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Executive functions and memory strategies in healthy individuals with high and low cognitive reserve: A comparative study

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ABSTRACT

Objective: *In this study, we aim to explore differences in executive functions, memory, and memory strategies, between healthy individuals with high and low levels of Cognitive Reserve (CR).*

Method: *A total of 70 participants underwent neuropsychological assessment, 36 females and 34 males, aged between 50 and 85 years. The instruments administered were BSI, MoCA, QRC, LMS I and II (EMW-III), DMS (WAIS – III), TMS, VFT, SCWT, and WCST.*

Results: *We confirm the influence of the CR, including education level, on the performance of the neuropsychological tests, with higher CR and education level leading to better neuropsychological performance. At the TMS test, there were no group differences in those conditions with higher demand on executive functions, while in those with the material externally organized the differences were significant. While age had a lesser influence on performance, middle-aged participants with a higher CR presented better performances, when compared to older participants.*

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Conclusions: *Results suggest that the use of memory strategies is more effective in participants whose executive functioning is preserved, regardless of age. A greater capacity for coding structured word patterns, was observed, compared to unstructured patterns. It was also found that a higher level of cognitive reserve enhanced the participants cognitive performance.*

Keywords:

neuropsychological assessment; healthy aging; executive functions; memory strategies; cognitive reserve.

RESUMEN

Objetivo: *En este estudio, nuestro objetivo es explorar las diferencias en las funciones ejecutivas, la memoria y las estrategias de memoria entre individuos sanos con niveles altos y bajos de Reserva Cognitiva (RC).*

Método: *Un total de 70 participantes fueron sometidos a evaluación neuropsicológica, 36 mujeres y 34 hombres, con edades entre 50 y 85 años. Los instrumentos administrados fueron BSI, MoCA, QRC, LMS I y II (EMW-III), DMS (WAIS – III), TMS, VFT, SCWT, WCST.*

Resultados: *Confirmamos la influencia de la RC, incluido el nivel educativo, en el rendimiento de las pruebas neuropsicológicas, con una mayor RC y nivel educativo que conducen a un mejor rendimiento neuropsicológico. En la prueba TMS en aquellas condiciones con mayor demanda de funciones ejecutivas no hubo diferencias de grupo, mientras que en aquellas con el material organizado externamente las diferencias se hicieron significativas. La edad parece tener una menor influencia en el rendimiento. Todavía los sujetos de mediana edad con mayor RC presentan mejores desempeños, en comparación con los sujetos de edad avanzada.*

Conclusiones: *Los resultados sugieren que el uso de estrategias de memoria es más efectivo en sujetos cuyo funcionamiento ejecutivo está preservado, independientemente de la edad. Se observó una mayor capacidad para codificar patrones de palabras estructuradas, en comparación con patrones no estructurados. También se encontró que un mayor nivel de reserva cognitiva mejoró el rendimiento cognitivo de los participantes.*

Palabras Claves:

evaluación neuropsicológica; envejecimiento saludable; funciones ejecutivas; estrategias de memoria; reserva cognitiva.

INTRODUCTION

Population aging is a growing phenomenon worldwide. In Portugal, recent data point to the existence of 165 older adults per 100 young people, according to Pordata[1]. Ageing is often associated with the approximation of the end of our physical, cognitive, social, behavioral, and emotional functional capacities, consequently affecting our quality of life[2-6]. Understanding the difficulties commonly experienced of normal aging can help in the development of alternative and effective cognitive strategies, as well as the maintenance of our capacities, especially executive functions and memory that are affected with age-related cognitive decline [7-10].

The executive functions (EF) enable successful engagement in independent and intentional behaviors[11-13]. Two of the main components of EFs are Inhibitory control and cognitive flexibility. The inhibitory control includes inhibition of usual responses. Cognitive flexibility is the ability to produce several ideas, change cognitive set, consider the various alternatives of response, process, and modify behaviors in order to manage the circumstances of life that are constantly changing[8-9,14-15].

As such, these negative associations between age and EF performance may be related to the fact that the functions of the frontal lobe are the first to suffer a decline over aging and also with the changes in the cellular scope that occur in the hippocampus which, in part, are also responsible for cognitive and executive decline[7-9,13].

These EFs decline have relevant impact in the performance of memory test and the implementation of memory strategies. A recurrent concern related to aging refers to episodic memory loss, usually signaled from the age of 65, as a consequence of the gradual deterioration of the regions of the medial temporal lobe, especially, hippocampus atrophy[3,16]. The ability to create cognitive strategies for information encoding and/or retrieval requires the executive functioning that enhances memory in new or highly demanding tasks[3,16]. Memory strategies are a cognitive ability that allows individuals of advanced age to compensate for memory failures and can be classified as internal strategies or external strategies[17-19].

Internal memory strategies include the construction of mental images, the repetition of information and/or the development of mnemonic techniques (e.g., acronyms) that incorporate the task to be remembered. In turn, external memory strategies are implemented by adapting the environment for the provision of memory clues are examples, writing notes, placing important objects or annotations in places of immediate visual access[17-19]. Older adults tend to prefer external memory strategies, since cognitive resources decrease with age. On the contrary, the use of internal memory aids is associated with superior cognitive abilities, namely executive functioning, and fluid intelligence[54]. Bor et al.[52] in a study focusing on memory strategies, found that structured patterns were more easily coded than unstructured patterns in a spatial task. Additionally, Bailey et al.[51] observed that cognitive strategies improved performance on complex memory tasks (e.g., encoding strategies).

In the course of the aging process, brain networks naturally lose their effectiveness. In this sense, literature has highlighted the role of the CR by defining it as a brain capacity to deal with damage through compensatory mechanisms or more flexible and adaptive networks, to increase or optimize performance[2,4,9-10,20]. In general, studies suggest that high education, crystallized and fluid intelligence, complex professional activities, involvement in stimulating cognitive and social activities, regular physical exercise and a Mediterranean diet are some of the compensatory mechanisms that contribute to CR [17,21-25].

The present study main objective is to explore differences on executive functions (cognitive flexibility and inhibitory control), memory and memory strategies, between healthy individuals with high and low levels of CR. Significant differences are expecting between the level of CR and the performances in each neuropsychological test, with individuals with high CR exhibiting superior performances, compared to individuals with low

Table 1. Descriptive Statistics of Demographical Data and Cognitive Reserve Levels

		M	SD
Demographical data			
Age groups, years, n (%)		64 years (*M* = 63.7)	
	50 to 65	37 (53%)	
	65 to 85	33 (47%)	8.7
Sex, n (%)			
	Female	36 (51%)	
	Male	34 (49%)	
Civil status, n (%)			
	Married	58 (83%)	
	Widowers	7 (10%)	
	Divorced	4 (6%)	
	Single	1 (1%)	
Education level, n (%)		2	
	Fourth grade	22 (31%)	
	11 years	28 (40%)	
	Secondary/higher education	20 (29%)	0.78
Socioeconomic status, n (%)			
	Low	35 (50%)	
	Medium	26 (37%)	
	High	7 (10%)	
	Never worked	2 (3%)	
Cognitive reserve levels			
Groups			
	High CR	35 (50%)	
	Low CR	35 (50%)	
Points			
	Lower	C1: ≤ 6	
	Medium-low	C1-C2: 7-9	
	Medium-high	C2-C3: 10-14	
	Top	C4: ≥ 15	

CR. Also, we aimed to explore the differences between the age groups and educational levels in the performance in each neuropsychological test, expecting that with more age, worse performances and with more education, better performances.

All the factors mentioned above have not been studied together with specific cognitive tests for each domain. Therefore, the aim of the present work was to study if there are relationships between CR, inhibition, cognitive flexibility, and memory strategies. Furthermore, it was explored whether or not these effects were influenced by the age of the participants. It was hypothesized that higher CR levels would directly influence the EFs abilities as well as the ability to implement cognitive strategies needed for the performance of memory tests. Finally, we hypothesized that CR would not be influenced by the age factor.

METHOD

Participants

This study had quantitative cross-sectional design. The sample included 70 healthy adult participants (Table 1). Participation in the study included the following inclusion criteria: healthy individuals aged between 50 and 85 years. In turn, individuals with psychopathological, neurological diagnoses and metabolic diseases, or individuals infected with COVID-19 were excluded.

The study was conducted in Oporto district and participants were recruited according to their availability through a non-probabilistic snowball sampling procedure. All data collection were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Prior to data collection, participants were informed about the research goals and the voluntary and confidential nature of the study and signed an informed consent form. Next, socio-demographic information and CR variables were collected in order to identify specific characteristics of the sample under study (e.g., gender and age), particularly relevant for the calculation of the CR level.

Instruments

Screening assessment:

Brief Psychopathological Symptoms Inventory (BSI)[26-27] aims to evaluate psychopathological symptoms, using 53 items. The instrument has a good internal consistency, and the subscales internal consistency range between .62 and .80.

Montreal Cognitive Assessment (MoCA)[28-29] is a brief screening instrument for mild cognitive decline that can quickly and accurately assesses short term memory, visuospatial abilities, executive functions, language, orientation to time and place, attention, concentration and working memory, and is currently used in the evaluation protocols of various clinical groups. Has a very good internal consistency (Cronbach's Alpha = .83) and the cutoff point used was ≥ 26 (Absence of Cognitive Decline)[30].

Cognitive Reserve Questionnaire (QRC)[31-32] that evaluates a set of eight items of equal importance: Schooling; Parent's Education; Training Courses; Labor Occupation; Musical Training; Languages; Reading Activity; Intellectual Games. Has a very good internal consistency (Cronbach's Alpha = .80).

Neuropsychological tests:

Logical Memory Subtests I and II of the Memory Wechsler Scale - 3rd Edition (EMW-III)[33-34] assess immediate and late verbal declarative memory, providing a time interval of 30 minutes. Has very good internal consistency, and the subscales range between .87, for the logical memory subtest I, and .83 for the logical memory subtest II. In the current study, the instrument presented an excellent internal consistency (α = .93).

Digit Memory Subtest of the Wechsler Adult Intelligence Scale - 3rd Edition (WAIS – III)[35-36] evaluates the memory capacity of auditory work, short-term memory and attention, consisting of eight digits of direct order and seven of reverse order. Has an excellent internal consistency (Cronbach's Alpha between .90 and .92). In the present study, the instrument presented an acceptable internal consistency (α = .60).

Test of Memory Strategy (TMS)[6,37] consists in a task of verbal learning where the need to use memory strategies gradually decreases. Thus, it allows us to check whether memory deficits are associated with a pure memory deficit or the use of memory strategies. The instrument has a good internal consistency (Cronbach's Alpha = .74). In this study the internal consistency was α = .77.

Stroop Color and Word Test[38-39] assesses executive functions, verbal fluency, and cognitive efficacy. It encloses three parts and allows for the evaluation of inhibition control and attention processes. Showed an acceptable internal consistency (Cronbach's Alpha = .66). In the present study, it presents a very good internal consistency (Cronbach's Alpha = .82).

Verbal Fluency Test[40-41] assesses non-motor processing speed, language, production, and executive functions (mental flexibility), through the naming of animals (semantic fluency) and words related to specific letters (phonemic fluency). Has an acceptable internal consistency for semantic fluency (Cronbach's Alpha = .74) and a high internal consistency for phonemic fluency (Cronbach's Alpha = .89). In the present investigation, the instrument presents a very good internal consistency for both fluencies (Cronbach's Alpha = .85).

Wisconsin Card Classification Test (WCST)[42-43] allows the evaluation of cognitive flexibility, assessing several components of executive functions such as abstract reasoning, planning, working memory, monitoring, perseveration inhibition and formation of problem-solving strategies in the face of modifiable stimulation conditions. Has excellent internal consistency, and presents Cronbach Alphas of .93 for persevering responses, .92 for persevering errors, and .88 for non-persevering errors.

Data Collection Procedures

The neuropsychological evaluation protocol was administered individually and took approximately one hour. Assessment sessions occurred from February 2020 to June 2020.

The data collection procedure was applied in two phases. First, a screening was performed to verify the absence of psychopathology and/or cognitive decline, assessed through the Psychopathological Symptoms Inventory (BSI) and the Montreal Cognitive Assessment (MoCA), respectively. In cases where the participants met the inclusion criteria of the study, a battery of neuropsychological tests was administered comprising tasks evaluating executive functions and memory capacity.

Statistical Analyses

Data analysis was preceded by a grouping of variables in order to organize statistical procedures and, consequently, contribute to the achievement of significant results. Thus, the variable "Cognitive Reserve" was first constructed, dividing the participants into low levels (1) and high levels (2) from the results in QRC test [up to 6 points- lower category; between 7-9 points- medium-low → (1) low levels; and between 10-14 points- medium-high); more than 15 points- superior → (2) high levels]. In turn, the construction of the variable "Age Groups" consisted of the distribution of the participants into 2 subgroups of age specifically, adult individuals (1: 50 to 65 years) and advanced age (2: > 65 – 85 years). Finally, the variable "Socioeconomic Status" allowed the distribution of participants by three groups (1: low; 2: medium; 3: high), according to the classification of Simões[44].

Descriptive statistics were conducted to analyze demographic variables and mean scores in all variables, using the IBM SPSS. Student t-Tests were used to test differences between CR levels and performances obtained in neuropsychological tests, to analyze the differences between age groups and performance obtained in the tests, as well as to test the differences in CR levels as a function of age. To determine the effect size, Cohen's d was calculated, and the following interpretation guidelines were used: 0.2 to 0.4 – small effect; 0.5 to 0.7 – moderate effect; higher than 0.8 – large effect.

In turn, ANOVAs were performed for independent samples, in order to compare age groups and the CR in the performance obtained by the participants. When the assumption of homogeneity of variances was violated the Welch and Brown-Forsythe F-ratios were used to produce a valid ANOVA F and we opted for the Games-Howell post hoc procedure given its accuracy when the population variations are different. The effect size was measured using eta square. According to Cohen[45], a small effect size is .01, average 0.6, and large .14.

Finally, Spearman's Correlations aimed to explore the association between CR levels and performance in each neuropsychological test. The size of the correlations was interpreted according to Cohen's suggestions[45]: between .10 and .29 – weak; between .30 and .49 - moderate; greater than .50 - strong association.

RESULTS

Differences between participants as a function of CR

Student t-Tests were performed to explore differences in inhibition (SCWT), cognitive flexibility (WCST and VFT) and memory tests and memory strategies (LMS I and II, DMS and TMS), in participants with high and low CR. The results are displayed in Tables 2 and 3.

As can be seen in Table 2, there were statistically significant differences, with individuals with high CR having better performance. In particular, the most marked differences were reported in tasks

Table 2. Analysis of Performance Differences between Participants with High and Low CR in Memory Tests and Memory Strategies

		M	SD	t	df	p	D
LM1 Story A							
	Low Reserve	12.3	3.4	-3.37	68	.001	-0.81
	High Reserve	15.2	3.63				
LM1 Story B (evocation 1)							
	Low Reserve	11.8	3.1	-1.99	68	.050	-0.48
	High Reserve	13.3	3.3				
LM1 Story B (evocation 2)							
	Low Reserve	14.5	3.3	-3.60	68	.001	-0.86
	High Reserve	17.3	3.21				
LM2 Recognition							
	Low Reserve	24.3	2.39	-2.60	68	.011	-0.62
	High Reserve	25.8	2.30				
DS Forward							
	Low Reserve	7.9	2.2	-4.59	68	.000	-1.10
	High Reserve	10.3	2.1				
DS Backward							
	Low Reserve	5.2	1.0	-5.43	58	.000	-1.30
	High Reserve	6.9	1.5				
TMS-1							
	Low Reserve	3.7	1.7	.127	64	.900	-
	High Reserve	3.7	2.1				
TMS-2							
	Low Reserve	4.5	1.1	-1.17	60	.247	-
	High Reserve	4.9	1.5				
TMS-3							
	Low Reserve	5.4	.81	-2.04	55	.046	-0.49
	High Reserve	5.9	1.3				
TMS-4							
	Low Reserve	6.1	.10	-4.02	68	.000	-0.96
	High Reserve	7.2	1.2				
TMS-5							
	Low Reserve	6.2	.10	-5.03	68	.000	-1.20
	High Reserve	7.6	1.2				
TMS Total Score							
	Low Reserve	26	3.5	-2.86	55	.006	-0.68
	High Reserve	29.3	5.8				

LM1 story A [$t(68) = -3.37$, $p < .001$, $\eta 2 = -0.81$] and LM1 story B (2nd evocation) [$t(68) = -3.60$, $p < .001$, $\eta 2 = -0.86$], verifying high effect sizes. Additionally, differences were observed in the DS Forward [$t(68) = -4.59$, $p < .001$, $\eta 2 = -1.10$] and DS Backward [$t(58) = -5.43$, $p < .001$, $\eta 2 = -1.30$] subtests. And in the TMS-3

Table 3. Analysis of Performance Differences between Participants with High and Low RC in Executive Tests

		M	*SD*	*t*	*df*	*p*	*d*
Stroop W							
	Low Reserve	65.0	14.3	-7.19	68	.000	-1.72
	High Reserve	86.8	10.9				
Stroop C							
	Low Reserve	55.2	10.7	-4.53	68	.000	-1.08
	High Reserve	68.2	13.3				
Stroop CW							
	Low Reserve	39.5	10.4	-2.41	58	.019	-0.58
	High Reserve	47.4	16.4				
Semantic Fluency							
	Low Reserve	13.0	3.3	-4.75	68	.000	-1.14
	High Reserve	17.4	4.3				
Phonemic Fluency							
	Low Reserve	27.1	5.9	-5.25	57	.000	-1.26
	High Reserve	37.0	9.5				
WCST Conceptual Responses							
	Low Reserve	47.5	5.6	-5.84	58	.000	-1.40
	High Reserve	51.4	3.6				
WCST Perseverative Errors							
	Low Reserve	7.7	2.6	5.50	58	.000	1.32
	High Reserve	4.8	1.6				
WCST Perseverative Responses							
	Low Reserve	8.1	3.0	5.19	56	.000	1.24
	High Reserve	5.0	1.8				

[$t(55) = -2.04$, $p < .05$, $\eta 2 = -0.49$], TMS-4 [$t(68) = -4.02$, $p < .001$, $\eta 2 = -0.96$], and TMS-5 [$t(68) = -5.03$, $p < .001$, $\eta 2 = -1.20$] tasks.

On the other hand, there were no statistically significant differences in the TMS-1 and TMS-2 tasks ($p > .05$). However, considering that the differences were not significant, participants with high CR demonstrated greater ease performance than participants with low CR.

Through the analysis of Table 3, it can be seen that there were differences in the tasks of semantic fluency and naming the color [$t(68) = -4.53$, $p < .001$, $\eta 2 = -1.08$], observing large effect sizes. In addition, there were differences both in the task of semantic fluency and in all phonemic fluency [$t(57) = -5.25$, $p < .001$, $\eta 2 = -1.26$] tasks, observing large effect sizes. Thus, individuals with a high CR ($M = 17.4$, $SD = 4.3$) presented a higher performance in the task of semantic fluency [$t(68) = -4.75$, $p < .001$, $\eta 2 = -1.14$]. At the same time, the same pattern was observed in phonemic fluency tasks ($M = 37.0$, $SD = 9.5$) and in the SCWT [$t(58) = -2.41$, $p < .05$, $\eta 2 = -0.58$].

In the WCST, were observed strong differences with those presenting high CR, in the conceptual level responses [$t(58) = -5.84$, $p < .001$, $\eta 2 = -1.40$], in persevering errors [$t(58) = 5.50$, $p < .001$, $\eta 2 = 1.32$], as well as in persevered responses [$t(56) = 5.19$, $p < .001$, $\eta 2 = 1.24$], since large effect sizes were observed.

Analysis of the relationship between CR and performances obtained in neuropsychological tests

Table 4 displays Spearman Correlation analyses performed to explore the relationship between CR and the performances in neuropsychological tests.

Table 4. Spearman Correlation Analyses between CR and Neuropsychological Test Performance

	Cognitive Reserve
	r_s
LM1 Story A	.39***
LM1 Story B (evocation 2)	.42***
LM2 Recognition	.33***
DS Forward	.49***
DS Backward	.56***
TMS-3	.25*
TMS-4	.46***
TMS-5	.57***
TMS Total Score	.25*
Semantic Fluency	.50***
Phonemic Fluency	.53***
Stroop W	.68***
Stroop C	.44***
Stroop CW	.23*
WCST – Conceptual Responses	.57***
WCST – Perseverative Errors	-.55***
WCST – Perseverative Responses	-.53***

Note: *$p < .05$*; ** $p < .01$; *** $p < .001$

As can be seen in Table 4, moderate to strong and positive correlations were found between CR and the majority of the tests. Additionally, there are low and positive correlations between CR levels and the TMS-3 (r_s = .25, p <.05), total score of TMS (r_s = .25, p <.05) and the SCWT naming task (r_s = .23, p <.05). Finally, there were moderate to strong negative correlations between CR and performance in persevering errors (r_s = -.55, p <.001) and persevering responses (r_s = -.53, p <.001) in the WCST.

Effect of age and CR in the TMS performance

In the tasks TMS 1 [F (1, 34) = 11.10, p < .01] and TMS 3 [F (1, 767) = 6.67, p < .05], there were no statistically significant differences between the participants' performances and the CR level, observing only statistically significant differences between the age group and the performances. In general, as age progressed, performance decreased in both groups. In reference to TMS 1, younger participants (M = 4.34, SD = .29) had a better performance, compared to participants of advanced age (M = 2.91, SD = .31). In the case of TMS 3, it was found that regardless of the level of CR, the youngest performed better (M = 5.97, SD = .18), than the older (M = 5.29, SD = .19). In the tasks TMS 4 [F (1, 1606) = 13.23, p < .01] and TMS 5 [F (1, 28) = 22.22, p < .001], there were no statistically significant differences between the performances of the participants and age groups, only statistically significant differences between the CR level and the performances. The results suggest that the participants' performance improved according to a higher level of CR, regardless of age. Finally, the Total TMS Score indicates the level of CR, F (1, 114) = 5.38, p < .05, as a protective factor against the normative losses associated with age, F (1, 151) = 7.13, p = .01 (Figure 1).

Effect of age and CR in the SCWT performance

In SCWT, we verify in the word and color tasks significant statistical differences for CR and age groups, in isolation. Thus, the results seem to indicate that younger participants with a higher level of CR, obtained better performances. In contrast to the poorer performance of older individuals

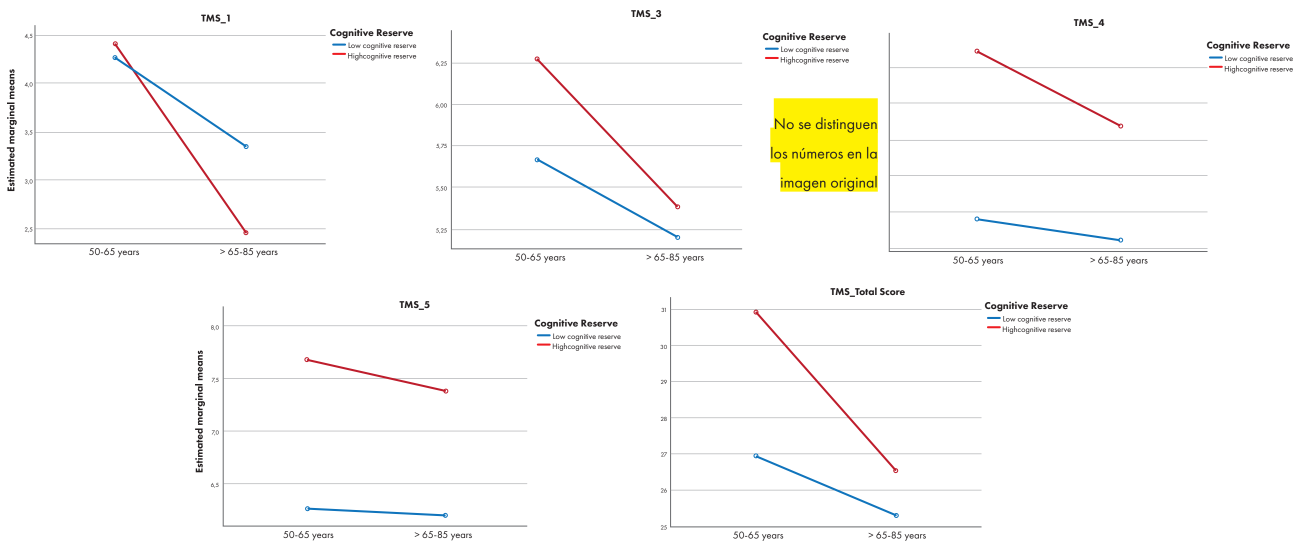

Figure 1. Estimated Marginal Means for TMS.

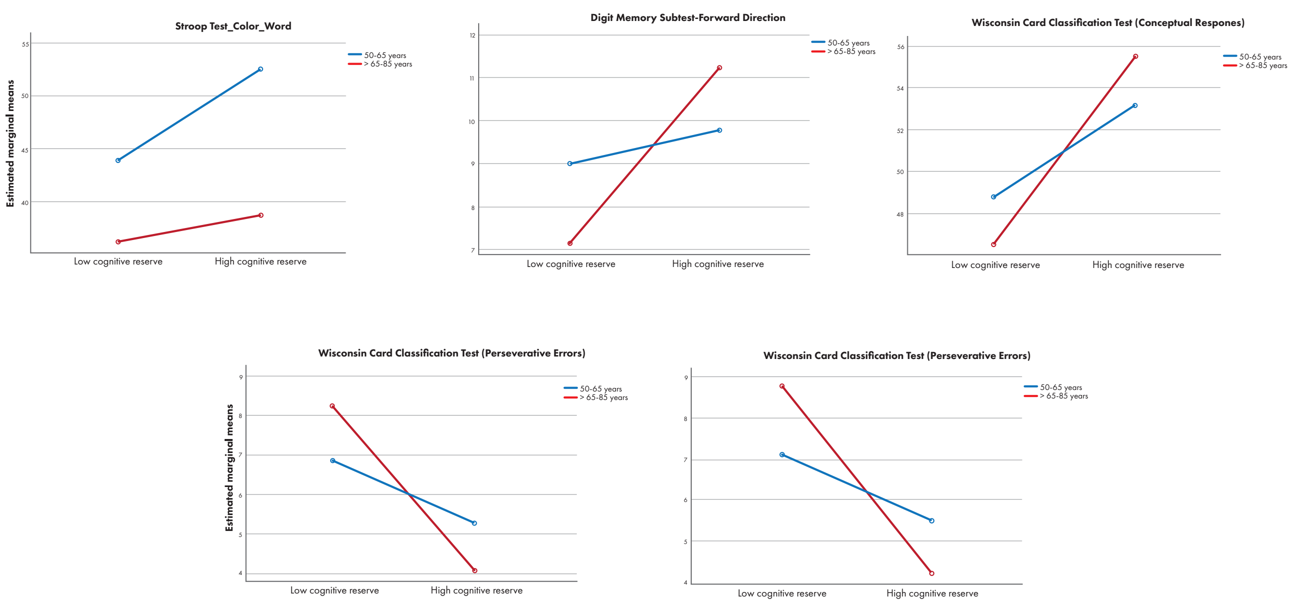

Figure 2. Estimated Marginal Means for SCWT (Color-Word), DMS (Forward Direction) and WCST (Conceptual Responses, Perseverative Errors and Perseverative Responses).

with low CR. In the third part color-word, there were only significant statistically differences for the age groups, F (1,1946) = 11.89, $p < .01$, standing out the younger individuals with better performances (Figure 2).

Effect of age and CR in the DMS of the WAIS

In DMS, only the forward task demonstrated interception between the participants' performances, CR level and age groups, F (1, 46) = 11.16, $p < .01$, with a high effect size ($\eta 2 = .15$). The results indicate that a higher level of CR improves the performance of individuals in both age groups (Figure 2).

Effect of age and CR in the WCST performance

In the WCST, for the conceptual level response [F (1, 88) = 4.17, $p < .05$], perseverative errors [F (1, 27) = 6.40, $p < .05$] and perseverative responses [F (1, 36) = 6.32, $p < .05$] the effect of the interception between the participants' performances, level of CR and age groups was observed, with a moderate effect size ($\eta 2 = .06$ - .09). In this sense, older participants with high CR obtained a higher number of responses at the conceptual level, compared to younger ones with high CR, as well as it was observed that older participants with low CR committed more errors and perseverative responses, compared to young people with low CR and older with high CR (Figure 2).

Effect of age and CR in the VFT performance

In the semantic fluency subtest, significant statistically differences were observed for the CR [F (1,252) = 18.14, $p < .001$] and for the age groups [F (1, 82) = 5.93, p <. 05]. The data indicate that the younger individuals with a higher level of CR had a greater capacity for naming and verbal fluency. In turn, in the phonemic fluency subtest significant statistical differences were observed for the CR and age groups. The data suggest that younger individuals with higher levels of CR show greater verbal fluency, compared to younger participants with low CR and older participants with high and low CR.

Effect of age and CR in the LMS I and II of the MWS

It was found that in the LMS, only one intersection was identified in history B (2nd evocation). Thus, the data point to one interception between the CR level and age range of the participants, F (1,39) = 4.17, $p < .05$, $\eta 2 = .06$. With a higher level of CR, it is observed that the younger participants (M = 17.45, SD = 3.22), as well as the older participants (M = 17.15, SD = 3.31), showed a high cognitive performance. In contrast, at a lower level of CR, it was the older participants (M = 13.10, SD = 2.17) who stood out negatively, compared to the younger ones with a low CR (M = 16.47, SD = 3.62).

DISCUSSION

The main goal of this study was to analyze how CR influences the performance of tasks implying inhibition control, cognitive flexibility, memory, and an effective use of memory strategies in middle-aged and older individuals. Overall, results suggest that middle-aged individuals demonstrated a higher CR level when compared to older individuals. In general, there were differences between individuals with high CR and low CR in all neuropsychological tests, with the former presenting better performances.

Regarding performance analysis as a function of CR levels, in the LMS I and recognition task it is suggested that individuals with high CR tend to demonstrate a higher immediate and late verbal declarative memory capacity compared to participants with low CR since the first trial and, as the stories are verbally repeated, these differences become more evident[49]. In addition, the impact of a higher level of CR was also verified in the tasks of the DMS, indicating that the higher the level of CR, the greater the auditory working memory skills, short-term memory, and attention.

In particular, in TMS only differences were found between the conditions TMS-3 (non-conscious semantics disordered categories), TMS-4 (non-conscious semantics sorted categories) and TMS-5 (conscious semantics sorted categories). In this sense, the results seem to indicate that as the external context is facilitating the organization of the material, their performances improve[6,16,37]. This effect could be due to the greater ability to access and effectively use memory strategies, especially in those individuals with high CR. As verified in the literature, memory tasks with word lists organized by categories are more easily memorized, compared to scattered word lists[51-52].

On the contrary, in the case of the TMS-1 task (incidental learning), it is possible that the initial instruction may influence participants' performance and not directly ones' CR level or memory strategy. In turn, in the TMS-2 task (non-semantic relationship), since words do not appear associated, coding, and immediate recall seem to become more difficult to all participants. As previously described, individuals with higher CR, showed the capacity to use preserved alternative memory strategies, namely the internal memory strategy of mechanical repetition[53]. Here we have demonstrated that memory strategies as well better at localizing and implementing the contextual cues to improve performance in memory tasks. In fact, these results agreed with the perspective of preference for external memory strategies in the aging process[19] and confirm the hypothesis of preservation of superior cognitive abilities[20,54-55]. This result seems to meet the neural compensation mechanism of CR, suggesting the recruitment of several neural networks to maintain cognitive performance, in tasks of greater demand[20,55].

In general, healthy aging is associated with gray and white matter damage, atrophy, and functional disturbances that affect most areas of the brain. Older adults seem to form a homogeneous group in response to their decreased performance on memory tasks. However, there may be comparable performances between younger and older adults. What has been proven is that variability in memory performance in old age may, in part, be related to the ability of older people to engage neural compensatory mechanisms in response to structural/functional decline in other brain regions or networks[2,4,9-10]. This leads us to the concept of cognitive reserve, which the literature is consistent with regarding the relationship between CR, better executive functioning, and memory. In this sense, we verified that there are some factors that help to compensate/attenuate the negative effects of age-related neural decline, and/or neuropathology, on cognitive function in a later stage of life, such as education, performance in reading activities and writing, involvement in social activities and the exercise of occupational or professional activities that are also cognitively stimulating[46-50].

The abilities described above mainly depend on executive functioning. Therefore, we tested, in this sample, how EFs are influenced by CR. Regarding the SCWT, individuals with high CR demonstrated significantly superior results in the three tasks that constitute the test, resulting in greater capacities of reading processing speed, inhibition control and sustained and selective attention[9]. In turn, in the VFT, the influence of CR on the participants' performances was also observed, since individuals with high CR presented a higher performance in the semantic fluency and phonemic tasks, indicating that the higher the CR, the higher the skills of non-motor processing speed, language, production and mental flexibility. Also, in the WCST there were strong differences between individuals with high and low CR, at the level of conceptual level responses, persevered errors, as well as in persevering responses, confirming that individuals with a high CR have a higher performance in conceptual level responses, compared to individuals with low CR, reflecting greater capacities of flexibility of thought, abstract reasoning, planning, working memory, monitoring, and inhibition of perseveres. Conversely, individuals with a low CR presented more persevering errors, non-persevering errors, and persevered responses, compared to participants with high CR, corroborating the fact that the lower the CR, the lower the probability of error, insistence on error and less flexibility in the formation of problem-solving strategies in the face of modifiable stimulation conditions[56].

An important factor to consider for the interpretation of our results was age. There were differences in the performance of participants from different age groups in the tasks of the LMS I and recognition task. This result is consistent with the study of Aronov et al.[54], showing that younger individuals exhibit better performances in memory tasks that imply a time interval between the encoding period and the time of recall. Additionally, after 65 years of age, individuals tend to resort to emotional and thought strategies to identify the source of memory[16].

Contrary to what was expected, only the DS forward task demonstrated interception between the participants' performances, CR level and age groups. The results indicated that a higher level of CR improves the performance of individuals in both age groups. This can be explained by the fact that the forward task is more related to a phonological circuit and involves little intervention of the executive system[36]. On the other hand, DS backward task requires greater attention to repeat the sequence of numbers in reverse. This working memory process is responsible for strategies for the selection, control and coordination of the mechanisms involved in short-term storage involving, simultaneously, the storage and processing of information[23,36,57].

In addition, in the TMS the results suggested that the participants' performance improved according to a higher level of CR, regardless of age. Thus, CR showed a greater impact on participants' performance, compared to age. Specifically, the CR impact is more pronounced in those tasks that imply a greater cognitive demand[23,50].

In the case of the SCWT, significant CR levels and age differences were found in the tasks of word naming and color naming. Significant age group differences were found in color-word task. These results seem to indicate that younger participants with a higher level of CR, obtained better performances, in contrast to the poorer performance of older individuals with low CR. This may reflect lower reading processing speed capacities, lower accuracy of responses, inhibition control and sustained and selective attention with increasing age[9,14,47].

In the Verbal Fluence Test significant statistical differences were observed for the CR and for the age groups. Taken together, these results are in line with previous studies, showing that younger individuals with a higher level of CR have a better performance in VFT, demonstrating higher skills of non-motor processing speed, language, production, and mental flexibility[9,47].

In the WCST, for the conceptual level response, perseverative errors, and perseverative responses, was observed a moderate effect of the interception between the participants' performances, level of CR and age groups. In this sense, older participants with high CR obtained a higher number of responses at the conceptual level, compared to younger ones with high CR. Also, it was observed that older participants with low CR committed more errors and perseverative responses, compared to young people with low CR and older with high CR. These results indicate that CR seems to have a higher influence on the performance in WCST. Participants with higher CR seems to have superior capacities of flexibility of thought, abstract reasoning, planning, working memory and inhibition of perseverations, corroborating the scientific literature that suggested that poorer cognitive flexibility was related to poorer cognitive restructuring skills and perseverative thinking was related to poorer cognitive restructuring skills and higher CR was the main correlate of better cognitive performance[11,14].

Finally, the correlation analyses showed that higher levels of CR were associated with better performances in all tests that assess memory. In particular, our study indicates that having a higher CR seems to be associated with better capacities of late verbal declarative memory, auditory working memory, short-term memory, attention and a greater selection of internal memory strategies, results that corroborate the scientific literature[17-18,48,56].

Moreover, and according to the existent literature[9,22,47] higher CR levels were also associated with better processing speed abilities, inhibiting control, sustained and selective attention, non-motor processing, language, production, mental flexibility, abstract reasoning, planning, working memory and inhibition of perseverations, as well as the lower tendency to perform and persist on errors, beyond one's age.

Limitations and Future Suggestions

The present investigation presented some limitations. Firstly, the distribution of the sample may have interfered in the results of age analyses with some non-significant tests (e.g., WCST), and prevented us to explore results of advanced age participants (> 70 years old). In fact, access to older adults was particularly difficult given the pandemic context, as older adults are considered a high risk group, as well as the fact that most of these individuals present comorbidities and/or pathologies. Future studies may want to reach a proportional number of cognitively healthy older individuals and compare the performances of the healthy and clinical population according to CR. Additionally, longitudinal studies are needed to monitor and analyze the aging process, in order to differentiate age related cognitive decline from neurodegenerative pathology. Early detection could contribute to accelerating the discovery of the causes and mechanisms of neurodegenerative diseases and to the development of preventive treatments, more appropriate to the symptoms of each of the diseases.

CONCLUSION

This study focuses on the process of healthy aging, exploring the normative differences associated with age and other relevant variables such as CR. Presenting higher levels of CR seems to protect the brain to compensate and delay the normative changes from age related cognitive decline, especially on the abilities to localize and implement contextual cues and on EFs. This study corroborated the existent literature, by showing that individuals with higher CR perform better in neuropsychological tasks than those with lower levels of CR. These results may have important influence, for the design of new cognitive interventions in the older. Therefore, the training of the localization and use of contextual cues as well as EFs such as planning, reasoning and flexibility could help for the improvement of episodic memory abilities.

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