The relation of education and cognitive activity to mini-mental state in old age: the role of functional fitness status

Andreas Ihle^{1,2} · Élvio R. Gouveia^{2,3,4} · Bruna R. Gouveia^{2,4,5} · Duarte L. Freitas^{3,6} · Jefferson Jurema⁷ · Rui T. Ornelas³ · António M. Antunes³ · Bárbara R. Muniz⁸ · Matthias Kliegel^{1,2}

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Abstract It remains unclear so far whether the role of cognitive reserve for cognitive functioning in old age may differ between individuals with low, compared to those with high functional fitness status. Therefore, the present study set out to investigate the relation of education and cognitive leisure activity as key markers of cognitive reserve to mini-mental state in old age (as an indicator of the extent of cognitive impairment) and its interplay with functional fitness status in a large sample of older adults. We assessed MMSE in 701 older adults ($M = 70.4$ years, $SD = 6.9$, range: 60–91). We measured functional fitness status using the Senior Fitness Test battery and interviewed individuals on their education and cognitive leisure activity. Results showed that better functional fitness status, longer education, and greater engagement in cognitive leisure activity were significantly related to higher MMSE scores. Moderation analyses showed that the relations of education and cognitive leisure activity to MMSE scores were significantly larger in

individuals with low, compared to those with high functional fitness status. In conclusion, cognitive functioning in old age may more strongly depend on cognitive reserve accumulated during the life course in older adults with low, compared to those with high functional fitness status. These findings may be explained by cross-domain compensation effects in vulnerable individuals and may (at least partly) account for the large variability in cognitive reserve–cognition relations debated in the literature.

Keywords Cognition · Cognitive reserve · Functional fitness status · Older adults

Introduction

Cognitive reserve and cognitive functioning in old age

A major goal in current gerontological research is to understand how interindividual differences in cognitive functioning in old age emerge (Hultsch et al. 1999). To address this issue, the cognitive reserve concept postulates that interindividual differences in the effective recruitment of neural

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✉ Andreas Ihle
Andreas.Ihle@unige.ch

¹ Department of Psychology, University of Geneva, Geneva, Switzerland

² Center for the Interdisciplinary Study of Gerontology and Vulnerability (CIGEV), University of Geneva, Geneva, Switzerland

³ Department of Physical Education and Sport, University of Madeira, Funchal, Portugal

⁴ Madeira Interactive Technologies Institute, Funchal, Portugal

⁵ Health and Social Affairs Administration Institute, Secretary of Health of the Autonomous Region of Madeira, Funchal, Portugal

⁶ Department of Mathematical Sciences, University of Essex, Colchester, UK

⁷ Coordination of Physical Education and Sport, Amazonas State University, Manaus, Brazil

⁸ City Hall of Manaus, Amazonas - Municipal Secretary of Youth Sports and Leisure, Manaus, Brazil

networks and cognitive processes explain differences in individuals' capacity to cope with or compensate for age-related decline (Stern 2009, 2012). In individuals with healthy cognitive functioning, these mechanisms contribute to the adaptation of brain activity when task difficulty level is increased and thereby enhance cognitive performance (Stern 2012). Empirically corroborating the predictions of the cognitive reserve concept, evidence showed that longer education in early life and cognitive leisure activity in midlife and old age contribute to the buildup of cognitive reserve during the life course and are related to better cognitive functioning such as memory and executive functioning in old age (Gatz et al. 2001; Karp et al. 2006; McDowell et al. 2007; see Hertzog et al. 2008; Opdebeeck et al. 2016, for overviews). Differentiating early-life markers of cognitive reserve (i.e., education) and midlife/late-life markers of cognitive reserve (i.e., cognitive leisure activity), Opdebeeck and colleagues (2016) reported in their meta-analysis considerably higher effect sizes for education ($r_s .23-.31$), compared to cognitive leisure activity ($r_s .08-.27$) in relation to screening measures, episodic memory, working memory, executive functioning, visuospatial ability, language, and overall cognitive functioning in old age.

However, there is still ongoing controversy about the role of education and cognitive activities for cognitive functioning in adulthood (see Hertzog 2009; Hertzog et al. 1999; Salthouse 2006; Van Dijk et al. 2008, for discussions). The large variability in findings on this topic debated in the literature suggests that the cognitive reserve–cognition relation is complex and may be moderated.

Cognitive reserve and the vulnerability framework

Recently, one avenue in solving this puzzle of inconsistent results became to investigate the role of cognitive reserve in certain vulnerable (compared to less vulnerable) individuals. From a conceptual perspective following theoretical models on vulnerability and successful aging, differences between vulnerable (compared to less vulnerable) individuals seem reasonable. For instance, in the most recent overarching framework of vulnerability, Spini et al. (2017) defined vulnerability as a weakening process and lack of resources that expose individuals to greater difficulty to cope with, for example, health restrictions in old age. Moreover, as postulated in the selective optimization with compensation (SOC) model (Baltes and Baltes 1989), a lack of resources in a given domain can (at least partly) be compensated with the help of resources in another domain (see also, e.g., Bäckman and Dixon 1992, for further conceptualization of psychological compensation mechanisms). In line with the SOC model (Baltes and Baltes 1989) and the cognitive reserve concept (Stern 2009, 2012), such cross-domain compensation mechanisms allow the compensation of a lack of health resources

by buffering resources in terms of cognitive reserve to maintain cognitive functioning in old age. As postulated in the vulnerability framework of Spini et al. (2017), vulnerable individuals have greater difficulty (than less vulnerable individuals) to cope with health restrictions. Therefore, the need for cross-domain compensating resources in terms of cognitive reserve would be disproportionately higher in vulnerable (compared to less vulnerable) individuals. Empirically corroborating these conceptual assumptions, recent research suggests that cognitive functioning may more strongly depend on individuals' cognitive reserve in older individuals with chronic diseases and in obese individuals (Arenaza-Urquijo et al. 2015; Ihle et al. 2016, 2017; Robertson 2013).

According to the vulnerability framework of Spini et al. (2017), a group of particularly vulnerable individuals are older adults with low functional fitness status. Specifically, evidence showed that low functional fitness status is related to lower cognitive status, faster cognitive decline, and higher risk of cognitive impairment in old age (Bjork et al. 2016; Erickson et al. 2011; Gray et al. 2013; Veronese et al. 2016). Hence, it seems an appealing question whether the role of cognitive reserve for cognitive functioning in old age may differ between individuals with low, compared to those with high functional fitness status due to the aforementioned cross-domain compensation effects. Yet, to the best of our knowledge, no study so far targeted this question.

The present study

Therefore, the present study set out to investigate the relation of key markers of cognitive reserve (i.e., education and cognitive leisure activity) to mini-mental state in old age (as an indicator of the extent of cognitive impairment) and its interplay with functional fitness status in a large sample of older adults. Specifically, to advance the ongoing debate about the large variability in cognitive reserve–cognition relations observed in prior research, we investigated whether those relations may differ between individuals with low, compared to those with high functional fitness status and whether such moderation patterns may be universal or specific for early-life markers of cognitive reserve (i.e., education) or late-life markers of cognitive reserve (i.e., cognitive leisure activity) and/or for certain cognitive domains.

Methods

Participants

The sample comprised 701 community-dwelling older adults from Fonte Boa, Apuí, and Manaus, Brazil (268 men and 433 women). Mean age was 70.4 years ($SD = 6.9$, range: 60–91; see descriptive statistics for the overall sample as

well as separately for individuals with low and those with high functional fitness status in Table 1). Participants were volunteers recruited via advertisements distributed through newspapers, local radio, churches, and senior centers. Inclusion criteria were: living in one of the three geographic areas of Brazil, being at least 60 years old, and being able to walk independently to visit the laboratory. As we explicitly aimed to take the full range of interindividual differences available in cognitive status of participants into account, no inclusion/exclusion criteria based on MMSE scores were applied. All participants gave informed consent, and the present study included adherence to the declaration of Helsinki and had been approved by the local ethics commission.

Materials

Mini-mental state examination

We used the mini-mental state examination (MMSE; Folstein et al. 1975) as an indicator of the extent of cognitive impairment. The MMSE consists of five subsections

covering orientation (0–10 points), immediate and delayed free recall (0–3 points each), counting backwards (0–5 points), and language (0–9 points). A total score can be derived by adding the five subsection scores (0–30 points).

Markers of cognitive reserve

Education Participants were asked to indicate the total time in years they had spent for education (comprising primary school, secondary school, and university; see, e.g., Fritsch et al. 2007; Opdebeeck et al. 2016, for studies analyzing the time in years spent for education as marker of cognitive reserve).

Cognitive leisure activity Participants were asked to indicate the average time per day they usually spend in total for cognitively stimulating leisure activity such as playing cards, scrabble, etc.; doing crossword puzzles, sudoku, etc.; and reading (these examples were verbally given to participants; there was no time interval specified referring to the number of last weeks; see, e.g., Murphy and O’Leary 2010;

Table 1 Descriptive statistics of measures

Group	Overall $N = 701$	Low fitness $N = 351$	High fitness $N = 350$	d
Variables				
MMSE total score (points)	24.41 (4.23) [11–30]	23.76 (4.47) [11–30]	25.05 (3.88) [16–30]	0.31***
Education (years)	5.36 (5.54) [0–23]	4.94 (5.31) [0–23]	5.77 (5.74) [0–21]	0.15*
Cognitive leisure activity (min/day)	10.87 (37.26) [0–360]	11.28 (37.89) [0–240]	10.46 (36.67) [0–360]	0.02 ns
30-s chair stand test (repetitions)	11.74 (3.22) [3–26]	9.98 (2.37) [3–17]	13.49 (2.98) [7–26]	1.30***
30-s arm curl test (repetitions)	13.12 (4.24) [2–28]	11.18 (3.48) [2–25]	15.06 (4.04) [4–28]	1.03***
Chair sit and reach test (cm)	2.85 (9.51) [– 30 to + 38]	– 1.44 (8.73) [– 30 to + 20]	7.15 (8.23) [– 18 to + 38]	1.01***
Back scratch test (cm)	– 9.85 (12.16) [– 50 to + 30]	– 14.09 (11.37) [– 50 to + 10]	– 5.60 (11.45) [– 41 to + 30]	0.74***
8-foot up-and-go test (s)	6.30 (1.97) [3.34–20.58]	7.13 (2.41) [4.02–20.58]	5.46 (0.77) [3.34–8.16]	0.94***
6-min walk test (m)	419.82 (87.33) [100–750]	375.00 (76.45) [100–585]	464.77 (73.40) [144–750]	1.20***
Age (years)	70.36 (6.87) [60–91]	72.32 (7.55) [60–91]	68.40 (5.46) [60–87]	0.60***
Sex (sample proportions)	men: 38.2% women: 61.8%	men: 36.8% women: 63.2%	men: 39.7% women: 60.3%	$\chi^2 = 0.53$ ns
Number of chronic diseases (number)	1.46 (1.09) [0–6]	1.61 (1.10) [0–6]	1.31 (1.07) [0–6]	0.28***

Descriptive statistics for the overall sample as well as separately for individuals with low and those with high functional fitness status in terms of mean (SD) [range] as well as sample proportions. d = Cohen’s d , standardized mean difference for low versus high functional fitness status. Note that the division into low versus high functional fitness status in this table (based on a median-split approach) is for descriptive purposes only. For moderator analyses, we did not artificially dichotomize functional fitness status (in low versus high using a median-split approach) and instead analyzed it as a continuous score. The range of negative and positive scores for the chair sit and reach test as well as the back scratch test emerged as follows: In the chair sit and reach test, the participant slowly bended forward sitting on a chair, reaching as far as possible with the hands toward the tip of the toes; the distance from the tip of the middle fingers to the tip of the toes was measured (if the middle fingers did not reach the toes, the distance was recorded as a negative score; if the middle fingers touched the toes, as zero score; and if the middle fingers passed beyond the toes, the distance was recorded as a positive score). In the back scratch test, the participant stood erect and placed the preferred hand over the same shoulder, while placing the other arm around the back of the waist and approaching the extended middle fingers of both hands; the distance between the tip of the middle fingers of both hands was measured (if the middle fingers did not touch, the distance was recorded as a negative score; if the middle fingers just touched, as zero score; and if the middle fingers overlapped, the distance was recorded as a positive score).

*** $p < .001$; * $p < .05$; ns = nonsignificant, $p > .05$

Opdebeeck et al. 2016, for studies analyzing the time per day spent for current cognitive leisure activity as marker of cognitive reserve).

Functional fitness status

We assessed functional fitness status using the Senior Fitness Test (SFT; Rikli and Jones 2013). This battery includes a 30-s chair stand test (lower body strength), 30-s arm curl test (upper body strength), chair sit and reach test (lower body flexibility), back scratch test (upper body flexibility), 8-foot up-and-go test (agility and dynamic balance), and 6-min walk test (aerobic endurance). For analyses, we used a composite score of the six tests as an overall indicator of functional fitness (Buchman et al. 2011).

Control variables

We controlled for age, sex, and comorbidity (number of chronic diseases calculated from participants' self-reports) in additional control analyses, as it is common to control for these covariates when investigating predictors of late-life cognitive functioning (see, e.g., Opdebeeck et al. 2016, for an overview on prior research).

Statistical analyses

First, we inspected bivariate relations between MMSE scores, education, cognitive leisure activity, and functional fitness status (by calculating Pearson's correlation coefficients r). Second, we investigated whether the relation of education/cognitive leisure activity to MMSE scores varied as a function of functional fitness status. Specifically, we regressed MMSE scores on education/cognitive leisure activity as respective predictor plus functional fitness status as predictor plus an interaction term constituting the moderation effect. Note that for these moderation analyses, we did not artificially dichotomize functional fitness status and instead analyzed it as a continuous score. In a subsequent set of simple slope analyses, we investigated moderation patterns in more detail. Specifically, to evaluate the direction of

moderation effects, we estimated the relation of education/cognitive leisure activity to MMSE scores at low and high values of the continuous variable functional fitness status (i.e., -1 SD and $+1$ SD, respectively) in the respective moderation model (Preacher et al. 2006).

Results

Bivariate relations between measures

Longer education and greater engagement in cognitive leisure activity were significantly related to higher MMSE total score. In addition, better functional fitness status was significantly related to higher MMSE total score (see Table 2 for the full correlation matrix).

Moderation analyses

Regarding our main goal, there was a significant moderation of the relations of education and cognitive leisure activity to MMSE total score by functional fitness status (see left panel of Table 3). Together with these significant moderation effects, subsequent simple slope analyses indicated that the relations of education and cognitive leisure activity to MMSE total score were significantly larger in individuals with low, compared to those with high functional fitness status (see right panel of Table 3; see Supplemental Fig. 1 for an illustration).

With respect to the MMSE subsections, there was a significant moderation of the relations of education to MMSE orientation and of cognitive leisure activity to MMSE language by functional fitness status (see left panel of Table 4). Together with these significant moderation effects, subsequent simple slope analyses indicated that the relations of education to MMSE orientation and of cognitive leisure activity to MMSE language were significantly larger in individuals with low, compared to those with high functional fitness status (see right panel of Table 4).

Table 2 Full correlation matrix of measures

Variable	1	2	3	4	5	6	7
1. MMSE total score	–						
2. Education	.54***	–					
3. Cognitive leisure activity	.09*	.21***	–				
4. Functional fitness status	.20***	.09*	– .03 ns	–			
5. Age	– .19***	– .14***	.04 ns	– .35***	–		
6. Sex (0 = men; 1 = women)	– .03 ns	.15***	.12**	– .04 ns	– .12**	–	
7. Number of chronic diseases	– .02 ns	.05 ns	.07 ns	– .18***	.01 ns	.22***	–

*** $p < .001$; ** $p < .01$; * $p < .05$; ns = nonsignificant, $p > .05$

Table 3 Moderation analyses to investigate whether the relation of education/cognitive leisure activity to MMSE total score varied by functional fitness status

Variable	Moderation analysis				Simple slope analysis	
	β_{CR}	β_F	β_I	R^2	β_L	β_H
Education	.53***	.14***	-.08*	.32***	.44***	.37***
Cognitive leisure activity	.09*	.20***	-.08*	.05***	.13***	< .01 ns

Left panel: Moderation analyses to investigate whether the relation of education/cognitive leisure activity to MMSE total score varied by functional fitness status. β_{CR} = standardized coefficient of education/cognitive leisure activity as respective predictor of MMSE total score. β_F = standardized coefficient of functional fitness status as predictor. β_I = standardized coefficient of the respective interaction term constituting the moderation effect. R^2 = resulting total variance that is accounted for by the model. Right panel: Subsequent simple slope analyses to estimate the relation of education/cognitive leisure activity to MMSE total score at low and high values of functional fitness status (i.e., - 1 SD and + 1 SD, respectively) in the respective moderation model. β_L = standardized coefficient of education/cognitive leisure activity as respective predictor of MMSE total score, estimated at a low value (- 1 SD) of functional fitness status. β_H = standardized coefficient of education/cognitive leisure activity as respective predictor of MMSE total score, estimated at a high value (+ 1 SD) of functional fitness status

*** $p < .001$; * $p < .05$; ns = nonsignificant, $p > .05$

Table 4 Moderation analyses to investigate whether the relation of education/cognitive leisure activity to MMSE subsection scores varied by functional fitness status

Variable	Moderation analysis				Simple slope analysis	
	β_{CR}	β_F	β_I	R^2	β_L	β_H
Education						
Orientation	.42***	.17***	-.10**	.22***	.37***	.26***
Immediate free recall	.03 ns	.08*	-.02 ns	.01 ns	.03 ns	.01 ns
Delayed free recall	.01 ns	.22***	-.03 ns	.05***	.02 ns	-.02 ns
Counting backwards	.49***	-.01 ns	-.03 ns	.24***	.38***	.35***
Language	.43***	.07*	-.05 ns	.19***	.34***	.29***
Cognitive leisure activity						
Orientation	.09*	.22***	-.05 ns	.06***	.10**	.03 ns
Immediate free recall	-.03 ns	.09*	-.01 ns	.01 ns	-.01 ns	-.03 ns
Delayed free recall	-.03 ns	.23***	-.06 ns	.06***	.02 ns	-.07 ns
Counting backwards	.13***	.05 ns	-.04 ns	.02**	.12**	.06 ns
Language	.00 ns	.11**	-.11**	.03***	.08*	-.08*

Left panel: Moderation analyses to investigate whether the relation of education/cognitive leisure activity to MMSE subsection scores varied by functional fitness status. β_{CR} = standardized coefficient of education/cognitive leisure activity as respective predictor of MMSE subsection scores. β_F = standardized coefficient of functional fitness status as predictor. β_I = standardized coefficient of the respective interaction term constituting the moderation effect. R^2 = resulting total variance that is accounted for by the model. Right panel: Subsequent simple slope analyses to estimate the relation of education/cognitive leisure activity to MMSE subsection scores at low and high values of functional fitness status (i.e., - 1 SD and + 1 SD, respectively) in the respective moderation model. β_L = standardized coefficient of education/cognitive leisure activity as respective predictor of MMSE subsection scores, estimated at a low value (- 1 SD) of functional fitness status. β_H = standardized coefficient of education/cognitive leisure activity as respective predictor of MMSE subsection scores, estimated at a high value (+ 1 SD) of functional fitness status

*** $p < .001$; ** $p < .01$; * $p < .05$; ns = nonsignificant, $p > .05$

Additional control analyses

We additionally repeated moderation analyses simultaneously controlling for age, sex, and the number of chronic diseases. In these control analyses, the previously observed significant relations of education and cognitive leisure activity to MMSE scores as well as the previously observed significant moderation of these relations by

functional fitness status remained significant ($ps < .020$). Together with these significant moderation effects, subsequent simple slope analyses simultaneously controlling for age, sex, and the number of chronic diseases again indicated that the relations of education and cognitive leisure activity to MMSE scores were significantly larger in individuals with low, compared to those with high functional fitness status.

Moreover, we investigated whether results differed by age. For this purpose, we repeated analyses with age being entered as moderator. In these control analyses, neither the relations of education and cognitive leisure activity to MMSE scores nor the moderation of these relations by functional fitness status varied according to age ($ps > .881$).

In addition, to investigate whether results may differ between cognitively healthy individuals and those with probable impairments (MMSE < 24; Lopez et al. 2005), we repeated analyses with cognitive impairment status (MMSE scores of at least 24 [$N = 441$; 62.9%] vs. < 24 [$N = 260$; 37.1%]) being entered as moderator. In these control analyses, neither the relations of education and cognitive leisure activity to MMSE scores nor the moderation of these relations by functional fitness status varied according to cognitive impairment status ($ps > .123$). Additionally, applying a lower MMSE cutoff that has been adapted for socially disadvantaged populations such as low-educated individuals as in the present study with an MMSE score of 19 (Tuijl et al. 2012), we repeated analyses with cognitive impairment status (MMSE scores of at least 19 [$N = 618$; 88.2%] vs. < 19 [$N = 83$; 11.8%]) being entered as moderator. Again, neither the relations of education and cognitive leisure activity to MMSE scores nor the moderation of these relations by functional fitness status varied according to cognitive impairment status ($ps > .415$).

Furthermore, we investigated whether results may vary between the different fitness measures. For this purpose, we repeated analyses with functional fitness test type being entered as moderator. In these control analyses, the moderation of the relations of education and cognitive leisure activity to MMSE scores by functional fitness status did not vary according to functional fitness test type ($ps > .392$).

Additional analyses showed that the relations between the investigated variables were not better explained by alternative mechanisms such as that functional fitness status may be a mediator of the cognitive reserve–cognition relation, which we did not observe (all indirect [mediated] relations $\beta s < .01$, $ps > .143$).

Discussion

The present study set out to investigate the relation of education and cognitive leisure activity as key markers of cognitive reserve to mini-mental state and its interplay with functional fitness status in a large sample of older adults. First of all, results showed that better functional fitness status was related to higher MMSE scores. This confirms the role of low functional fitness status being an important correlate of cognitive impairment in old age (Gray et al. 2013; Veronese et al. 2016). Furthermore, results showed that longer education and greater engagement in cognitive leisure

activity were related to higher MMSE scores. This further corroborates the conceptual view that cognitive stimulation throughout the life course may contribute to cognitive reserve, thereby being related to better cognitive status in old age (Gatz et al. 2001; Hertzog et al. 2008; Opdebeeck et al. 2016).

Following our main goal, coherently for both investigated markers of cognitive reserve, we found that the relations of education and cognitive leisure activity to MMSE scores were larger in individuals with low, compared to those with high functional fitness status. This suggests that cognitive functioning in old age may more strongly depend on cognitive reserve accumulated during the life course in individuals with low, compared to those with high functional fitness status. Thus, present findings further corroborate prior evidence, suggesting that cognitive reserve may have greater compensating effects in vulnerable (compared to less vulnerable) individuals (Arenaza-Urquijo et al. 2015; Ihle et al. 2016, 2017; Robertson 2013) and that this may transfer to older adults with low functional fitness status as another group of particularly vulnerable individuals.

These findings may be explained by cross-domain compensation effects in vulnerable individuals. Specifically, in line with the SOC model (Baltes and Baltes 1989) and the cognitive reserve concept (Stern 2009, 2012), these cross-domain compensation mechanisms may allow the compensation of a lack of health resources in terms of low functional fitness status (as well as chronic diseases and metabolic syndromes such as obesity; see Ihle et al. 2016, 2017) by cognitive reserve as a buffering resource. Given that vulnerable individuals have greater difficulty (than less vulnerable individuals) to cope with such lack of health resources (as postulated in the vulnerability framework of Spini et al. 2017), the need for cross-domain compensation by cognitive reserve may be disproportionately higher in vulnerable (compared to less vulnerable) individuals. Thus, present findings that the relation of cognitive reserve to cognitive functioning in old age may be more pronounced with larger degrees of vulnerability dovetail with the conceptual view that cognitive reserve only gets manifest when some kind of vulnerability (e.g., onset of cognitive impairment) sets in (Stern 2009, 2012). This corroborates models of cognitive reserve with regard to the notion that physical vulnerability in old age (such as low functional fitness status) may also initiate cognitive reserve effects.

To further advance the ongoing debate about the large variability in cognitive reserve–cognition relations observed in prior research, we investigated whether the present moderation patterns by functional fitness status may be universal or specific for certain markers of cognitive reserve and/or for certain cognitive domains. Interestingly, analyses disentangling the MMSE subsections showed that the observed fitness-moderation patterns seem to be specific for certain

cognitive domains with regard to the cognitive reserve marker considered. Specifically, the moderation of the relations of the cognitive reserve markers to MMSE orientation by functional fitness status was only present for education as an early-life marker of cognitive reserve, while the moderation regarding MMSE language was only present for cognitive leisure activity as a late-life marker of cognitive reserve in our study. Although this has to remain speculative at that point, one possible explanation could be that education may be a more basic contributor to the buildup of cognitive reserve in early life (Stern 2009) that may particularly interact with low functional fitness status as a basic facet of vulnerability (Spini et al. 2017) regarding its relations to more basic domains of cognitive functioning such as orientation. In contrast, cognitive leisure activity seems to be positively related to the language domain in low fitness individuals, while we found a negative relation in high fitness individuals. Again speculative at that point, individuals who have the impression that their cognitive functioning may have declined and who are still able to engage in activities (thus likely those with a high rather than those with a low fitness status) may strongly engage in cognitive leisure activities in the expectation to postpone or counteract the experienced decline. This could then lead to the observed negative relation between cognitive engagement and cognitive functioning with present cross-sectional data. Therefore, future longitudinal research will have to pin down the underlying mechanisms in detail. Interestingly, our speculations that in high fitness individuals higher activity may be a compensatory means to counteract incipient cognitive decline nicely dovetail with a similar compensation hypothesis with regard to negative associations between cognition and conscientiousness that have empirically been found, that is, individuals get more conscientious as a compensatory means against cognitive decline (e.g., Moutafi et al. 2004; Soubelet 2011).

In terms of possible clinical and policy implications, one could argue that the present results may underline the role of cognitive reserve accumulated during the life course to compensate for vulnerability effects on cognitive functioning in old age. However, given the limitations of present cross-sectional data, we underline that future longitudinal studies will have to further investigate the present observations before making suggestions. In the context of the latter notions, we acknowledge that the present study is limited by its cross-sectional design that does not allow for causal inferences. The directionality of observed relationships cannot be established with present cross-sectional data. Thus, we cannot clearly disentangle between individuals who decline because of reducing cognitively stimulating activity and individuals who reduce cognitively stimulating activity because of cognitive decline. Yet, for the observed relations of educational attainment *in early life* to cognitive

status in old age, it is much less likely that they are driven by individuals who reduced cognitively stimulating activity because of cognitive decline. More generally, analyses of the present study give only information about interindividual differences in cognitive status but do not allow drawing conclusions regarding cognitive decline (i.e., intraindividual changes over time), for which longitudinal research is needed. Likewise, we acknowledge that due to the cross-sectional design, the significant interaction effects could as well mean that relations of functional fitness status to cognitive performance are stronger in individuals with lower education/cognitive leisure activity compared to those with higher cognitive reserve. Yet, due to the conceptual view on greater need for cross-domain compensating resources in vulnerable compared to less vulnerable individuals (Spini et al. 2017), we prefer the interpretation that functional fitness status is the moderator.

We further acknowledge that observed moderation effects by functional fitness status were of relatively small size. Note that the influences of cognitive stimulation during the life course on cognitive functioning in old age are multifaceted (see, e.g., Hertzog et al. 2008; Opdebeeck et al. 2016, for a discussion). Therefore, functional fitness status seems to only account for a relatively small proportion of the heterogeneity in cognitive reserve findings. The reason why there were significant moderation effects for orientation and language but not for the other MMSE subsections may be due to the fact that the MMSE subsections orientation (0–10 points) and language (0–9 points) have a much larger possible score range, while for immediate and delayed free recall (0–3 points each) and counting backwards (0–5 points), variance is restricted due to the smaller possible score range (e.g., individuals who can remember one item likely can also remember all three in the memory tests). Moreover, one may argue that the relation of functional fitness status to cognitive functioning may to some extent be due to factors such as age, sex, and comorbidity. Yet, controlling for these covariates in additional analyses revealed the same pattern of results. Further, control analyses showed that the pattern of results did not differ by age, functional fitness test type, nor differ between cognitively healthy individuals and those with probable impairments. Additional analyses also showed that the relations between the investigated variables were not better explained by alternative mechanisms such as that functional fitness status may be a mediator of the cognitive reserve–cognition relation, which we did not observe. We further acknowledge that the MMSE is a rough screening indicator only and therefore future research needs to use more comprehensive cognitive test batteries. As an outlook, the present study may stimulate future longitudinal research assessing decline in a comprehensive set of cognitive domains as well as markers and determinants of functional fitness status and cognitive reserve (also in other,

better educated western populations) to gain further insights into the interplay of the buildup of cognitive reserve during the life course, functional fitness status, and cognitive impairment in old age.

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Compliance with ethical standards

Conflict of interest None.

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