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How cognitive reserve influences older adults' cognitive state, executive functions and language comprehension: A structural equation model

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ABSTRACT

Cognitive reserve has been defined as the individuals' ability to tolerate age-related and neurodegenerative changes in the brain without developing clinical symptoms or signs of disease. Formal education, occupational attainment, and knowledge of other languages have been assessed as the most relevant factors determining cognitive reserve. The main objective of this study was to develop a structural equation model that reflects the direct influence of cognitive reserve on old adults' general cognitive status and executive functioning, and indirectly on sentence comprehension performance through executive functions mediation. One hundred and fifty eight Spanish-speaking older adults, cognitively intact, were assessed to obtain cognitive reserve data, general cognitive status, executive functioning (inhibitory control, working memory and cognitive flexibility), and sentence comprehension measures. High indicators of adjustment of the proposed model were obtained. The most related factors to cognitive reserve were education and occupational attainment. As we hypothesize, cognitive reserve had a higher direct significant relation to cognitive status and, in a lesser extent, to executive functioning. Participants' general cognitive status and executive function were high and directly related. Furthermore, cognitive reserve has an indirect positive relation to sentence comprehension via executive functions' mediation.

1. Introduction

Cognitive reserve (CR) has been defined as the individuals' ability to tolerate age-related and neurodegenerative changes in the brain without developing clinical symptoms (Meng & D'Arcy, 2012). Education has been regarded as one of the most relevant factors promoting CR (Xu et al., 2016). In their systematic review, Meng and D'Arcy (2012) showed that a higher educational level was associated with a significant reduction in the prevalence and incidence of dementia. Higher education masks the clinical manifestations of dementia at the early stages but after brain pathology reaches a threshold, there is a faster cognitive decline than in normal conditions (Milgram, Siwak-Tapp, Araujo, & Head, 2006).

In adulthood, type of work provides one of the most important sources of cognitive stimulation that contributes to CR (Feldberg, Hermida, Tartaglini, Somale, & Allegri, 2016). In a systematic review based on 29,000 individuals, those professions described as more demanding were associated with around 50% of the risk reduction for dementia (Valenzuela & Sachdev, 2006). In a longitudinal study, conducted with 462 twin individuals (Finkel, Andel, Gatz, & Pedersen, 2009), relationships between work complexity (defined according to the difficulty to cope with information, people and things) and participants' performance in four cognitive domains (verbal, spatial perception, memory and processing speed) were analysed. Only the group with high complexity occupation related to people obtained better scores in three of the four cognitive domains, especially in the verbal domain.

Additionally, the knowledge of other languages, apart from the maternal one, has been shown to be one of the factors that seem to increase CR across the life span (Abutalebi et al., 2015). Some authors have also suggested that bilingualism boost a number of executive functions (EF), such as inhibitory control, conflict monitoring, selective attention and working memory (WM; Rossi & Diaz, 2016). Furthermore, according to the study of Craik, Bialystok, and Freedman (2010),

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a delay of between 3 and 5 years has been found in the appearance of AD symptoms in bilingual subjects (71.4 years on average for monolinguals and 75.5 years for bilinguals). Similarly, bilingual older people obtained a significantly higher performance than monolinguals in a paradigm of task change (Gold, Kim, Johnson, Kryscio, & Smith, 2013).

Another relevant issue is to know if CR exerts its influence in different cognitive domains and how it is done. For example, Opdebeeck, Martyr, and Clare (2016) examined the relationship between CR and memory, EF, visuospatial ability and language, applying a meta-analysis procedure. They defined CR in terms of educational level, occupational status and engagement in cognitively stimulating activities. Their results pointed out that a higher educational level was associated with better performance across all four cognitive domains, while the other two proxies exhibited a greater variation between different domains. Structural models also include commonly related indicators to analyse the impact of CR on particular cognitive domains. Lojo-Seoane, Facal, Guàrdia-Olmos, and Juncos-Rabadán (2014) developed a structural equation model (SEM) to study the influence of CR on cognitive performance in a sample of adults older than 50 years with subjective memory complaints. The model revealed that the CR construct consisting of two factors, educational level and lifestyle, had significant direct effects on episodic memory, WM, and general cognitive performance, as well as indirect effects on episodic memory via WM. Other neuropsychological studies have also shown a consistent link between CR and EF (Head, Allison, Lucena, Hassenstab, & Morris, 2017; Roldán-Tapia, García, Cánovas, & León, 2012). We haven't found any published SEM study focused on the direct effects of CR on sentence comprehension (SC), but alternatively there were studies including different language ability/processing measures. For example, O'shea et al. (2015) used an extensive neuropsychological battery, with a sample of more than 3000 healthy older adults, to investigate whether CR moderated the association between depressive symptoms and cognition. They concluded that the association between late life depressive symptoms and cognition varies depending on the individual CR (education and reading level). As depressive symptoms increased, participants with a higher CR showed a greater decrease in cognition (memory, EF, and language performance) than those with a lower CR. In a recent study, Thow et al. (2018) assessed episodic memory, WM and language processing, annually over 4 years, in 359 healthy older adults who attended university for a minimum of 12 months, and were compared against 100 healthy controls. CR improved in older adults who undertook further late-life education (Lenehan et al., 2016). Using multiple group latent growth curve modelling, they found improved language processing capacity in the group of older adults with formal further education, without an effect of late-life education on episodic memory, WM, or EF relative to a no-educated control group.

Another relevant question is the fact that older adults' performance in language tasks seems to be related to changes in attention and EF (Stine-Morrow, Shake, Miles, & Noh, 2006). Sentence comprehension (SC) requires that the listener/reader direct his/her attention toward the relevant pieces of information, hold them in WM to develop a meaningful representation, and inhibit incorrect analyses or misinterpretations. For example, Colman et al. (2009) compared the performance of patients with Parkinson's disease (PD) and a control group in a sentence–picture matching task. They found that lower performance in PD patients depended on cognitive flexibility, which is necessary during the comprehension of complex sentences to inhibit an expected canonical thematic assignment. In the study of Goral et al. (2011), with healthy older adults, they pointed out that participants with a better WM span and greater set switching capabilities performed better in two listening comprehension tasks. In a recent study, young and older adults were tested with a multiple negative comprehension task and an information processing battery (Yoon et al., 2015). Results pointed out that both groups exhibited poorer performance for implausible sentences. Inhibition efficiency predicted comprehension of implausible sentences in older adults only, suggesting that adults with better inhibition performance also showed better comprehension than those with poorer inhibition skills.

The main objective of this study was to develop a structural model that reflects how CR exerts its influence in different cognitive domains. We hypothesized that CR would be directly related to older adult's general cognitive state and EF, and indirectly to SC performance through EFs' mediation.

2. Method

2.1. Participants

Two hundred and eight Spanish-speaking older adults voluntarily participated in the study. They were recruited from the Centre for the Prevention of Cognitive Impairment (a public health institute in Madrid City), and other centres for seniors in Madrid. After a data screening process, in which all cases with missing or out of range values in selected variables were excluded, the definitive sample was reduced to 158 participants (110 females and 48 males). All participants had normal or corrected hearing and vision. None of them fit mild cognitive impairment (MCI) criteria (Petersen, 2016), neither a GDS-15 score higher than 9 points (Geriatric Depression Scale; Yesavage & Sheikh, 1986). Table 1 shows descriptive statistics for sociodemographic variables, CR, GDS-15 and neuropsychological measures.

2.2. Materials

Screening tests and questionnaires. Sociodemographic data were collected through a questionnaire that includes a specific question about the number of years of education. We used two items in the CR Questionnaire (CRQ; Rami et al., 2011) to measure participants' occupational attainment and other languages knowledge. Occupational attainment score in CRQ ranges from 0 (non-qualified work) to 4 (management level). The scale for other languages knowledge (foreign languages) ranges from 0 (only maternal language) to 3 (more than two languages). Participants' general cognitive state was assessed using the Mini-Mental State Examination (MMSE; Spanish adaptation by Lobo et al., 1999), and the Spanish version of the 7-Minutes test (Del Ser et al., 2004).

Tests of executive functions. We obtained a measure of inhibitory control with the Stroop's test (Golden, 1978). Maintaining and manipulation in WM were assessed through the subtest of backward digits included in the third edition of the Weschler Memory Scale (WMS-III; Wechsler, 1997). Trail Making Test parts A and B (TMT-A & TMT-B; Lezak, 1995) were also used to obtain a measure of cognitive flexibility (computing the ratio score B/A; Lamberty, Putnam, Chatel, Bieliauskas, & Adams, 1994).

Sentence comprehension (SC). SC was assessed by means of a sentence–picture simple verification task included in the ECCO_Senior test,

Table 1
Descriptive statistics for sociodemographic variables, CR, GDS-15, and neuropsychological measures.

	Mean	Std. Deviation
Age	71.19	4.93
Years of education	13.42	5.59
Occupational attainment	2.19	1.04
Languages knowledge	0.64	0.89
MMSE	28.60	1.50
7 minutes test	68.14	10.05
GDS-15	2.17	2.52
ECCO_nonCanonicalSentences	14.27	2.16
ECCO_2PropositionsSentences	14.95	2.44
TMT-ratio	2.28	0.86
Backward Digits	3.81	0.99
Stroop_WordsColors index	45.48	9.39

Table 2
Correlation matrix between variables included in SEM model.

	Years of Educ	Occup. Att.	Lang knowl	MMSE	7 min	TMT-ratio	Inverse-Digits	Stroop W-C	ECCO Non CanonicalS
Occupational attainment	.78**								
Languages knowledge	.42**	.42**							
MMSE	.25**	.31**	.13						
7 minutes test	.32**	.30**	.21**	.31**					
TMT-ratio	−.30**	−.32**	−.23**	−.33**	−.24**				
Inverse-Digits	.34**	.30**	.17*	.13	.28**	−.16*			
Stroop_WordsColors	.40**	.39**	.28**	.42**	.39**	−.36**	.32**		
ECCO_nonCanonicalS	.33**	.40**	.34**	.21**	.37**	−.28**	.37**	.42**	
ECCO_2PropositionsS	.34**	.38**	.36**	.22**	.33**	−.30**	.31**	.39**	.92**

** $p < .01$.
* $p < .05$.

published in Spain (Exploración Cognitiva de la Comprensión de Oraciones para mayores; English translation: Cognitive Assessment of Sentence Comprehension for seniors; see López-Higes, Martín-Aragoneses, Del Río, & Mejuto, 2012). This test enables to assess the thematic role assignment process ("who did what to whom") with a set of 36 items. Items are either congruent or incongruent; incongruent items were syntactic or lexical foils. In syntactic foils, thematic roles are reversed in the picture with respect to the sentence statements, whereas in lexical foils there is a change in the picture with regard to an action, a person, or an object mentioned in the sentence. For this study, we selected a subset of sentences from the test, non-canonical items (example: "The man is kicked by the girl") and sentences containing two propositions (example: "*The girl kissed by her grandmother was sitting in a chair*", since they pose a higher burden over language comprehension.

2.3. Procedure

Neuropsychological assessment was conducted by an experienced professional. In the first session, participants were informed about the main goal of the study and, if they gave their informed consent, then they completed the screening tests (e.g., MMSE, GDS-15), as well as the CRQ. The remaining tests were applied in a second session. The complete assessment of each participant (session 1 and 2) lasted approximately 50 min. Although there was a fixed block of tests for each session, the order of presentation was randomized between participants. All tests were applied and scored following instructions provided in the users' manuals. Given the relevance of visual acuity for the Stroop test performance we asked participants if they were able to read the words o if they could distinguish the colours well before each Stroop's condition, at the time of giving them the instructions. Furthermore, they were asked to do the required task pointing out them a concrete example. In any case, they were always allowed to perform the test with their glasses, if they thought fit.

2.4. Definition of the model

In order to develop the structural model we have considered three CR proxies: years of education (given by participants in the socio-demographic questionnaire), and the scores corresponding to occupational attainment and knowledge of other languages in the CRQ. The latent variable associated with these observed proxies was *background*. CR was defined in the model as the second order factor, and background is supposed to influence CR.

The structural model allows the direct effect of CR construct in two non-observable factors: *general cognitive status* and *executive functioning (EF)*. General cognitive status includes participants' observed scores in two well-known screening tests, that is, MMSE and the 7-minutes test. EF comprises the participants' scores in backward digits (WMS-III), Stroop's interference condition (Words & Colours), and TMT-ratio score. We assume that general cognitive status influences EF. Furthermore, according to the proposed model, CR exerts its influence on *sentence comprehension*, the third non-observable factor, indirectly, that is via EF. As mentioned before this factor includes two observed measures of the ECCO_Senior test.

2.5. Statistical analysis

We used AMOS 22.0 for Windows to appraise the structural model proposed and the Generalized Least Squares (GLS) as parameter estimation method. As goodness of fit indices we examined: 1) the magnitude of $\chi 2$ divided by its degrees of freedom (CMIN/DF, indicating a good fit when is minor to 3); 2) Root Mean Square Error of Approximation (RMSEA indicating a good fit when is minor to .05); 3) Standardized Root Mean Residual (SRMR indicating a good fit when is minor to .08); 4) Corrected goodness index (AGFI); 5) Goodness of Fit (GFI); and 6) Comparative Fix Index (CFI). The values of these indices should be close to .90 or above to be considered a good fit (Tabachnick & Fidell, 2013). We used the Mardia coefficient considering multivariate normality when its critical ratio is equal or minor than 1.96 (Bian, 2011). There were no missing cases in the sample so it was not necessary to use any imputation method.

3. Results

Table 2 shows bivariate correlations between variables included in the proposed SEM model. Apart from ECCO_Senior indices, which present the highest correlation, other significant and high correlation was the one observed between years of education and occupational attainment. Other languages knowledge shows moderate and significant correlations with years of education and occupational attainment; the correlation between non-canonical sentences in the ECCO_-Senior test and the interference condition in the Stroop's test is also of the same magnitude.

A critical ratio for Mardia coefficient equal to 1.63 was obtained, so multivariate normality was assured. Fig. 1 shows the standardized solution for the proposed model. The numbers next to the arrows are standardized regression weights (betas), so they should be interpreted as correlations. Their squared values would express the percentage of criterion's variance they explain. Coefficients next to predictor boxes are squared multiple correlations, so each one should be interpreted as reflecting that the predictor selected explains a specific percentage of its own variance. This model showed adequate goodness-of-fit indices: CMIN/DF = 0.94, RMSEA = .00 (LO90 = .00, HI90 = .05); SRMR = .04; AGFI = .95, GFI = .97; CFI = .99.

In the model, CR construct can be described successfully by a first order factor called background, which has three indicators, but years of education and occupational attainment have the highest factor loadings. Languages knowledge scores has a lower, although high, factor loading in the background factor, and therefore in the CR factor.

CR had a significant impact on cognitive status and was also related,

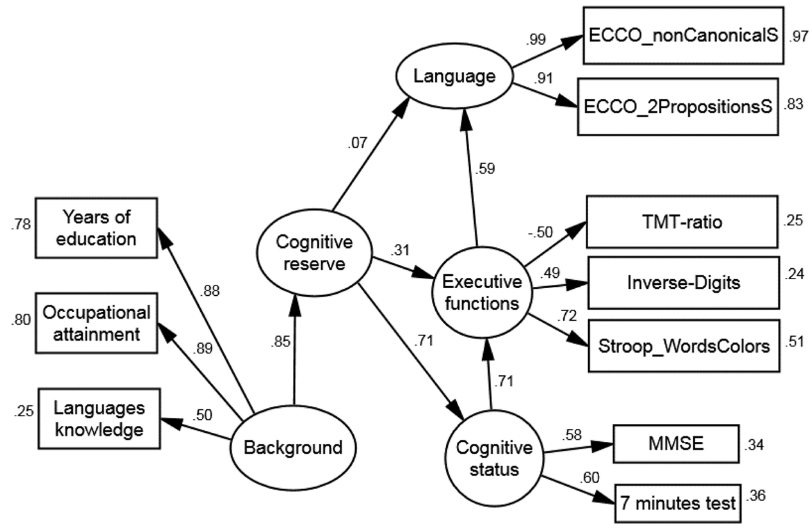

Fig. 1. Standardized solution for the proposed structural model.

although to a lesser extent, to EF performance. However, the direct effect of CR on sentence comprehension was not significant. CR has an indirect effect on sentence comprehension mediated by EF performance. Cognitive status and EF were highly related.

4. Discussion

The structural model proposed was supported by the results, that is: CR has a direct influence on older adults' general cognitive status and executive functioning, and affects indirectly to language comprehension performance through EFs' mediation.

The CR construct is formed by a background latent variable, including measures related to individuals' experiences along life which have been proposed as protective factors against cognitive decline. It has a high factor loading in the construct (.85) and explains 72% of CR total variance, thus only a little part of it (28%) would be explained by other latent variables. One candidate could be, for example, lifestyle, as it appears in the model proposed by Lojo-Seoane et al. (2014) to account for the influence of CR on cognitive performance in adults with subjective memory complaints. Other proposals have included variables such as socioeconomic status (Levi, Rassovsky, Agranov, Sela-Kaufman, & Vakil, 2013), or even participants' age, with CR having a moderating role in reducing the direct negative effect of age on verbal episodic memory and on EF (Giogkaraki, Michaelides, & Constantinidou, 2013). Background has a greater factor loading in our sample of intact older adults than in the study of Lojo and colleagues, who was conducted with a sample of participants with subjective memory complaints. Another differences between both studies are the participants' mean age, that is higher in our study (71.19 +/− 4.97 vs. 66.62 +/− 9.03), and the global cognitive status which is also higher in our study (28.60 +/− 1.50 vs. 26.49 +/− 3.03).

Our results show a moderately strong positive relation between CR and general cognitive status (0.71), as we stated in our previous hypothesis. This indicates that individual background, defined mainly by higher education and a qualified occupational attainment (and also by other languages knowledge, but with a lesser extent) is related to higher performance in the previously mentioned cognitive screening tests. This result is consistent with many other previous studies. Lojo-Seoane et al. (2014) validated a SEM model in which CR (that includes educational and lifestyle variables) had strong and significant direct eff ;ects on general cognitive performance in a sample of participants with subjective memory complaints. The magnitude of the relation between CR and general cognitive status in the present study is lower than the one obtained by these authors. Experiences and environmental stimuli throughout the life cycle promote CR and this improves cognitive performance, especially in verbal capacity tasks, sustained attention and divided attention, and learning curve (Roldán-Tapia et al., 2012; Salthouse, 2010). For example, Mitchell, Shaughnessy, Shirk, Yang, and Atri (2012) found that CR (involving years of education and reading ability) was positively correlated with performance in several cognitive domains (memory/language, attention and processing speed/EF) in a sample of healthy and memory-impaired older adults. Recently, a study conducted by Lavrencic et al. (2018) with a sample of oldest-old, have found that higher CR (education, social class, marital status, engagement in mental activities, social participation and physical activity) was associated with better global cognitive functioning (measured by MMSE).

Our results also pointed out that CR has a mild influence on EFs (0.31), which could be interpreted as reflecting that it affects positively to performance in inhibitory control, maintenance and manipulation in WM and cognitive flexibility. It should be noted that the weight of the inhibitory control measure in the latent variable EF is higher (0.72) than the other observed measures. Negative sign in TMT ratio means that the lower the ratio B/A, the greater the cognitive flexibility is. There are many studies that have presented similar results showing relationships between CR and EF. Siedlecki et al. (2009), for example, investigated the construct validity of CR by comparing the factor loadings of neuropsychological tests and CR variables on memory, processing speed, EF, and CR itself, and found good indices of model fit across three samples of cognitively normal adults. Results in the most demanding condition, of both convergent and discriminant validity, suggest that CR is highly related to the executive functioning variables (correlations higher than 0.75). Mitchell et al. (2012) used confirmatory factor analysis to test a four-factor model that includes memory/language, processing speed/EF, attention, and CR factors in order to compare performance from a group of cognitively healthy older adults to a group of participants along the spectrum of amnestic MCI to Alzheimer disease (AD). In particular, the correlation between CR and their processing speed/EF domain was 0.43, in both groups, thus higher than the one observed in our study (0.31), in which the latent variable EF is related to inhibitory control, cognitive flexibility and maintenance/manipulation of information in WM. Apart from other interesting results, these authors found evidence to support that memory/language and processing speed/EF latent variables may be particularly sensitive measures for tracking cognitive decline related to AD. A recent study of Lavrencic et al. (2018), using a regression method, have pointed out that CR (years of education) was associated with attention, EF, verbal and working memory, and orientation; but it was not significantly related to emotion perception, processing speed, or motor performance.

In our model, cognitive status is directly related to executive functioning (0.71). This is an expected result since the two screening tests include items that could be linked to EF.

As we stated in the introduction, CR does not have a direct influence on SC (0.07), but it has an indirect positive effect on it via EF (there is a moderate and positive correlation between EF and SC: 0.59). We have not found any previous SEM study that reports a structural relationship between the CR and SC mediated by EF. However, as we have tried to show in the introduction there is an extensive corpus of evidence showing relations between EF and language performance or language processing (see for example, Hussey & Novick, 2012). Successful SC implies the regulation of multiple processes; in order to reach a final interpretation, executive control processes monitor the occurrence of conflicts and select among competing alternatives. Monitoring processes may serve to reanalyse previous inputs and check for possible mistakes. Furthermore, if the conflict occurs because of the appearance of an unexpected information, selection processes would be activated. Thothathiri, Asaro, Hsu, and Novick (2018) used passive constructions that described a more plausible situation (congruent) or a relatively implausible situation (incongruent). In both conditions, the visual display contained the target picture that matched the sentence, the picture that depicted the reversed scenario, and two unrelated distractors. Any given sentence appeared after a congruent Stroop trial in two lists and after an incongruent Stroop trial in two other lists of items. Their results showed that prior cognitive control engagement (Stroop trial) facilitated the resolution of syntax-semantics conflict in thematic role assignment by biasing processing towards the intended analysis.

The proposed model could be used to identify the effects of CR on cognitively intact older adults' general cognitive state, EF and SC, making it possible to explore their evolution over time.

One possible limitation of this study has to do with the size of the sample, which, if greater, would guarantee better reliability in the estimates of standard errors and adjustment indices. The application of this model to the data that we are collecting actually, in a longitudinal study carried out with adults over 50 with and without a family history of AD, could serve to confirm the current results in the near future. On the other hand, in future studies other indicators related to RC could also be included in the model, as well as other tests related to different executive functions not considered in the present study. Another possible extension of the present study would be to compare the results obtained here with others based on a sample of patients with mild cognitive impairment.

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Declarations of interest

None.

CRediT authorship contribution statement

María Luisa Delgado-Losada: Conceptualization, Supervision, Writing - original draft. **Susana Rubio-Valdehita:** Conceptualization, Methodology, Writing - original draft. **Ramon Lopez-Higes:** Conceptualization, Funding acquisition, Writing - original draft. **Inmaculada Rodríguez-Rojo:** Supervision, Writing - review & editing. **José M. Prados Atienza:** Data curation, Resources, Writing - review & editing. **Sophie García-Cid:** Data curation, Investigation. **Mercedes Montenegro:** Writing - review & editing.

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