VARIABLES THAT ALLOW A RELIABLE CLASSIFICATION OF OLDER PEOPLE WITH DIFFERENT LEVELS OF COGNITIVE STATE

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Abstract

To assess the general cognitive state and identify potential cognitive deterioration issues, screening tests such as the Mini-Mental State Examination have been widely utilized. Various studies have aimed to determine the socio-demographic variables (e.g., age, education) and cognitive abilities (memory, language, executive functions) most closely linked to the cognitive state assessed through tests like the MMSE. The primary objectives of this study were as follows: (a) assess the impact of socio-demographic variables, such as age and cognitive reserve, and other cognitive abilities (working memory, comprehension of written sentences) in accurately classifying a sample of older individuals with varying general cognitive statuses; (b) calculate optimal cut-off points for variables with the greatest importance in classification, striking a balance between true positive rate (sensitivity) and false positive rate (1 - specificity). The participants comprised 159 Spanish older adults, aged 60 to 89, categorized into two groups based on their 35-item MMSE scores: those with scores equal to or greater than the 60thile (normal/high scores: N/Hs group) and those with scores equal to or lower than the 25thile (low scores: Ls group). All participants underwent tests evaluating working memory and comprehension of written sentences, including the digit reordering test, the sequential version of the ECCO-senior test, and the written sentence comprehension test of the Batería de Evaluación de los Trastornos Afásicos (BETA; English translation: Battery for the assessment of aphasic disorders). Cognitive reserve estimation was obtained through Rami et al.'s Cognitive Reserve Questionnaire. Binary logistic regression analysis was initially conducted following a hierarchical method to identify significant variables explaining correct classification. Subsequently, ROC curve analyses were performed to determine optimal cut-off points for relevant variables, as well as measures of overall model quality. The final logistic equation incorporates cognitive reserve, digit reordering, and performance on BETA's sentences focused on the object and on sentences with one proposition not fitting canonical word order in Spanish in the ECCO test. Area under the curve (AUC), ROC and precision/exhaustivity curves, an overall model quality index, and optimal cut-off values were computed for all these significant variables. Results are discussed in the context of the reviewed literature.

Keywords: *Cognitive reserve, working memory, sentence comprehension, MMSE, ROC analysis.*

1. Introduction

There is a continuum from normality to dementia (Petersen et al., 2014) in which different trajectories of greater or lesser cognitive decline may occur that depend on factors such as age (Salthouse, 2012), cognitive reserve (Jones et al., 2011), presence of anxiety or stress (Lupien et al., 2007), depressive symptoms (Liew, 2019), or serious cardiovascular diseases (Walker et al., 2019), among others. The Mini-Mental State Exam (MMSE; Spanish adaptation by Lobo et al., 1979) has been used as a screening test to detect the presence/absence of cognitive impairment (Vilalta-Franch et al., 1996). This has allowed researchers to study the variables that are more strongly associated with this dichotomous classification. Some have already been mentioned (age, cognitive reserve), but others are of interest because they belong to cognitive domains such as working memory (Kirova et al., 2015), or to another area that has been poorly studied, such as sentence comprehension.

The first objective of this work is to explore the differences between cognitively intact older adults and older people with cognitive impairment, according to their scores on MMSE, concerning variables such as age, cognitive reserve, working memory capacity, and different indices related to sentence comprehension. As a second objective, this study aims to determine which variables have the greatest weight to reliably classify participants, and which of these would be the best predictors in terms of their statistical properties.

2. Method

2.1. Participants

A sample of 208 Spanish older adults (age range: 60 - 89 years old) was initially assessed in the context of a research project on normal and pathological aging. Two groups were established using the scores obtained by the participants in the MMSE-35 (Lobo et al., 1979): (G1) the **cognitively intact** group [MMSE-35 ≥ 60thile], and (G2) the **cognitive impairment** group [MMSE-35 ≤ 25thile]. The percentage of females was 54.7% in G1 and 59.6% in G2. Regarding formal education, in G1 there was 78.5% of participants with higher education, whereas in G2 the percentage decreased to 51%.

2.2. Materials

MMSE-35 (Lobo et al., 1979) was used as a screening/grouping test. Cognitive reserve estimation was done by the Cuestionario de Reserva Cognitiva (English trad.: Cognitive reserve questionnaire; Rami et al., 2011). A digit reordering task (MacDonald et al., 2001) allows us to assess individuals' working memory capacity. Written sentence comprehension was assessed through two tests, the Exploración Cognitiva de la Comprensión de Oraciones (ECCO_Senior test; English translation: Cognitive assessment of sentence comprehension; López-Higes et al., 2020), and the subtest of sentence-picture matching of the Batería de Evaluación de los Trastornos Afásicos (BETA; English translation: Battery for the assessment of aphasic disorders; Cuetos & González-Nosti, 2009). Sentence comprehension indexes from the BETA subtest corresponded to the following types of structures: active, cleft subject, relative clause, passives, and cleft object. From the ECCO test, we used four indexes corresponding to sentences fitted to canonical word order in Spanish (WOS: Subj.+Verb+Obj.) with one proposition, sentences not fitted to canonical WOS with one proposition, sentences fitted to canonical WOS with two propositions, and sentences not fitted to canonical WOS with two propositions.

2.3. Procedure

All the tests were administered following the instructions in their manuals. All participants were informed about the objectives of the study and were invited to participate after signing an informed consent form.

2.4. Statistical analysis

All analyses were computed using IBM SPSS v.27. A multivariate ANOVA was used to find significant differences between groups. A binary logistic regression with the variables that were significant in the multivariate ANOVA as predictors was computed to establish the classification of the participants. A final ROC curve analysis was also performed with the variables that had an important role in subjects' classification to obtain cut-off values with clinical significance.

3. Results

Descriptive statistics in all the relevant variables are shown in Table 1. Multivariate ANOVA revealed that the two groups differ significantly in all variables (see the right side of the table). Consider all the following acronyms that appeared in the table. C1SP: sentences fitted to canonical word order in Spanish (WOS) with one proposition; NoCS1P: sentences not fitted to canonical WOS with one proposition; C2SP: sentences fitted to canonical WOS with two propositions; NoCS2P: sentences not fitted to WOS with two propositions.

3.1. Participants' classification

The logistic regression analysis included the following predictor variables: age, cognitive reserve, digit reordering, BETA actives, BETA passives, BETA relative clause, BETA cleft subject, BETA cleft object, ECCO C1SP, ECCO NoCS1P, ECCO C2SP, and ECCO NoCS2P. The final equation (see Table 2) allowed 82.9% of subjects' classification. When Exp(B) is less than 1 it indicates that decreasing values of the predictor correspond to increasing odds of the event's occurrence.

Table 1. Descriptive statistics by group across all relevant variables and multivariate ANOVA.

	COGNITIVE STATE					
	Intact participants (MMSE ≥ Pc60)		Impaired participants (MMSE ≤ Pc25)			
	Mean	*SD*	*Mean*	*SD*	*F(1,158) =*	*Sig.*
Age	68.26	7.66	74.43	6.62	27.01	**
MMSE	34.02	.87	27.43	3.07	400.50	**
Cognitive reserve	13.51	4.22	7.60	3.46	80.78	**
Digit reordering (series)	12.56	2.23	9.28	3.75	47.81	**
BETA active sentences	3.77	.45	3.23	.88	25.52	**
BETA cleft subject sentences	3.78	.56	3.36	.79	14.69	**
BETA relative clause sentences	3.71	.49	3.25	.91	17.66	**
BETA passive sentences	3.65	.59	3.15	.81	20.42	**
BETA cleft object sentences	3.64	.64	2.85	1.19	29.28	**
ECCO CS1P	8.48	.93	7.40	1.56	29.56	**
ECCO NoCS1P	8.25	1.21	6.75	1.57	45.55	**
ECCO CS2P	8.15	1.14	6.67	1.75	41.67	**
ECCO NoCS2P	7.20	1.82	5.74	1.66	26.02	**

**: $p < .001$

Table 2. Logistic regression: variables in the final equation.

	B	***standard error***	***Wald***	***df***	***Sig.***	***Exp(B)***	***95% C.I. for EXP(B)***	
							Inferior	*Superior*
Cognitive reserve	-.291	.070	17.134	1	.000	.747	.651	.858
Digit reordering (series)	-.227	.092	6.074	1	.014	.797	.665	.955
BETA cleft object	-.612	.290	4.456	1	.035	.542	.307	.957
ECCO NoCS1P	-.347	.172	4.062	1	.044	.707	.505	.990
Constant	5.318	3.080	2.982	1	.084	204.076		

3.2. Quality of significant predictors

To explore the quality of these four significant predictors individual ROC curve analysis was computed for each one. Relevant parameters in ROC curve analysis are (a) Area Under the Curve (AUC), which is a metric that quantifies the overall performance of a binary classification model; (b) Sensitivity, which ranges from 0 to 1, where 0 indicates low sensitivity (no true positives correctly identified) and 1 indicates high sensitivity (all true positives correctly identified); (c) Specificity, it also ranges from 0 to 1, where 0 indicates low specificity (no true negatives correctly identified) and 1 indicates high specificity (all true negatives correctly identified); (d) Kolmogorov-Smirnov (K-S) is an index showing how far are separated the rate of true positives from the rate of false positives, indicating if the model is good enough for classification. Based on K-S metric it is possible to determine the optimal cut-off point for each predictor variable. Due to space limitations, only the figures corresponding to the two predictor variables that have the best properties will be shown.

Figure 1 shows the ROC curve and the overall quality of the model if cognitive reserve (CR) is considered as predictor variable for classification. In this case AUC = .851, K-S = .551 (moderately high quality to distinguish between the two groups), and the optimal cut-off for CRQ (max: 25) = 9.5.

The ROC curve and the overall quality of the model for ECCO sentences not fitted to WOS with one proposition (NoCS1P) appear in Figure 2. In this analysis AUC = .787, K-S = .413 (moderate quality), and the optimal cut-off for NoCS1P (max: 9) = 7.5.

Parameters for digit reordering (DO) are the following: AUC = .778, K-S = .482 (moderate quality), and the optimal cut-off for DO (max: 15 points) = 10.5. The results obtained for BETA cleft object sentences (COS) are: AUC = .698, K-S = .347 (low moderate quality), and the optimal cut-off for COS (max: 4) = 3.5.

Figure 1. ROC curve and overall model quality corresponding to CR.

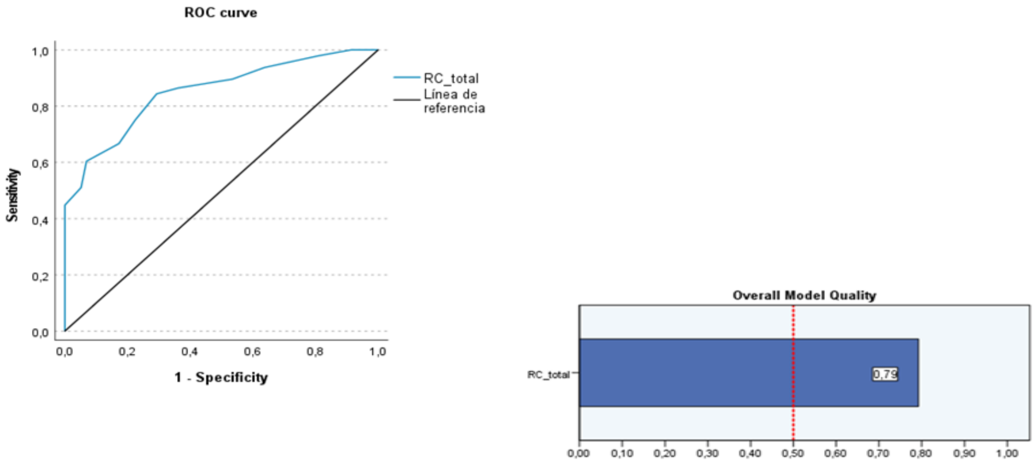
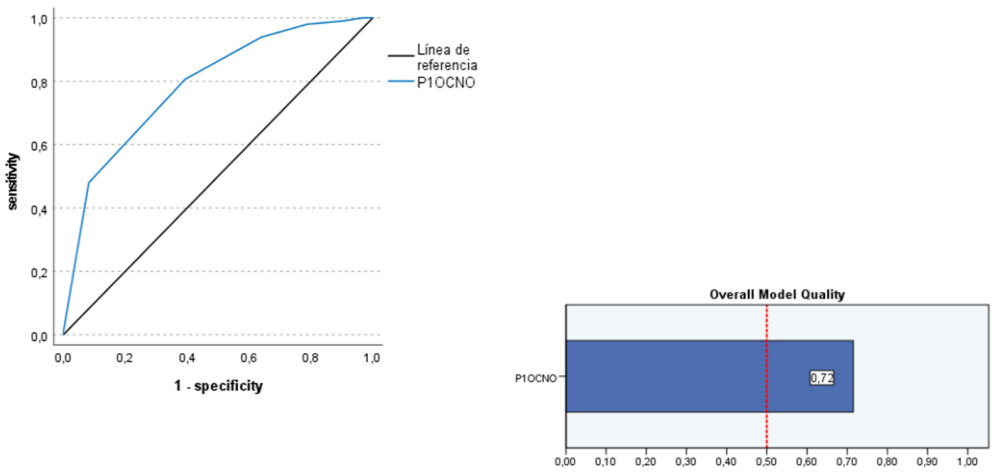


Figure 2. ROC curve and overall model quality corresponding to ECCO NoCS1P.



4. Conclusions

The differences between the MMSE-based groups appeared in well-studied factors such as AGE (Nagaratnam et al., 2020), COGNITIVE RESERVE (CR; Lojo-Seoane et al., 2014), or WORKING MEMORY (Lojo-Seoane et al., 2020; López-Higes et al., 2023), which can be considered as a mechanism through which CR exerts its protector role on other cognitive domains. But they are also observed in a domain that has not traditionally received much attention, LANGUAGE, and more specifically written SENTENCE COMPREHENSION (assessed by BETA and ECCO tests in this study).

An excellent classification (83%) is achieved using four predictor variables: CR, Digit reordering, BETA Cleft Object sentences, and ECCO NoCS1P. These last two are related to the comprehension of syntactically complex sentences (Karimi & Ferreira, 2016). In a recent study (López-Higes, Rubio, Rodrigues, & Fernandes, in press) the discrepancy between participants' performance on sentences fitted and non-fitted to canonical WOS was the most significant predictor to distinguish between healthy and SCD+ older adults matched in age, years of education, episodic memory, global cognitive state, and mood. ROC curves analysis pointed out that the order of relevance of predictors for binary classification purposes was the following: CR > ECCO NoCS1P > Digit reordering > BETA Cleft Object.

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