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Relationship Between Decline in Cognitive Resources and Physical Activity

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Objective: This study aimed to test whether the level of cognitive resources explains engagement in physical activity across aging and whether the age-related decline of cognitive resources precede the decline in physical activity. ***Method:*** 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 moderate physical activity and its evolution across aging were dependent on cognitive resources. Cognitive resources and physical activity were measured 5 times over a 12-year period. Delayed recall, verbal fluency, and the level of education were used as indicators of cognitive resources. The frequency of engagement in moderate physical activity was self-reported. Dynamic structural equation models (SEM) were used to assess the temporal precedence of changes in cognitive resources and physical activity. ***Results:*** Lower cognitive resources were associated with lower levels and steeper decreases in moderate physical activity across aging. Results further revealed a time-ordered effect with a stronger influence of cognitive resources (delayed recall and verbal fluency) on subsequent changes in moderate physical activity than the opposite. ***Conclusion:*** These findings suggest that, after age 50, the level of engagement in moderate physical activity and its trajectory depend on the availability of cognitive resources.

Keywords: physical activity, aging, cognition, bidirectional associations

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During evolution, the ability to minimize energetic costs provided an advantage for survival by extending the time individuals could chase a pray or search for shelter, thereby increasing their odds of success (Cheval, Radel et al., 2018; Cheval, Sarrazin, Boisgontier, & Radel, 2017; Lieberman, 2015). As they provided a vital advantage, the behaviors associated with energetic minimization evolved into automatisms (Cheval, Tipura et al., 2018; Selinger, O'Connor, Wong, & Donelan, 2015). These energy-saving automatisms are in line with the resource conservation principle stating that individuals are naturally inclined to avoid

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Boris Cheval and Matthieu P. Boisgontier designed the analyses, analyzed the data, and drafted the manuscript. All authors critically appraised and approved the final version of the manuscript. Informed consent was obtained from all participants included in the study. This study was part of the SHARE study. This SHARE dataset is available at http://www.share-project.org/data-access.html. SHARE (Waves 1-4) was approved by the Ethics Committee of the University of Mannheim. SHARE (Waves 4-8) was approved by the Ethics Council of the Max Plank Society. This work uses data from SHARE Waves 1, 2, 3 (SHARELIFE), 4, 5 and 6 (DOIs: 10.6103/SHARE.w1.600; 10.6103/SHARE.w2.600; 10.6103/SHARE.w3.600; 10.6103/SHARE.w4.600; 10.6103/SHARE.w5.600; 10.6103/SHARE.w6.600). The SHARE data collection was primarily funded by the European Commission through FP5 (QLK6-CT-2001-00360), FP6 (SHARE-I3: RII-CT-2006-062193; COMPARE: CIT5-CT-2005-028857; SHARELIFE: CIT4-CT-2006-028812), and FP7 (SHARE-PREP: no.211909; SHARE-LEAP: no.227822; SHARE M4: no.261982). Additional funding from the German Ministry of Education and Research, the Max Planck Society for the Advancement of Science, the U.S. National Institute on Aging (U01_AG09740-13S2, P01_AG005842, P01_AG08291, P30_AG12815, R21_AG025169, Y1-AG-4553-01, IAG_BSR06-11, OGHA_04-064, HHSN271201300071C), and from various national funding sources is gratefully acknowledged (see http://www.share-project.org). Boris Cheval is supported by an Ambizione grant (PZ00P1_180040) from the Swiss National Science Foundation (SNSF). We thank Stephen Aichele for the support on the bivariate latent change score models.

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wasting resources (Brehm & Self, 1989; Klein-Flügge, Kennerley, Friston, & Bestmann, 2016; Prévost, Pessiglione, Météreau, Cléry-Melin, & Dreher, 2010; Skvortsova, Palminteri, & Pessiglione, 2014). In modern societies, where opportunities to avoid physical activity are ubiquitous, this automatic attraction to energetic cost minimization has contributed to spread the pandemic of physical inactivity across the world (Kohl et al., 2012). Recent results suggested that cognitive resources are required to counteract this automatic attraction and engage in physical activity (Cheval, Rebar et al., 2019; Cheval, Tipura et al., 2018). These results are consistent with the temporal self-regulation theory (Hall & Fong, 2007), which contends that executive control resources are needed to resist automatic behavioral tendencies and translate conscious intentions into actual behaviors. Based on this literature, cognitive resources appear as being key in the regulation of physical activity.

In healthy aging, observational studies have widely reported the protective effect of physical activity on cognitive functioning (Baumgart et al., 2015; Blondell, Hammersley-Mather, & Veerman, 2014; Hamer, Terrera, & Demakakos, 2018; Lindwall et al., 2012; Morgan et al., 2012; Sofi et al., 2011).Yet, the evidence stemming from intervention studies in older adults is inconclusive. Some studies observed this protective effect of physical activity (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008; Colcombe & Kramer, 2003), whereas more recent ones did not (Andrieu et al., 2017; Loprinzi, Scott, Ikuta, Addoh, & Tucker, 2019; Sink et al., 2015; Snowden et al., 2011; Young, Angevaren, Rusted, & Tabet, 2015). Other studies supported the prospective effect of cognition and education on physical activity (Cheval, Sieber et al., 2018; Sabia et al., 2017). Finally, one study suggested a bidirectional relationship between cognitive functioning and physical activity, with a stronger effect of cognitive function on physical activity than in the opposite direction (Daly, McMinn, & Allan, 2015). Yet, the analytical strategy of this study consisted in using physical activity (vs. cognitive resources) in the model as either the outcome or the predictor, which did not allow to formally test potential bidirectional associations, nor the temporal precedence of the observed changes. Overall, this literature questions the unidirectionality of the relationship between cognition and physical activity. To fill this knowledge gap and clarify the nature of the relationship between cognitive resources and physical activity, we used an analytical strategy suited for estimating bidirectional associations and temporal precedence.

To investigate whether cognitive resources explain participation in moderate physical activity and its trajectories across aging, we used data from 105,206 adults aged 50 years and older collected over 12 years. Both the effect of interindividual differences and intraindividual changes in cognitive resources were tested. Based on the literature contending that cognitive resources are required to counteract the attraction to energetic cost minimization, thereby facilitating the engagement in physical activity, we hypothesized that lower cognitive resources (both inter- and intraindividual) are associated with less frequent engagement in physical activity (Hypothesis 1 [H1]) and a more pronounced decline of this engagement across aging (Hypothesis 2 [H2]). We also hypothesized that the decline in cognitive resources precedes the decline in physical activity (Hypothesis 3 [H3]).

Method

Population and Design

Our analyses used data from the Survey of Health, Ageing, and Retirement in Europe (SHARE; Börsch-Supan, Brandt, & Schröder, 2013), a European database of individuals aged 50 years or older including five repeated measurements between 2004 and 2015. Physical activity and cognitive function (delayed recall and verbal fluency) were assessed at Measurements 1, 2, 4, 5, and 6. Education was measured when the participant joined the study. Participants aged 50 to 90 years with at least one measure of physical activity and cognitive functioning were included in our analyses. The relevant ethics committees in the participating countries approved SHARE and all participants provided written informed consent.

Measures

Physical activity. According to the World Health Organization (2010), physical activity is any bodily movement produced by skeletal muscles that requires energy expenditure, which includes playing sports, exercising, but also domestic and recreational activities. In our study, moderate physical activity was measured using the following 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?" (Cheval, Sieber et al., 2018; de Souto Barreto, Cesari, Andrieu, Vellas, & Rolland, 2017; Lindwall, Larsman, & Hagger, 2011). 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 statistical models, the variable was reversed so that higher values indicated higher physical activity.

Cognitive resources. Cognitive resources were measured using the following three indicators: delayed recall, verbal fluency, and highest educational attainment. In the 10-word delayed recall test (Harris & Dowson, 1982), participants listened to a list of 10 words that were read out loud by the interviewer. Immediately after reading the word list, the participants were asked to recall as many words as possible. This was asked again after a delay during which the verbal fluency 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 (Rosen, 1980), participants named as many different animals as they could think of in 60 s. The score consisted of the total number of correctly named animals. Verbal fluency and delayed recall tasks were used to assess fluid cognitive abilities (Aartsen et al., 2019), with verbal fluency reflecting executive functioning (e.g., as executive control, selective attention or selective inhibition; Lezak, Howieson, Loring, & Fischer, 2004) and delayed recall reflecting memory performance (Zhao, Lv, Zhou, Hong, & Guo, 2012). Yet, it is important to acknowledge that emerging research suggests that verbal fluency is also highly related to verbal skills and thus, is not a perfect measure of executive functioning (Shao, Janse, Visser, & Meyer, 2014). The UNESCO's International Standard Classification of Education (ISCED) was used to group participants into primary, secondary, and tertiary levels of education (UNESCO, 2006).

Covariates. The following covariates were used: gender, measurement occasions, birth cohort, attrition, chronic health conditions, country of residence, and dementia (online supplemental material 1).

Statistical Analysis

Physical activity trajectories across aging and the effects of cognitive resources on these trajectories were estimated in an accelerated longitudinal design (Duncan, Duncan, & Hops, 1996) using mixed effects models (Boisgontier & Cheval, 2016). By accounting for the nested structure of the data (i.e., repeated observations within a single participant), these models allow examining both the average engagement in physical activity across aging and the interindividual variabilities in this engagement as well as the rate of change. Mixed effects models do not require an equal number of observations across participants. Therefore, participants with missing observations were included in these models. These models can separate within- and between-person 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 interindividual differences. For example, individuals with higher levels of cognitive resources may have, on average, higher levels of physical activity. The coefficient of the deviation estimates intraindividual changes. For example, for a given individual, having a higher level of cognitive resources than usual may be associated with a higher level of physical activity than usual.

The fitted models included linear age, quadratic age, and the 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 centered at the midpoint of the sample's age range (70 years) and was then divided by 10. Thus, a 1-unit change in the coefficients yielded effects on the physical activity rate of change over a 10-year period. Model 1 tested the association of an indicator of cognitive resources (within- and between-person effects) and the mean level of physical activity in older adults. In Model 2, interaction terms between cognitive resources (within- and between-person effects) and linear and quadratic age were included to assess the influence of cognitive resources on physical activity trajectories. The quadratic effect of age was added to account for the potential influence of cognitive resources on the accelerated (or decelerated) decline of physical activity across aging. Specifically, the interactions of between-participants differences with age tested whether between-participants 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 of within-person differences with age tested whether having a lower (or 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. We also fitted a fully adjusted model including the three indicators of cognitive resources. Statistical analyses were performed using the lme4 and lmerTest R packages (Bates, Mächler, Bolker, & Walker, 2015; Kuznetsova, Brockhoff, & Christensen, 2016; R Core Team, 2017). Pseudo R^2 were calculated to estimate effect size.

We performed eight sensitivity analyses: (a) including health behaviors (smoking, alcohol consumption, dietary behavior), health-related covariates (depression, body mass index, and self-rated health), and additional sociodemographic variables (partner status and satisfaction with household income); (b) excluding participants with dementia; (c) excluding participants with a suspicion of dementia (as indicated with a score >2 on a time orientation question); (d) excluding participants who died during the survey; (e) excluding participants who dropped out during the survey; (f) excluding participants with hearing problems; (g) excluding participants with frailty; (h) excluding participants with less than three measurements. Online supplemental material 2 provides more details on the covariates used in the sensitivity analyses.

We performed three robustness analyses: (a) Participants who answered *more than once a week* were classified as "physically active," whereas the other participants were classified as "physically inactive." This analysis was used to reduce a potential misclassification bias in which physically inactive participants would be wrongly classified as physical active. (b) Participants who answered *hardly ever or never* were classified as "physically inactive," whereas the other participants were classified as "physically active." This analysis was used to reduce a potential misclassification bias in which physically active participants would wrongly be classified as physical inactive. (c) Participants who answered *hardly ever or never* or *one to three times a month* were classified as "physically inactive," whereas the others participants were classified as "physically active." This cutoff was used to test a potential misclassification bias in-between the ones of the first two robustness analyses. Online supplemental material 3 provides more details on the covariates used in the robustness analyses.

Bivariate latent change score models (BLCSMs; McArdle, 2001) were used to examine the temporal precedence of changes in cognitive resources and physical activity. BLCSMs are structural equation models (SEM) that combine latent growth curves models (Meredith & Tisak, 1990) with autoregressive cross-lag models (Jöreskog, 1970). We adopted a step-by-step modeling strategy (Aichele et al., 2018; Aichele & Ghisletta, 2018; Grimm, Ram, & Estabrook, 2016). The fitted models included dynamic parameters: coupling and autoproportional effects. BLCSM1 did not include cross-lag paths between cognitive resources and physical activity and served as the baseline comparison model. In BLCSM2, a unidirectional coupling from cognitive resources predicting subsequent changes in physical activity was included. In BLCSM3, a unidirectional coupling from physical activity to predicting subsequent changes in cognitive resources was included to BLCSM1. BLCSM4 was a bidirectional coupling model that included both pathways. BLCSM2 assessed the temporal precedence of cognitive resources on physical activity, BLCSM3 assessed the temporal precedence of physical activity on cognitive resources, and BLCSM4 assessed the reciprocal associations between cognitive resources and physical activity. The models were run separately for each cognitive indicator (verbal fluency and delayed recall), were fitted using Mplus (Muthén & Muthén, 2012) with full-information maximum-likelihood estimation, and were tested against the baseline model (BLCSM1). A likelihood ratio test of changes was performed to determine whether the coupling parameters were significant. The alpha criterion was set to .01. The weighted Bayesian information criterion [w(BIC)] (Wagenmakers & Farrell, 2004) was used to select the best fitting model. All the models were also tested using vigorous physical activity (online supplemental material 4).

Results

At baseline, 11.4% of the participants were hardly ever or never active, 6.0% were active one to three times per month, 13.8% were active once a week, and 68.7% were active more than once a week (see Table 1). Physically active participants showed better delayed recall and verbal fluency, higher education, lower 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 (see Table 1).

Cognitive Resources and Level of Physical Activity

Results showed that lower levels of delayed recall, verbal fluency, and education were associated with lower engagement in physical activity (Table 2 and Table S1 in the online supplemental materials). For delayed recall and verbal fluency, this association was observed at the between- and within-person level. 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, lower delayed recall or verbal fluency were associated with lower engagement in mod-

Table 1
Sample Characteristics by Baseline Engagement in Moderate Physical Activity

Variables	Physically active (n = 86,861)		Physically Inactive (n = 18,345)		P
Cognitive resources					
Delayed recall (number of words), *SD*	3.9	2.1	2.9	2.1	<.001
Verbal fluency (number of words), *SD*	20.4	7.4	16.0	7.8	<.001
Education					
Primary	18172	20.9%	6617	36.1%	
Secondary	48964	56.4%	9240	50.4%	
Tertiary	19725	22.7%	2488	13.5%	<.001
Covariates					
Age at baseline (years), *SD*	62.8	9.2	67.4	10.9	<.001
Gender					
Women	47142	54.3%	10726	58.5%	
Men	39719	45.7%	7619	41.5%	<.001
Dementia					
Yes	1716	2.0%	1083	5.9%	
No	85145	98.0%	17262	94.1%	<.001
Chronic conditions (2 or more)					
Yes	34223	39.4%	10320	56.3%	
No	52628	60.6%	8025	43.7%	<.001
Countries					
Belgium	7073	8.1%	1373	7.5%	
Austria	4675	5.4%	942	5.1%	
Denmark	4760	5.5%	422	2.3%	
France	5782	6.7%	1195	6.5%	
Germany	6275	7.2%	833	4.5%	
Greece	4678	5.4%	1141	6.2%	
Israel	2220	2.6%	699	3.8%	
Italy	5268	6.1%	2097	11.4%	
Netherlands	4686	5.4%	554	3.0%	
Spain	5985	6.9%	1363	7.4%	
Sweden	5236	6.0%	401	2.2%	
Switzerland	3602	4.1%	488	2.7%	
Czech Republic	6386	7.4%	1710	9.3%	
Ireland	827	0.9%	139	0.8%	
Poland	1999	2.3%	766	4.2%	
Estonia	5991	6.9%	1325	7.2%	
Hungary	2161	2.5%	729	4.0%	
Portugal	1275	1.5%	740	4.0%	
Slovenia	4301	4.9%	778	4.2%	
Luxembourg	1683	1.9%	278	1.5%	
Croatia	1998	2.3%	372	2.0%	<.001
Birth cohort					
After 1945	50621	58.3%	7701	42.0%	
Between 1939 and 1945	17085	19.7%	3331	18.2%	
Between 1929 and 1938	14914	17.2%	4746	25.9%	
Between 1919 and 1928	4241	4.8%	2567	13.9%	<.001

Note. Physically active participants scored 1 or 2 on the item assessing moderate physical activity; physically inactive participants scored 3 or 4. *SD* = Standard Deviation.

Table 2
Association of Cognitive Resources With the Levels and Trajectories of Moderate Physical Activity Across Aging

Models	Models delayed recall only		Models verbal fluency only		Models education only		Full models	
Moderate physical activity	*b* [95% CI]	*P*	*b* [95% CI]	*P*	*b* [95% CI]	*P*	*b* [95% CI]	*P*
Level								
Cognitive resources								
Between-person effects								
Delayed recall	.06 [.06, .06]	<.001					.02 [.02, .03]	<.001
Verbal fluency			.03 [.02, .03]	<.001			.02 [.02, .02]	<.001
Education (ref. primary)								
Secondary					.14 [.13, .16]	<.001	.08 [.06, .09]	<.001
Tertiary					.21 [.20, .23]	<.001	.07 [.05, .09]	<.001
Within-person effects								
Delayed recall	.01 [.01, .02]	<.001					.01 [.01, .01]	<.001
Verbal fluency			.01 [.01, .01]	<.001			.01 [.01, .01]	<.001
Rate of change (trajectories)								
Age (10-year follow-up)	−.22 [−.23, −.20]	<.001	−.20 [−.22, −.19]	<.001	−.25 [−.26, −.23]	<.001	−.19 [−.20, −.17]	<.001
Age (10-year follow-up) squared	−.11 [−.12, −.11]	<.001	−.11 [−.11, −.10]	<.001	−.12 [−.12, −.11]	<.001	−.11 [−.11, −.10]	<.001
Cognitive resources								
Between-person effects								
Linear effect								
Delayed recall	.06 [.06, .07]	<.001					.02 [.01, .02]	<.001
Verbal fluency			.08 [.08, .09]	<.001			.07 [.06, .08]	<.001
Education (ref. primary)								
Secondary					.02 [.01, .03]	.001	−.01 [−.02, .00]	.150
Tertiary					.08 [.07, .10]	<.001	.02 [.00, .04]	.020
Non-linear (quadratic) effect								
Delayed recall	.02 [.01, .02]	<.001					.00 [.00, .01]	.210
Verbal fluency			.02 [.02, .03]	<.001			.02 [.01, .02]	<.001
Education (ref. primary)								
Secondary					.03 [.02, .04]	<.001	.02 [.01, .03]	<.001
Tertiary					.04 [.03, .05]	<.001	.03 [.01, .04]	.001
Within-person effects								
Linear effect								
Delayed recall	.01 [.00, .01]	.004					.00 [.00, .01]	.390
Verbal fluency			.02 [.01, .02]	<.001			.02 [.01, .02]	<.001
Education (ref. primary)								
Secondary								
Tertiary								
Non-linear (quadratic) effect								
Delayed recall	.00 [.00, .01]	.160	.00 [.00, .01]	.180			.00 [.00, .00]	.570
Verbal fluency							.00 [−.00, .01]	.310

Note. All models were adjusted for gender, measurement occasion, dementia, chronic conditions, country of residence, birth cohort, and attrition. The models estimating the level of physical activity did not include interactions between cognitive resources and age (linear and quadratic). The models estimating the rate of change of physical activity included these interactions. "Age (10-year follow-up)" and "Age (10-year follow-up) squared" estimated the linear and quadratic changes in the odds of engagement in physical activity over a 10-year period.

erate physical activity. These associations remained significant in the fully adjusted model. Results of the sensitivity and robustness analyses were consistent with the main analyses (Table S5 in the online supplemental materials).

Cognitive Resources and Physical Activity Trajectories

Results showed that lower levels of delayed recall, verbal fluency, and education were associated with a steeper decline of physical activity across aging (Figure 1; Table 2, and Table S1 in the online supplemental materials). 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 were associated with a faster decline of physical activity, but without acceleration across aging. In the fully adjusted model, these associations were attenuated but cognitive resources remained associated with physical activity trajectories. In the latter model, cognitive resources explained 5.8 and 6.4% of the interindividual variance of the level and trajectories of moderate physical activity, respectively. Taken together, all the variables explained 21.8 and 19.2% of the interindividual variance of the level and trajectories of moderate physical activity, respectively. Overall, results of the sensitivity and robustness analyses were consistent with the main analyses (Table S2 in the online supplemental materials), thereby suggesting that the main results were not sensitive to specific subsample characteristics or dependent on the way we treated the dependent variable.

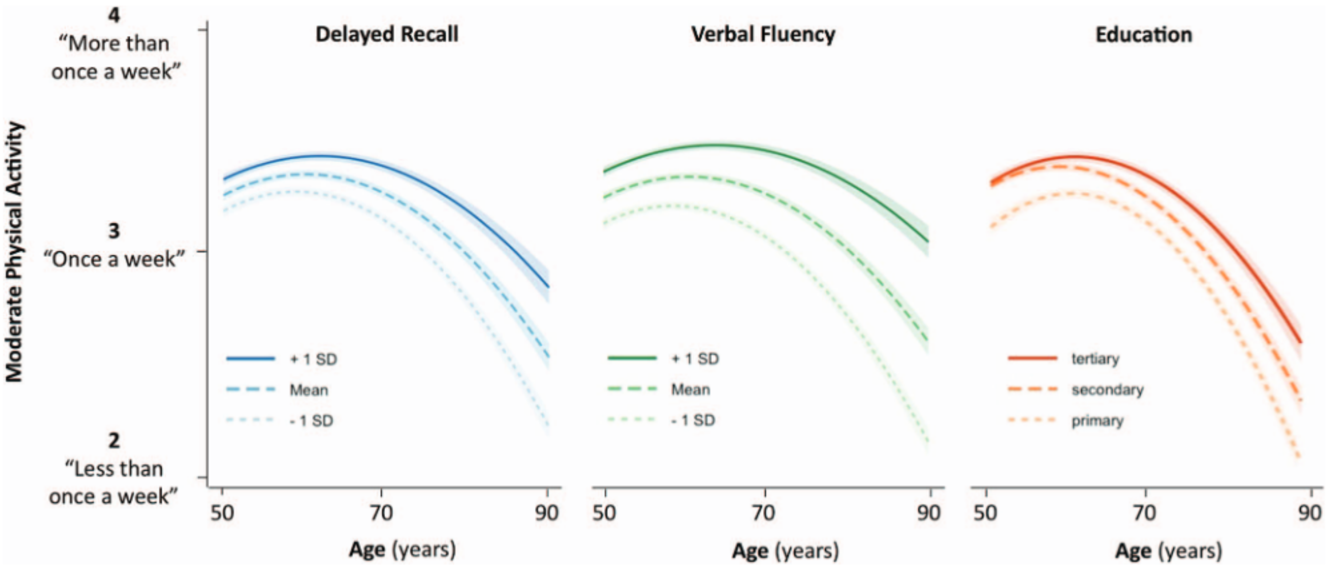

Figure 1. Associations between cognitive resources and trajectories of moderate physical activity across aging. For delayed recall and verbal fluency, the variables were standardized. The coefficients are interpreted as the effect of an increase of 1standard deviation. See the online article for the color version of this figure.

Temporal Precedence

Results showed a fit improvement when the cognitive resources (delayed recall and verbal fluency) → change in moderate physical activity coupling was included in the baseline model (BLCSM2 vs. BLCSM1). Including the moderate physical activity → change in cognitive resources coupling also improved the fit (BLCSM3 vs. BLCSM1), but to a lesser extent. The bidirectional couplings model showed better fit than the baseline model (BLCSM4 vs. BLCSM1). This better fit was mainly explained by the cognitive resources → change in moderate physical activity coupling. The weighted Bayesian information criterion favored BLCSM2 over all the other models. BLCSM2 accounted for 81.5% (for delayed recall) and 72.8% (for verbal fluency) of relative predictive accuracy. BLCSM3 accounted for 9.5% (for delayed recall) and 3.3% (for verbal fluency) of predictive accuracy. Overall, results of this step-by-step approach clearly showed that the model including the effect of the cognitive resources → changes in physical activity coupling (BLCSM2) was the model that best fitted the data (Table 3; Figure 2).

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 moderate physical activity

Table 3
Changes in Fit of the Bivariate Latent Change Score Models

Moderate physical activity Models	Parameters	chi2	*df*	CFI	BIC	w(BIC)	RMSEA	delta chi2	delta *df*	*P*
Delayed recall										
No coupling	19	1845.90	46	.981	1772551.61	.064	.018			
Delayed recall → changes in moderate physical activity	20	1828.97	45	.982	1772546.52	.816	.018	−16.93	1	<.001
Moderate physical activity → changes in delayed recall	20	1833.26	45	.981	1772550.82	.095	.018	−12.64	1	<.001
Full coupling	21	1824.22	44	.982	1772553.47	.025	.018	−21.68	2	<.001
Verbal fluency										
No coupling	19	1431.12	46	.988	2387128.17	.235	.016			
Verbal fluency → changes in moderate physical activity	20	1417.17	45	.988	2387125.91	.729	.016	−13.95	1	<.001
Moderate physical activity → changes in verbal fluency	20	1423.34	45	.988	2387132.08	.033	.016	−7.78	1	<.001
Full coupling	21	1416.58	44	.988	2387137.01	.003	.016	−14.55	2	<.001

Note. CFI = comparative fit index; chi2 = deviance (−2 × log-likelihood); *df* = change in deviance per degrees freedom; BIC = Bayesian information criterion; w(BIC) = weighted Bayesian information criterion; RMSEA = root mean square error of approximation. Delta chi2 is estimated in comparison with the no coupling model, with lower values indicating better fit. *p* = *p*-value for the log likelihood-ratio test of change in model fit.

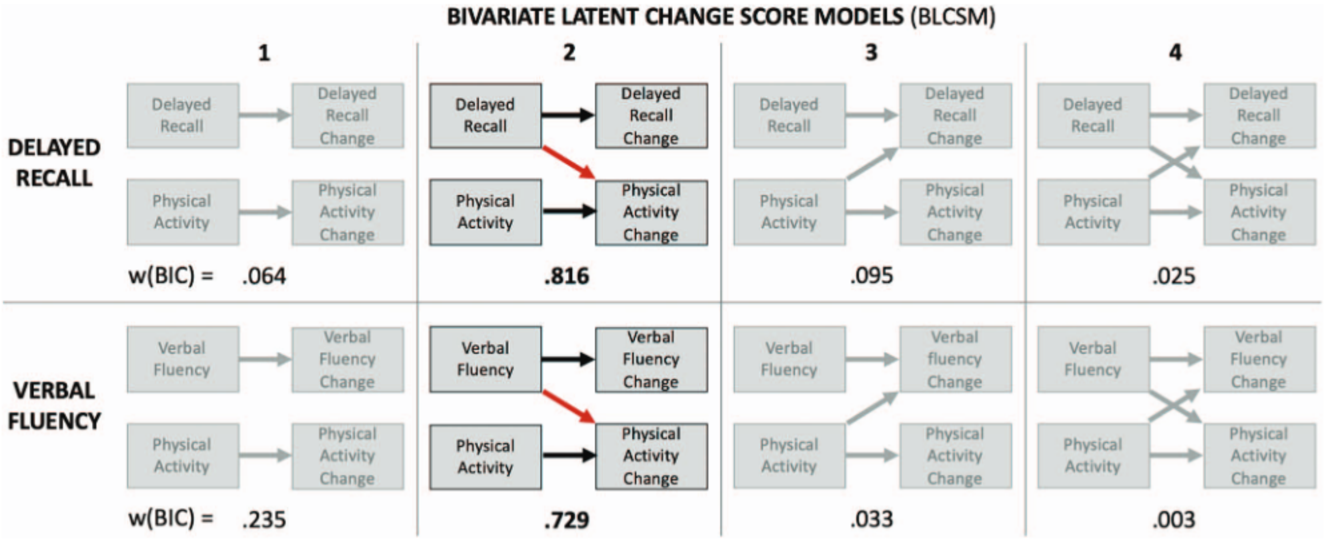

Figure 2. Fit of the bivariate latent change score models (BLCSM1 to 4) in two cognitive resources that changed across aging (delayed recall and verbal fluency). BLCSM1 = baseline comparison model. BLCSM2 = unidirectional coupling from cognitive resources predicting subsequent changes in physical activity. BLCSM3 = unidirectional coupling from physical activity to predicting subsequent changes in cognitive resources. BLCSM4 = bidirectional coupling model that included both pathways. w(BIC) = weighted Bayesian information criterion. BLCSM2 best fitted the data in both cognitive resources. See the online article for the color version of this figure.

and with a steeper decline of this engagement across aging. These effects were observed across three cognitive indicators (delayed recall, verbal fluency, and education) and two levels of analysis (within- and between-person). These associations remained significant after adjusting for health behaviors, health-related covariates, and sociodemographic variables. These results using an analytical strategy suited to assess temporal precedence of changes between two variables further revealed, for the first time, that the decline of cognitive resources preceded the decline of moderate physical activity, with a weaker association in the opposite direction. Taken together, these results demonstrate that the engagement in moderate physical activity and its trajectory after age 50 depends on cognitive resources.

Comparison With Previous Studies

Results showed that lower cognitive resources were associated with lower engagement in moderate physical activity in adults aged 50 years and older (H1). This association was consistent across the three indicators of cognitive resources at the within- and between-person levels. These findings support previous studies that investigated the association between cognitive functioning and physical activity (Baumgart et al., 2015; Blondell et al., 2014; Hamer et al., 2018; Morgan et al., 2012; Sofi et al., 2011).

Results showed that lower levels of cognitive resources were associated with an accelerated decline of physical activity at the within- and between-person levels (H2). This association was robust as it remained significant after adjusting for multiple sociodemographic and health-related covariates, thereby confirming the critical role of cognitive resources in explaining physical activity. Of note, the results were consistent across the three indicators of cognitive resources, which targeted somewhat different cognitive processes. Therefore, multiple dimensions of cognitive resources may be required to engage in physical activity.

To the best of our knowledge, this study is the first one to formally test the temporal precedence of cognitive resources and moderate physical activity. Results showed that the influence of cognitive resources on subsequent changes in physical activity was stronger than the influence in the opposite direction (H3). While previous studies focused on the protective effect of physical activity on cognitive functioning (Angevaren et al., 2008; Colcombe & Kramer, 2003), our results showed that this relationship is not unidirectional. Cognitive resources are required to engage in physical activity and to slow down the decline of this engagement over the years. A potential explanation for these time-ordered associations is that cognitive resources are critical in counteracting a general tendency to minimize energetic expenditure and to engage in physical activity (Cheval, Radel et al., 2018; Cheval, Sarrazin, Isoard-Gautheur, Radel, & Friese, 2015; Cheval, Tipura et al., 2018). This rationale is in line with the resource conservation principle stated by other psychological (Brehm & Self, 1989; Hall & Fong, 2007) and neuroscientific (Klein-Flügge et al., 2016; Prévost et al., 2010; Skvortsova et al., 2014) perspectives of human motivation. This explanation is also supported by recent results showing that avoiding sedentary behavior opportunities requires higher brain activity in the frontal lobe (Cheval, Tipura et al., 2018), which has repeatedly been related to cognitive resources (Duncan & Owen, 2000).

The availability of the cognitive resources supporting the engagement in physical activity may be particularly important in modern societies, where opportunities to adopt sedentary behaviors are ubiquitous (Cheval et al., 2017). The fact that physical activity was also associated, although to a weaker extent, with subsequent changes in cognitive resources suggested a reciprocal relationship. This result is consistent with previous studies suggesting that physical activity is a determinant of cognitive functioning (Blondell et al., 2014; Colcombe & Kramer, 2003; Hamer et al., 2018), although most recent studies and those with a long follow-up (i.e., less prone to reverse causation biases) found no evidence of a causal effect of physical activity on cognitive decline (Andrieu et al., 2017; Sabia et al., 2017; Sink et al., 2015; Snowden et al., 2011; Young et al., 2015).

Strengths and Weaknesses

This study has many strengths. First, the repeated measurement of physical activity allowed investigating its evolution over 40 years (i.e., from age 50 to 90). Second, the repeated assessment of cognitive resources allowed examining the influence of interindividual differences and intraindividual changes. Third, sensitivity analyses excluding participants with dementia controlled for the potential confounding influence of this cognitive impairment. Fourth, results were robust after adjusting for health behaviors, health-related covariates, and additional sociodemographic variables. Fifth, this study was the first one to formally test the temporal precedence of the decline in cognitive resources and physical activity using dynamic structural equation models.

However, potential limitations should also be noted. The first limitation is related to physical activity. Our results were based on self-reported measures of moderate physical activity, which creates the potential for misclassification bias (Prince et al., 2008). However, the potential inaccuracy of these self-reports is unlikely to explain the observed associations between cognitive resources and physical activity. Furthermore, results of the robustness analyses testing different categorization were consistent with those of the main analysis. The scale also lacked granularity, which prevented the assessment of specific physical activity levels associated with health benefits, such as the 30 min of moderate physical activity intensity five times per week. Studies accurately determining thresholds of physical activity are needed. Additionally, the examples of physical activities used in the scale (e.g., gardening, cleaning the car, walking) may have biased participants' response toward activities that were more specifically associated with these social contexts. Moreover, the use of a single-item measure is associated with potential issues related to reliability and coverage of the construct of interest. Using other tools to assess physical activity more accurately is recommended for future research. It should also be noted that the results of the models examining vigorous physical activity showed a lower impact of cognitive resources on physical activity as adults grew older (online supplemental material 2). Results of the cross-lagged dynamic structural equation models failed to converge. These results suggested that other processes should be considered when investigating the factors explaining participation in vigorous physical activity, including age-related musculoskeletal limitations. The processes linking cognitive resources and vigorous physical activity may be different. The second limitations are potential selection biases related to the SHARE design. The recruitment procedure occurred late in life (i.e., after 50 years old) and participants who were able to respond to SHARE may have specific characteristics. Another selection bias was due to the loss of participants during the follow-up, which cannot be excluded, but cannot be avoided in long-term prospective studies. To attenuate this bias, our statistical analyses were adjusted for attrition, and sensitivity analyses excluded participants who died or dropped out during the follow-up. The third limitation is related to the cognitive resources. In the large and rich SHARE dataset, the gold standard procedures used to assess cognitive resources were not rigorously followed. For example, verbal tasks were performed between the immediate and delayed recall test, which may have introduced some noise. Yet, a computer assisted personal interview (CAPI) was used to increase the standardization of the procedure and improve measurement reliability between participants. In addition, measurement errors are more likely to decrease rather than increase the ability to detect associations between variables. Also, verbal fluency was used to assess fluid cognitive abilities, such as executive control and inhibition (Fitzpatrick, Gilbert, & Serpell, 2013; Lezak et al., 2004). Yet, previous studies showed that verbal fluency was not only affected by executive control ability, but also by verbal ability (Shao et al., 2014). Future studies could use tasks that are specifically designed to tap into the different domains of executive functions to determine their relative contribution to physical activity (Miyake & Friedman, 2012).

Conclusion and Policy Implications

Lower cognitive resources are robustly associated with lower engagement in moderate physical activity and faster decline of this engagement across aging. These findings support recent studies suggesting that cognitive resources are required to counteract a general attraction to effort minimization. Therefore, professionals aiming to improve the engagement of their patients or clients in physical activity might benefit from investigating the development of interventions designed to attenuate the decline of cognitive resources.

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