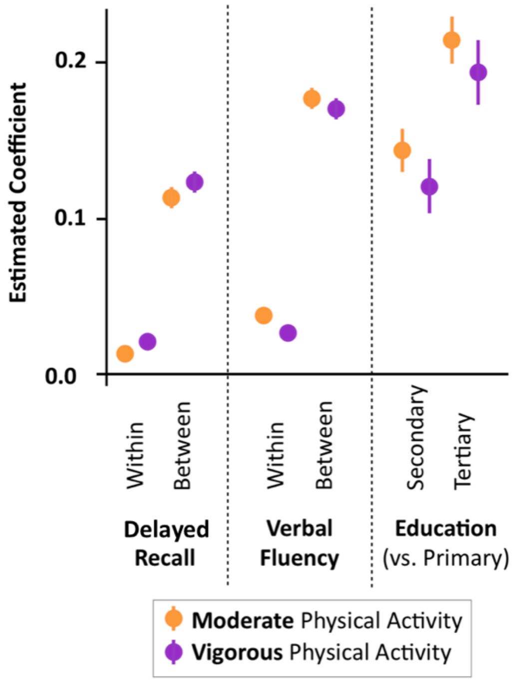

Figure 1. Associations between the cognitive resources and the frequency individuals engage in moderate and vigorous physical activity at old age. For delayed recall and verbal fluency, the variables were standardized, and the coefficients were interpreted as the effect of an increase of one standard deviation in delayed recall or verbal fluency on the frequency of engagement in physical activity. For education, the reference category is primary level. Vertical bars represent confidence intervals at 95% around the coefficient estimate.

Vigorous physical activity

Table S3 presents the models used to examine the engagement in vigorous physical activity as a function of cognitive resources and its evolution across aging.

The models examining the engagement in vigorous physical activity showed similar results as those related to moderate physical activity. Lower levels of delayed recall and verbal fluency, at both the within- and between-participant levels, and lower education were associated with lower engagement in vigorous physical activity (Figure 1). These associations remained significant in the fully-adjusted model including the three cognitive resources. At the within-person level, the models examining the trajectories of vigorous physical activity across aging showed results that were consistent with those related to moderate physical activity. Decreases in delayed recall or verbal fluency were associated with a steeper physical activity decline without acceleration across aging. At the between-person level, results showed that lower levels of delayed recall, verbal fluency, and education were associated with a decelerated decline of physical activity across aging (Figure 2). As such, unlike results related to moderate physical activity, the influence of cognitive resources on the engagement in vigorous physical activity was less pronounced as adults aged. In the fully-adjusted model including the three cognitive resources, the associations were attenuated with only verbal fluency and the tertiary level of education remaining significantly associated with the quadratic change of vigorous physical activity across aging. In this model, the variables under consideration explained 45.4% of the variance in the engagement in vigorous physical inactivity.

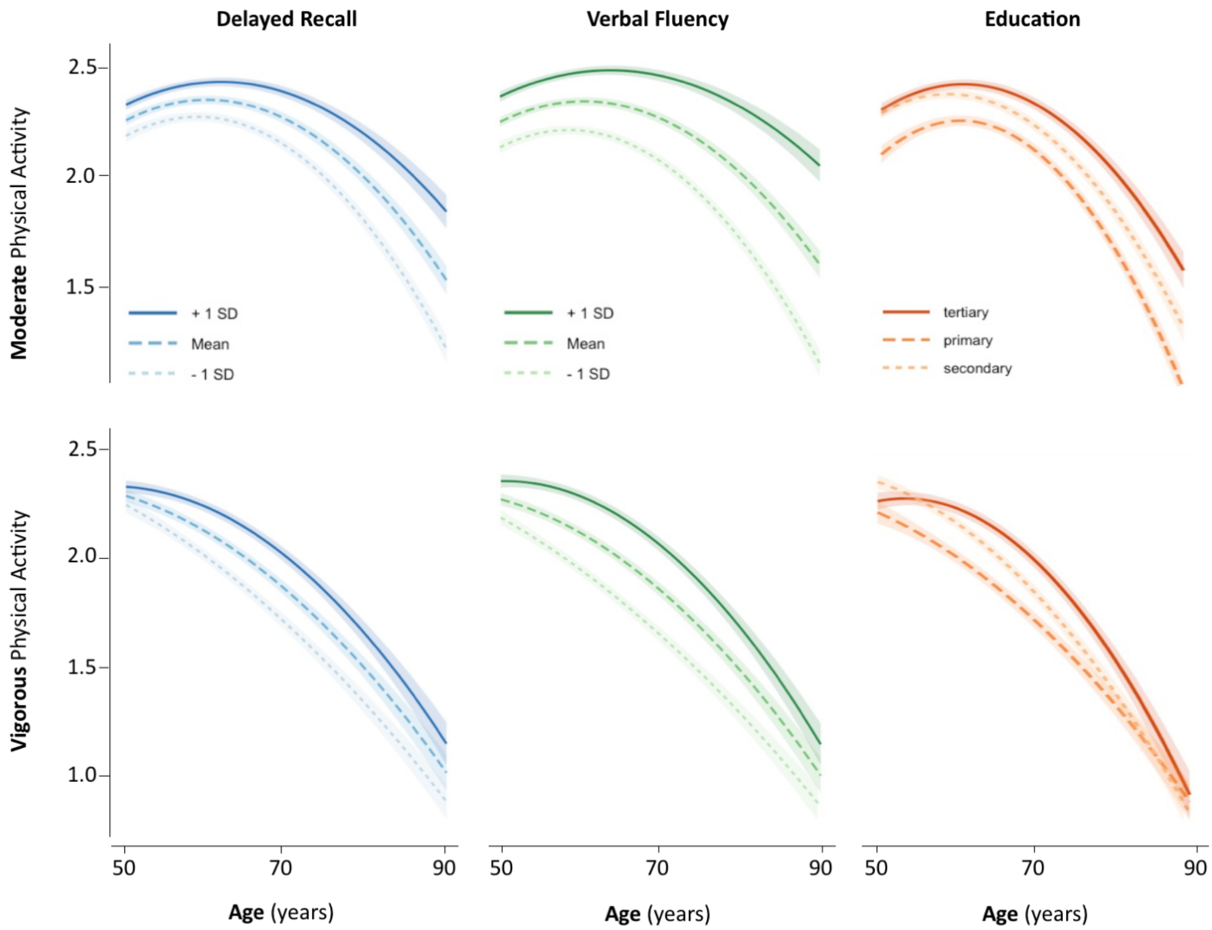

Figure 2. Associations of cognitive resources with the trajectories of moderate and vigorous physical activity across aging. For delayed recall and verbal fluency, the variables were standardized. Thus, the coefficients are interpreted as the effect of an increase of one standard deviation.

<u>Sensitivity analysis</u>

Results of sensitivity analyses adjusting for health behaviours (i.e., smoking, alcohol consumption, dietary behaviour), health-related covariates (i.e., depression, body mass index, and self-rated health), and additional sociodemographic variables (i.e., partner status and satisfaction with household income) were consistent with the main analyses (Table S5). Results excluding participants who dropped out, died, or had dementia were also consistent with the main analysis.

Discussion

Main findings

This study aimed to test whether cognitive resources were associated with the frequency of engagement in physical activity and its evolution across aging. In this large-scale longitudinal study including 21 European countries and 105,206 older adults, results showed that lower levels of cognitive resources were associated with less frequent engagement in physical activities and a steeper decline of this engagement across aging. These effects were observed across three cognitive indicators (i.e., delayed recall, verbal fluency, and education), two-levels of analysis (i.e., within- and between-participants) and two intensities of physical activity (i.e., moderate and vigorous). Moreover, inter-individual differences in cognitive resources showed a stronger impact on the engagement in moderate physical activity as adults grew older, but lower impact on the engagement in vigorous physical activity, which likely depends on other factors such as cardio-vascular fitness. These associations remained significant after adjusting for health behaviours, health-related covariates, and sociodemographic variables. Taken together, these results demonstrate that the engagement in moderate and vigorous physical activity and the trajectories of these engagements after the age of 50 are dependent on cognitive resources.

Comparison with previous studies

As hypothesized (H1), our results showed that lower cognitive resources were associated with lower engagement in moderate and vigorous physical activity in adults older than 50 years. These associations were consistent for the three indicators of cognitive resources (i.e., delayed recall, verbal fluency, and education) both at the within- and between-participant levels. These findings support previous studies that investigated the association between cognitive function and physical activity (7-11). However, unlike most of these previous studies focusing on the protective effect of physical activity on cognitive function, our results showed that cognitive resources are also required to engage in physical activity and to slow the decline of this engagement over the years.

We also hypothesized that lower cognitive resources were associated with faster decline of moderate and vigorous physical activity across aging. At the within-participant level, results showed an association between cognitive resources and physical activity trajectories irrespective of physical activity intensity (moderate vs. vigorous). Decreases in delayed recall or verbal fluency were associated with a linearly faster, but not accelerated, decline of physical activity. At the between-participant level, the associations were dependent on physical activity intensity. Lower levels of delayed recall, verbal fluency, and education were associated with an accelerated engagement decline in moderate physical activity, but with a decelerated engagement decline in vigorous physical activity. As such, the associations between cognitive resources and physical activity increased as adults grew older for moderate physical activity but decreased for vigorous physical activity. Taken together, these findings suggested that inter-individual differences in cognitive resources are more critical to explain the levels of moderate than vigorous physical activity as adults grows older. A potential explanation for these results is that, as adults aged, vigorous physical activity may become limited by physical factors, such as sarcopenia, thereby reducing the potential influence of cognitive resources. Importantly, results were robust after adjusting for multiple sociodemographic and health-related covariates, thereby confirming the critical role of cognitive resources in explaining physical activity.

Recent studies suggested that that cognitive resources are critical to counteract an innate tendency to minimize energetic expenditure and engage in physical activity (1, 4). Our results are in line with this suggestion. Previous studies also suggested that physical activity is a determinant of cognitive function, not the opposite (10, 11, 13). Yet, the most recent studies and those with a long follow-up (i.e., less prone to reverse causation biases) did not found evidence of a causal effect of physical activity on cognitive decline (15-18, 21). Moreover, this reverse causation is unlikely to explain the observed association between education and physical inactivity reported in our study, as physical inactivity in late adulthood cannot causally determine the level of education reached in early adulthood. Nevertheless, futures studies should formally test the time-ordered and reciprocal association between cognitive resources and physical activity using suited analytic strategies such as dynamic structural equation (22, 23).

Strengths and weaknesses

This study has many strengths. First, the repeated measurement of physical activity allowed to investigate the evolution of physical activity over 40 years (i.e., from age 50 to 90). Second, the repeated assessment of cognitive functions allowed to examine the influence of both inter-individual differences and intra-individual changes in these functions. Third, our study was based on data from more than 105,000 participants living in 21 European countries, thereby providing reliable and generalizable results. Fourth, we assessed the engagement in both moderate and vigorous intensities of physical activity and measured three different indicators of cognitive resources. Sixth, sensitivity analyses excluding participants diagnosed with dementia controlled for the potential confounding influence of this cognitive impairment. Finally, the results observed were robust even after adjusting for health behaviours, health-related covariates, and sociodemographic variables.

However, potential limitations should also be noted. First, our results are based on self-reported measures of physical activity, which creates the potential for misclassification bias (24). However, the potential inaccuracy of these self-reports is unlikely to explain the observed associations between cognitive resources and physical activity. Second, the SHARE design is associated with two selection biases. The first selection bias is linked to the recruitment procedure that occurs late in life (i.e., after 50 years old). As such, participants responding to SHARE may have specific characteristics (e.g., they are likely to be in better health than those not participating in the survey). The second selection bias is due to the loss of participants during the follow-up, which cannot be excluded, like in all long-term prospective studies. To attenuate this bias, our statistical analyses were adjusted for attrition and we also ran sensitivity analyses excluding for those participants who died or dropped out during the follow-up. Third, because our study was based on correlational data, a reverse causation between physical activity and cognitive resources cannot be excluded. Yet, as already mentioned above, the prospective effect of cognitive resources on physical activity is supported both theoretically (i.e., hypothesis of energetic cost minimization) and empirically (i.e., the reverse causation is unlikely for education).

Conclusion and policy implications

Lower cognitive resources are robustly associated with lower engagement in physical activity and faster decline of this engagement across aging. These findings support recent experimental work suggesting that cognitive resources are required to counteract an innate attraction to effort minimization. Interventions aiming to prevent the decline of cognitive resources should be implemented to improve the engagement in physical activity, which is associated with extensive health benefits (25), especially in older adults (26).

Methods

Study population and design

Our analyses used data from the Survey of Health, Ageing and Retirement in Europe (SHARE) (27), a European database of individuals aged 50 or older including 6 repeated measurements between 2004 and 2015. Physical activity and cognitive function (delayed recall and verbal fluency) were assessed at measurement 1, 2, 4, 5, and 6. Education was measured when the participant was included in the study. Participants aged 50 to 90 years with at least one measure of physical activity and cognitive functioning were included in our study. The relevant local research ethics committees in the participating countries approved SHARE. All participants provided written informed consent.

Measures

Outcomes

Physical activity was measured using two items (28-30). *Moderate physical activity* was assessed using this item: "How often do you engage in activities that require a low or moderate level of energy such as gardening, cleaning the car, or doing a walk?" *Vigorous physical activity* was assessed using this item: "How often do you engage in activities that require a vigorous level of energy such as gardening, cleaning the car, or doing a walk?" For each item, participants answered on 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, these variables were reversed so that higher values indicated higher physical activity.

Cognitive resources

Cognitive resources were measured using two indicators of cognitive function (delayed recall and verbal fluency) and one indicator of cognitive reserve (highest educational attainment) (31). In the 10-words delayed recall test (32), participants listened to a list of ten words that were read out loud by the interviewer. Immediately after reading the wordlist, the participants were asked to recall as many words as possible. This was asked again after a delay during which the verbal fluency and numeracy tests took place. The latter delayed recall score is the number of words that the respondent is able to recall, which ranges from 0 to 10. *In the verbal fluency test* (33), participants named as many different animals as they could think of in 60 seconds. The score that we used consisted of the total number of correctly named animals. UNESCO's International Standard Classification of Education (ISCED) was used to group participants into primary, secondary and tertiary levels of education (34).

Covariates

The following covariates were used: gender, measurement occasions (1, 2, 4, 5, 6), birth cohort [war (between 1914 and 1918 and between 1939 and 1945) / the Great Depression (between 1929 and 1928) / no war and no economic crisis (before 1913, between 1919 and 1938, and after 1945)], participant attrition [no dropout / dropout (participants who did not respond to both measurements 5 and 6) / death (participants who died during the survey)], participants' chronic conditions (e.g., hypertension, diabetes), country of residence (Austria, Belgium, Croatia, Czech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Luxembourg, Netherlands, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland), and dementia (dementia / no dementia). Dementia was assessed using the following question: "Has a doctor ever told you that you had / Do you currently have any of the conditions on this card?" (35, 36). It was specified that a doctor had told the participants that they currently have this condition or that they were treated or affected by the condition. Participants who had selected the option "Alzheimer's disease, dementia, organic brain syndrome, senility or any serious memory impairment" were categorized as having dementia.

Statistical analysis

Linear mixed models were used to examine the effect of cognitive resources on the engagement in physical activity and its trajectory across aging. By accounting for the nested structure of the data (i.e., repeated observations within a single participant) (37), these models allow to examine both the average engagement in physical activity across aging and the inter-individual variabilities in these levels and rate of change the years. Moreover, these models can separate within- from between-participant effects by introducing both the individual mean value of a particular variable and the deviation from this mean at each time point. The coefficient of the mean value estimates inter-individual differences. For instance, participants with lower levels of cognitive resources may have, on average, lower levels of physical activity. The coefficient of the deviation estimates intra-individual changes. For instance, for a given participant, having a lower level of cognitive resources than usual may be associated with a lower level of physical activity than usual.

The same modelling strategy was applied for the two outcomes of physical activity. The fitted models included linear age, quadratic age, and the a priori covariates as fixed effects. Their random structure encompassed random intercepts for participants and random linear slopes for the repeated measurements at the level of participants. These random effects estimated each participant's engagement in physical activity and the rate of change of this engagement over time. Age was centred at the midpoint of the sample's age range (70 years) and was then divided by 10. Thus, the coefficients yielded effects of the physical activity rate of change over a 10-year period. Model 1 tested the association between an indicator of cognitive resources (within- and between-participant effects) and the mean levels of physical activity in old age. In model 2, interaction terms between cognitive resources (within- and between-participant effects) and linear and quadratic age were included to assess the influence of cognitive resources on physical activity trajectories. Specifically, the interactions of between-participant differences with age tested whether between-participant differences in cognitive resources moderated the effect of age. For example, individuals with lower cognitive resources may show a faster decline of physical activity across aging. The interactions between within-participant differences and age assessed whether having a lower (vs. higher) level of cognitive resources than usual influenced physical activity trajectories. For instance, a faster decline in physical activity may be observed in individuals with a lower level of cognitive resources than usual. The models were fitted with one indicator of cognitive resources at a time, but we also fitted a fully-adjusted model that included the three indicators of cognitive function at the same time. Statistical analyses were performed using the R language and the lme4 and lmerTest packages (38-40). The conditional pseudo R^2 was used as an estimate of the effect size and was computed using the MuMin package. Finally, we performed 4 sensitivity analyses: 1) including additional covariates likely to influence both cognitive function and physical activity. Specifically, all the models were adjusted for health behaviours (i.e., smoking, alcohol consumption, dietary behaviour), health-related covariates (i.e., depression, body mass index, and self-rated health), and additional sociodemographic variables (i.e., partner status and satisfaction with household income); 2) excluding participants with dementia, 3) excluding participants who died during the survey, and 4) excluding participants who dropped out during the survey. Supplemental materials 1 provides more details on all covariates used in the sensitivity analyses.

Contributors
B.C and M.P.B designed the analyses. B.C. and M.P.B analysed the data. B.C. and M.P.B drafted the manuscript. All authors critically appraised and approved the final version of the manuscript.

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Preprint agreement
All authors are aware of and have agreed to submission of this manuscript as a preprint.

Competing interests
The authors declare no conflict of interests

Ethical approval
This study was part of the SHARE study, approved by the relevant research ethics committees in the participating countries, and all participants provided written informed consent.

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

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