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Development of a digital memory and learning test for elderly individuals

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Abstract

Background Population aging and the increase in memory-related diseases have motivated the search for accessible cognitive screening instruments. To develop a digital memory and learning test (DMLT) based on Rey's Auditory Verbal Learning Test (RAVLT) principles to assess cognition in the elderly and identify early cognitive decline.

Methods The research was divided into two phases: developing the digital test and the experimental phase of comparison with a reference test. The test was designed to assess episodic declarative memory through auditory-verbal learning. The experimental procedure involved 18 elderly participants and aimed to compare the performance on the digital test with the traditional RAVLT, followed by an evaluation of participant satisfaction.

Results Performance on the digital test and the RAVLT was comparable, with no significant statistical differences, indicating convergent validity between the instruments. Electroencephalographic activity analyses revealed correlations between wave patterns and test performance, suggesting that the digital test may provide additional insights into the neurophysiological processes underlying cognitive performance. Satisfaction assessment revealed high participant acceptance.

Conclusion The DMLT is a promising tool for cognitive assessment in the elderly, offering an accessible alternative. The high acceptance among elderly participants suggests that the test has potential for clinical and research use, although further studies are needed to validate its effectiveness in broader clinical settings.

Keywords Elderly, Cognitive training, Memory and learning tests, Neuropsychological tests, Electroencephalography

Background

The improvement in quality of life and the increase in public health policies justify the growth that the elderly population has experienced in recent decades. Alongside this growth, there has been an increase in the prevalence of diseases specific to this group. Among these are diseases involving cognitive decline, which directly affect the daily lives of this population and increase the need for daily and continuous care to perform activities of daily living [1].

Researchers presume that early detection of cognitive decline and the application of targeted interventions to individuals, even in the initial stages of dementia, could be effective strategies in avoiding cognitive and functional declines [2].

Neuropsychological tests generally use technically simple setups and few skills from the patient. However, these tests are less accessible in less developed countries and

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do not provide measurable neurophysiological aspects of specific brain areas while cognition is being assessed [3].

In the literature, some authors have already sought to measure cognition and identify simultaneous alterations in brain functioning. Recently, the Mini-Mental State Examination, combined with functional magnetic resonance imaging, has been used to compare groups of patients, attempting to find subtle discriminative characteristics in the human brain that could anticipate the diagnosis of Alzheimer's disease [4].

Electroencephalography (EEG) also has been studied in relation to cognitive function and cognitive impairment. Several studies have highlighted the utility of EEG in assessing cognitive abilities and cognitive decline [5–7]. EEG power and coherence have been shown to provide valuable information on synchronous oscillatory activity and cortico-cortical interactions during cognitive testing [5]. Additionally, EEG has been used to evaluate cognitive functions independently of motor responses [8]. Studies have demonstrated significant correlations between EEG measurements and cognitive abilities assessed through various tests [6, 7]. Furthermore, EEG features have been associated with cognitive decline in seniors [7], and EEG abnormalities have been linked to different cognitive profiles in Alzheimer's disease [9]. Moreover, EEG has been utilized to detect changes in cognitive load [10], assess cognitive load levels [11], and classify cognitive impairment [12]. Resting-state EEG coherence has been proposed as a marker for cognition in older adults at risk for dementia [13]. Additionally, EEG has been employed to construct cognitive assessment models for continuous evaluation of cognition levels [14].

The relevance of the integration of cognitive assessment and brain function measures by EEG will have possible clinical applicability in the future according to some authors. Some of them proposed that EEG may provide valuable information about cognitive decline [15, 16], early detection and monitoring cognitive dysfunction in Alzheimer's disease [6], prediction of cognitive performance and the potential of personalized strategies for evaluation and cognitive intervention [17], and about fluctuations in cognitive function through an objective and noninvasive method for continuous cognitive assessment [18, 19].

One of the most used tests in elderly patients to identify decline in cognitive domains such as learning ability and memory is the RAVLT (Rey's Auditory Verbal Learning Test) [20]. It is possible to observe the learning curve through its application, demonstrating the relative memory capacity and the patient's retention level. The test aids in identifying the type of memorization difficulty, indicating clues such as greater difficulty in storage or information retrieval [21].

In this sense, this research sought to develop a digital memory and learning test (DMLT) system based on the principles of the RAVLT, which can be accessible and allow for the concurrent evaluation of cerebral electroencephalographic activity.

Methods

This study was divided into two phases. The initial phase concentrated on methodology, intending to create a DMLT. Subsequently, the second phase employed an experimental approach to evaluate this interface. It utilized a quantitative method, comparing it with a well-established test in the literature known as RAVLT.

Design of the development phase

The DMLT was developed and used as a model instrument for evaluating episodic declarative memory by measuring auditory-verbal learning based on the recording and recalling of a word list.

The words in the digital test were different from the words used in the Portuguese version of the RAVLT to avoid the effect of word learning, considering that both were applied to subgroups I and II at different times. The choice of words was similar to that used in other studies, which also used common Portuguese words. The selection of these words was the initial step in formulating the cognitive test and aimed to reduce the difficulty in understanding them by elderly volunteers [22]. The strategies used to assess the recording and recall of words were developed based on modifications of the original procedures of the RAVLT test, as was also done in other studies [23, 24].

Next, a computer system was developed to apply the DMLT, which allowed interaction with the participant through the emission of recorded sounds and words and the capture of verbal responses. During the interaction period, electroencephalographic traces were recorded through electrodes in contact with the scalp for later analysis. With each response, the developed system compares the words obtained by the speech recognition algorithm and adds them to the browser's local memory, running the system. To implement speech recognition was used the p5.js library and its extension p5.Speech, from Processing®, configured for the pt-BR language. As the participant spoke the words, the system captured and recognized the speech, checked if it matched one of the predefined words for the current level, and updated their score accordingly. In order to guarantee the fidelity of the speech recognition system, the researcher who accompanied the application also manually wrote down the participant's words on a spreadsheet at every stage, and a similarity was observed between all the words pronounced and recorded. In addition, the brainwave values are copied to a txt file. After the tests, this information is copied to a spreadsheet so that the appropriate analyses can be carried out. An 8-channel OpenBCI Cyton Biosensing Board neural interface was used to recognize EEG waves. The computer used for the recordings was a Lenovo laptop running Windows 11. The collection application runs on the Java platform and the application developed for the research relied on a Node JS server and a browser focused on Firefox.

The word repetition phases of the DMLT were named A1, A2, A3, A4, A5, B, A6, and Recognition. In phases A1 to A5, participants listened to a group of 15 words and repeated as many words as they could remember using a computer system developed for this purpose. Phase B consisted of listening to a different group of words from Phase A. Phase B aimed to assess the degree of interference and its influence on the participant's memory before responding to Phase A6. Phase A6 followed the same rules as phases A1 to A5. Finally, in the Recognition phase, the participant identified those belonging to group A among a larger group of 30 words to verify recall without the isolated repetition of the 15 words from group A.

Design of the experimental phase

The experimental phase was carried out to assess the developed system, comparing it with a test considered the gold standard for evaluating these cognitive domains and the system's acceptance.

Study population

The sample consisted of 18 individuals, aged between 60 and 92 years, randomly selected from a Geriatrics outpatient clinic at a University Center in Brazil. After selection, the participants answered a questionnaire with questions about sociodemographic data (age and gender), lifestyle habits (habitual consumption of alcohol or cigarettes), known medical diagnosis of comorbidities that could influence cognitive and EEG assessment (dementia, epilepsy, depression and anxiety) and complaints of forgetfulness. Eligibility criteria were being literate and not having previous medical diagnosis recognized of moderate or advanced dementia that would compromise test commands and system use. Participants did not need computer skills because it is a simple system with minimal user interaction supervised by the researcher. There were no other restrictions regarding gender, social condition, or other characteristics that distinguish individuals.

Experiment and variables

Participants were randomly divided into two subgroups through simple randomization with numbers draw, with subgroup I consisting of a total of 7 elderly participants and subgroup II consisting of a total of 11. Both subgroups attended the system's use at two different times, with a minimum interval of 14 days between them. The first moment was called Visit 1, and the second visit was Visit 2. At the beginning of Visit 1, all participants signed the Informed Consent Form (ICF) and answered a demographic questionnaire for group comparison.

In Visit 1, subgroup I (7 participants) used the DMLT with concurrent capture of brain electroencephalographic waves. Meanwhile, subgroup II (11 participants) underwent evaluation using the RAVLT instrument to evaluate episodic declarative memory, with tests administered by neuropsychologists.

In Visit 2, subgroup I underwent evaluation using the RAVLT administered by neuropsychologists. In contrast, subgroup II used the DMLT, also with the capture of electroencephalographic records.

The performance variables in the tests, measured by the score in all phases of the application and the total score at both times, were recorded for comparison. Regarding electroencephalographic variables, the records and quantification of Delta, Theta, Alpha, Beta, and Gamma waves were captured during the application of the digital test for comparison with performance. The quantification was performed as a percentage of each wave spectrum, with the calculation of the averages and medians of Phases A1 to A5 and the Recognition phase afterwards to allow comparison.

Although simple, it was decided to use the power band averages to establish the basis for an initial analysis, but the connectivity and stability metrics were taken into account. Through these, it was possible to trace the relationship between power bands and concentration, as delivered by the intermediary system used and the application produced for the research. The OpenBCI application with exclusive modifications was used to allow the information to be exported to the tables for calculating the averages.

The capture of EEG records was not performed during the RAVLT test application, which was considered the gold standard compared to the developed test. This decision was intended to avoid influencing the participants' attention during the memory testing process using this test.

Satisfaction assessment

After using this computer system, a written questionnaire was administered using the NPS (Net Promoter Score), which aimed to measure the participants' satisfaction with its use. The NPS uses a single question (*how much would you recommend using the system to someone you know?*) and is answered on a scale from 0 (would not recommend) to 10 (would definitely recommend). The collected responses were recorded for quantitative analysis. Based on the answers, the "promoters" were grouped (10−9 rating, extremely likely to recommend), the "passively satisfied" (8−7 rating) and the "detractors" (6−0 score, extremely unlikely to recommend). The percentage of "detractors" was then subtracted from the percentage of "promoters". According to the literature, a percentage value above 80% indicates that users would be very willing to recommend this computer system. This instrument was chosen because it is a simple, validated, and effective way to assess user or customer satisfaction [25].

Statistical analysis

The results were tabulated using Excel 2016 for Windows® and analyzed using the R® statistical program. Categorical variables were expressed as absolute numbers and percentages. The mean and standard deviation were calculated for continuous variables, median, percentiles, minimum and maximum values, frequency, and prevalence rate. For comparing categorical variables in investigating their association, both the Pearson chi-square test and Fisher's exact test were utilized. The Mann-Whitney U-test was used to compare the characteristics of the participants in subgroups I and II. The analysis of the relationship between the results obtained through the DMLT and RAVLT (convergent analysis) was performed using Spearman's linear correlation test, with results analyzed according to the following classification: from 0.00 to 0.19 – absent or very weak correlation; from 0.20 to 0.39 – weak correlation; from 0.40 to 0.59 – moderate correlation; from 0.60 to 0.79 – strong correlation; and from 0.80 to 1.00 – very strong correlation [26]. A p-value < 0.05 was used to identify differences with statistical significance.

Table 1 Sociodemographic comparison between the subgroups submitted to the experimental phase

Variables	Total $N=18$	Sub-group I $N=7$	Sub-group II $N=11$	p^2 Value
Age[1]	67,5 ± 4,8 (67,5)	68,7 ± 5,7 (71,0)	66,7 ± 4,3 (67,0)	0,385
Female	13 (72)	4 (57)	9 (82)	0,326
Alcohol consumption	2 (11)	1 (14)	1 (9,1)	> 0,999
Smoking habit				
No	8 (44)	3 (43)	5 (45)	0,594
Former smoker	9 (50)	3 (43)	6 (55)	
Smoker	1 (5,6)	1 (14)	0 (0)	
Comorbidities				
Dementia	0 (0)	0 (0)	0 (0)	
Epilepsy	0 (0)	0 (0)	0 (0)	> 0,999
Depression	5 (28)	2 (29)	3 (27)	> 0,999
Anxiety	7 (39)	3 (43)	4 (36)	> 0,999
Complaint of forgetfulness	8 (44)	2 (29)	6 (55)	0,367

Note n (%); [1] Mean ± Standard Deviation (Median); [2] Mann-Whitney Test; Fisher's exact test

Source Developed by the authors

Ethical aspects

The research followed the ethical principles established by Resolution 466/2012 of the National Health Council (CNS), which defined the rules for research involving human subjects and was approved by the Institution's Research Ethics Committee (CAAE 70198823.7.0000.5054). The participation in the study was voluntary and occurred after the participant or their guardian signed the Informed Consent Form.

Results

Participants' analysis revealed that the average age was 67.5 ± 4.8 years and 13 (72%) were female. A small number of participants currently had the habit of consuming alcoholic beverages or smoking, with only 2 (11%) and 1 (5.6%), respectively. Regarding neuropsychiatric comorbidities, none were diagnosed with dementia or epilepsy, while 5 (28%) had been diagnosed with depression and 7 (39%) with anxiety. When asked about forgetfulness, 8 (44%) reported this complaint.

In comparing the two subgroups, no significant differences were observed in sociodemographic characteristics and evaluated comorbidities (Table 1).

The comparison of performance in both subgroups, regarding the score in all phases of applying the DMLT and the RAVLT, was similar, including progressive learning with word repetition, and there was no statistical difference in any of the phases. These results are illustrated in Fig 1.

The comparison between the total scores of participants from both subgroups obtained through the application of the DMLT and the RAVLT showed a positive linear correlation (rho = 0.73) by the Spearman test, with statistical significance ($p < 0.001$). This result suggests a strong convergence between the two measures, highlighting the convergent validity between these two instruments (Fig. 2).

The comparison between the means and medians of the percentage lengths of waves captured throughout the DMLT of participants from subgroups I and II during phases A1 to A5 and the Recognition phase, using the Mann-Whitney statistical test, showed no statistically significant difference (Table 2).

The scores from phases A1 to A5, during the application of the DMLT, were correlated with the means of the percentages of electroencephalographic waves recorded during these phases. There was a negative correlation between Theta activity and the mean scores during phases A1 to A5 (rho = -0.478; $p = 0.045$), indicating that higher levels of Theta activity are associated with lower scores throughout the test phases. Meanwhile, there was a positive correlation between Gamma activity and the mean scores during phases A1 to A5 (rho = 0.582; $p = 0.011$), indicating that higher levels of Gamma activity

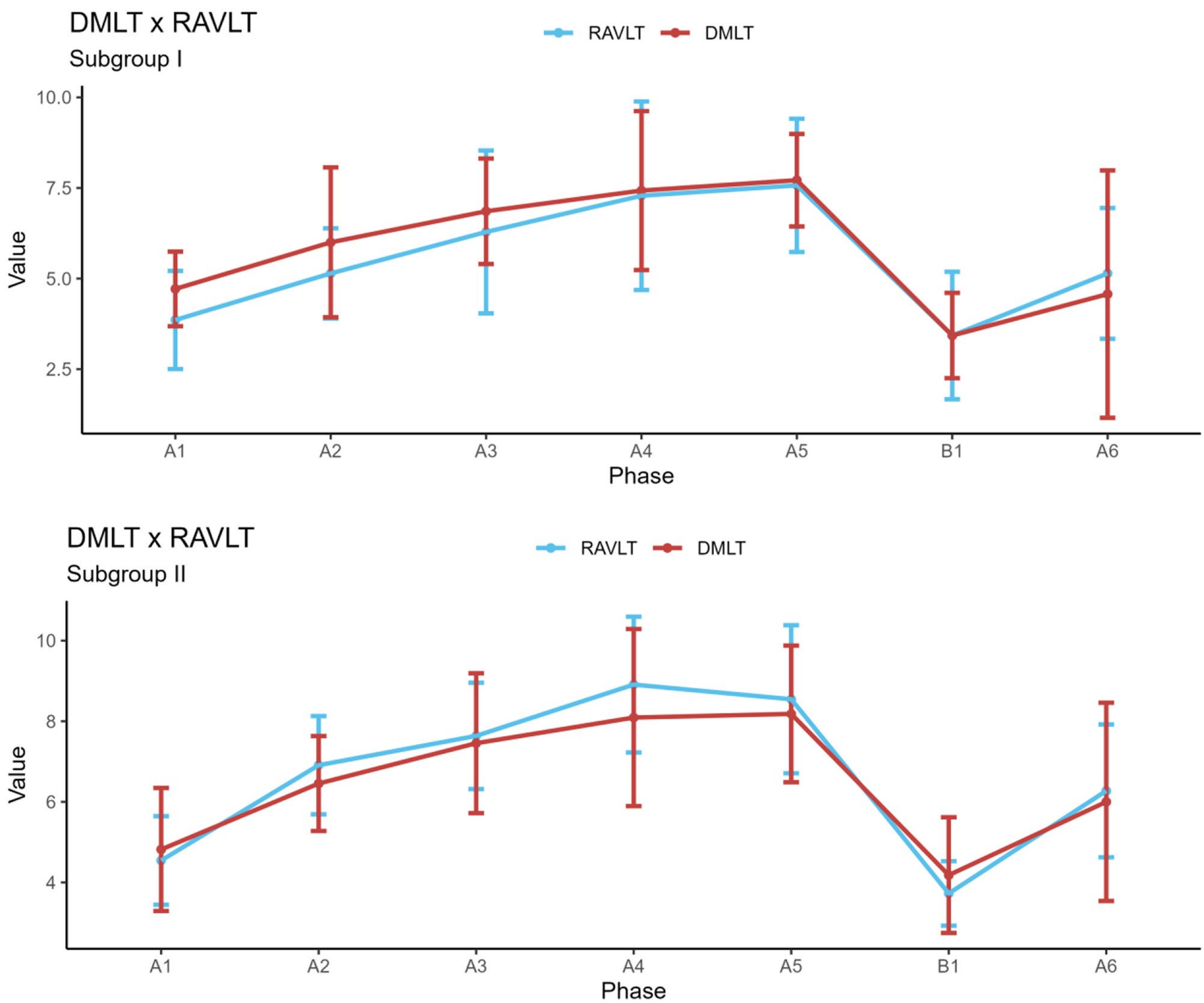

Fig. 1 Comparison of scores per phase between the digital memory and learning test (DMLT) and Rey's Auditory Verbal Learning Test (RAVLT) in subgroups I ($N=7$) and II ($N=11$) of the study. *Note* DMLT: digital memory and learning test,, RAVLT: Rey's Auditory Verbal Learning Test. Value: Mean ± Confidence Interval 95% *Source* Developed by the authors.

are associated with higher scores throughout the test phases (Table 3).

During the word Recognition phase, at the end of the DMLT, the mean scores obtained were compared with the means of the percentages of electroencephalographic waves recorded during this phase, showing no statistically significant correlation between these two metrics (Table 3).

However, a negative correlation was also identified between Alpha activity, obtained through the mean percentage of these wavelengths in the initial phase of the test (phases A1 to A5), and the mean performance in the Recognition phase (rho = -0.51, $p=0.03$), indicating that higher levels of Alpha activity at the beginning of the DMLT are associated with lower scores in the Recognition phase (Table 3).

Regarding the satisfaction assessment with NPS questionnaire, after applying the DMLT, 88.9% of scores were 10 ("promoters"), 11.1% of scores were 8 ("passively satisfied") and 0% of scores were "detractors". The total score was 88.9% (88.9% subtracted from 0%), classifying the test as excellent, according to the guidelines for applying this questionnaire.

Discussion

The results obtained in this study demonstrate the feasibility and efficacy of the DMLT, based on the principles of the RAVLT, for evaluating cognitive domains in elderly individuals. The absence of significant differences in scores between the DMLT and the RAVLT suggests that the former may be a viable and potentially more accessible alternative for cognitive assessment in this population. The significant positive correlation between the

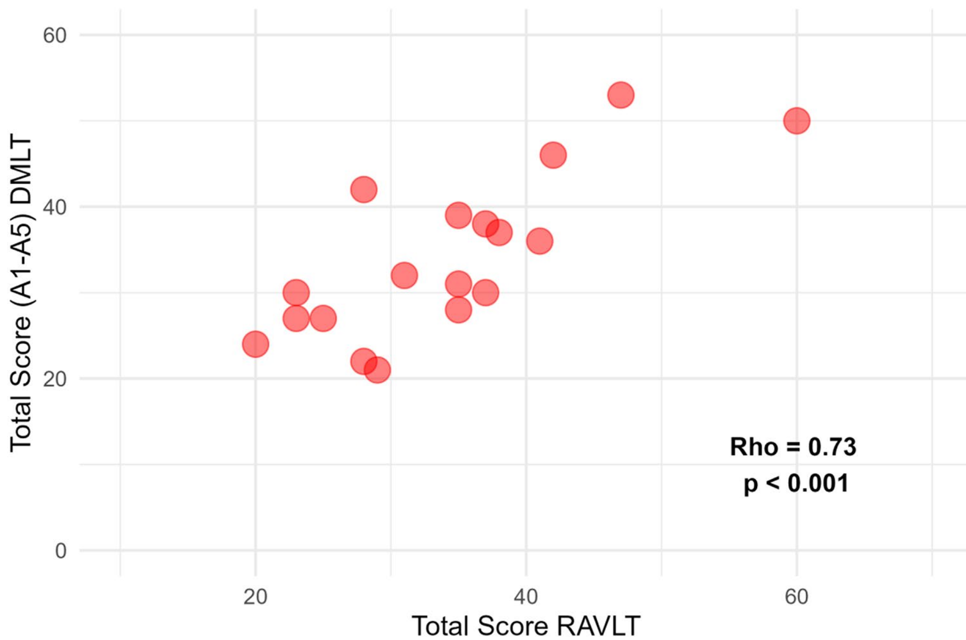

Fig. 2 Linear correlation between the total scores (A1-A5) obtained by participants ($N=18$) in the digital memory and learning test (DMLT) and in the Rey's Auditory Verbal Learning Test (RAVLT). *Note* DMLT: digital memory and learning test,, RAVLT: Rey's Auditory Verbal Learning Test *Source* Developed by the authors.

Table 2 Comparison between the percentage lengths of waves captured throughout the digital memory and learning test of participants from subgroups I and II during phases A1 to A5 and the Recognition phase

EEG Waves	*N*	Total[1]	Subgroup I $N=7$[1]	Subgroup II $N=11$[1]	*p*-value[2]
Phases A1 to A5					
Delta	18	33 ± 29 (34)	23 ± 30 (5)	40 ± 27 (51)	0.425
Theta	18	57 ± 36 (47)	47 ± 37 (31)	63 ± 35 (61)	0.461
Alpha	18	39 ± 13 (35)	37 ± 7 (34)	40 ± 15 (37)	0.930
Beta	18	79 ± 26 (91)	87 ± 20 (94)	73 ± 29 (89)	0.200
Gamma	18	74 ± 35 (99)	83 ± 27 (98)	68 ± 40 (100)	0.926
Recognition phase					
Delta	18	36 ± 31 (36)	23 ± 24 (9)	45 ± 32 (54)	0.151
Theta	18	60 ± 37 (58)	54 ± 42 (27)	64 ± 35 (78)	0.406
Alpha	18	39 ± 14 (34)	40 ± 17 (33)	38 ± 14 (36)	> 0.999
Beta	18	81 ± 25 (91)	85 ± 21 (95)	79 ± 28 (91)	0.612
Gamma	18	74 ± 34 (95)	77 ± 32 (98)	72 ± 36 (93)	0.927

Note[1]Mean ± Standard Deviation (Median); n (%); [2] Mann-Whitney statistical test; *Source* Developed by the authors

Table 3 Correlations between performance in digital memory and learning test and the mean percentages of electroencephalographic wave lengths obtained during the phases A1 to A5 and recognition phase

	rho	Lower CI	Upper CI	*p*-value[1]
Phases A1 to A5 (EEG waves vs. mean scores)				
Delta	-0.466	-0.772	0.016	0.051
Theta	-0.478	-0.778	0.001	**0.045**
Alpha	-0.342	-0.705	0.163	0.165
Beta	0.150	-0.354	0.586	0.553
Gamma	0.582	0.143	0.829	**0.011**
Recognition phase (EEG waves vs. mean scores)				
Delta	-0.256	-0.655	0.253	0.304
Theta	-0.272	-0.664	0.237	0.274
Alpha	-0.074	-0.534	0.419	0.769
Beta	0.234	-0.266	0.646	0.331
Gamma	0.103	-0.395	0.554	0.685
Phases A1 to A5 (EEG waves) vs. Recognition phase (mean scores)				
Delta	-0.438	-0.757	0.052	0.069
Theta	-0.322	-0.694	0.184	0.192
Alpha	-0.510	-0.794	-0.041	**0.031**
Beta	0.006	-0.474	0.483	0.980
Gamma	0.220	-0.289	0.632	0.380

Note CI confidence interval; [1]Pearson's chi-squared test
Source Developed by the authors

total scores obtained in both tests reinforces the convergent validity of the developed instrument, indicating that it can measure aspects of cognitive function like the RAVLT, a test already well-established in the literature.

The assertion that the DMLT is capable of measuring some similar aspects of cognitive function as the RAVLT is supported by recent researchers. Huijbers et al. (2023)

[27] discussed the clinical validity of digital cognitive assessments in individuals with mild cognitive impairment and Alzheimer's disease, indicating a shift towards digital tools in cognitive assessment. Vermeent et al. (2021) [28] provided evidence supporting the validity of the Philips IntelliSpace Cognition digital test battery, suggesting a transition towards digital testing as a reliable alternative to traditional analog assessments. Additionally, Chagas (2023) [29] developed and validated a brief digital cognitive test for older adults, further illustrating the increasing utilization of digital tools in clinical settings. These studies indicate a trend towards the adoption of digital cognitive tests to assess cognitive function. Although the specific comparison between DMLT and the RAVLT has not been directly addressed in the literature, digital tests have the potential to measure some similar aspects of cognitive function to traditional tests such as the RAVLT.

Several authors have demonstrated and discussed the benefits of using brain-computer interfaces to assess memory performance and even improve cognitive abilities in the elderly population. Chen et al. (2022) [30] developed a BCI-based Symbol Digit Modalities Test for cognitive assessment in healthy elderly volunteers, demonstrating the potential of BCIs in cognitive evaluation. The study by Hermes et al. (2019) [31] examined the measurement and structural invariance of cognitive ability tests following computer-based training. The research identified cognitive ability, technical comprehension, and complex psychomotor coordination as latent variables, with test scores from computer-based tests as manifest variables. Through the use of structural equation modeling and confirmatory factor analysis, the research demonstrates the effectiveness of computer-based cognitive tests in comparison to traditional methods, highlighting the crucial role of such assessments in understanding cognitive function.

The effectiveness of computer-based cognitive tests compared to traditional methods is a critical area of research with potential implications for cognitive assessment and healthcare delivery. Belkacem et al. (2020) [32] discussed how BCIs could enhance memory, attention, and consciousness in cognitively impaired elderly patients, highlighting the benefits of BCI technology in improving cognitive functions. Additionally, Rabipour & Davidson (2020) [33] emphasized the increasing prevalence of digital technology in cognitive assessment and enhancement for older adults, further supporting the use of digital tools, including BCIs, in evaluating cognitive function in the elderly population.

The development of the DMLT required forming a multidisciplinary team with professionals in neuropsychology, geriatric medicine, nursing, computer science, and digital media. Its application was designed for elderly individuals without a known diagnosis of dementia and with preserved hearing, with the assistance of a professional. Regarding the sample used for comparison, a statistical similarity was identified between the subgroups regarding sociodemographic variables, previously diagnosed comorbidities of interest and complaints of forgetfulness. This similarity between subgroups was used in previous works of development and validation compared with other cognitive assessment instruments by other authors [34].

In the convergence analysis, similarity was identified between the measures of the same theoretically related construct performed through the DMLT and the RAVLT. This comparison method has been used in validation experiments in similar studies [35].

In both subgroups, a similar learning curve behavior was observed with the repetition of words throughout phases A1 to A5, with an increase in the number of correct answers by participants, both in the DMLT and the RAVLT. This behavior was also similar in the subsequent phases B and A6 between the subgroups of elderly individuals. In a similar study, however, with patients diagnosed with Alzheimer's Disease or Mild Cognitive Impairment, Hammers et al. (2021) [36] evaluated hippocampal volume and compared learning from the convergent validity of the Hopkins Verbal Learning Test-Revised and the Brief Visuospatial Memory Test-Revised. These authors identified that comparing the scores was valid to identify learning between the two tests, regardless of the diagnosis.

The correlation between electroencephalographic activity levels and test performance suggests that the DMLT can offer additional insights into the neurophysiological processes underlying cognitive performance. In particular, the association between Theta and Gamma activity and cognitive performance indicates that the test may be sensitive to variations in brain activity related to specific cognitive processes, such as memory and learning. A negative correlation was identified between Theta activity, captured through continuous registration of electroencephalographic waves over phases A1 to A5, and the DMLT in these phases. For Gamma activity captured also at this exact moment, a positive correlation was identified with the score of this test. Animal studies have identified the association between Theta and Gamma activity and cognitive and memory processes [37].

Another study, now in humans, with electroencephalographic recording during mnemonic processes, revealed increased Gamma activity with successful associative recognition. These results point to the association of Gamma band oscillatory dynamics with cognitive processes related to memorization [38].

In patients with schizophrenia, some studies have found significant negative correlations between resting Theta activity and cognitive functions, such as visuospatial memory and executive function [39], verbal working memory and learning, and verbal memory [40]. Furthermore, Theta activity during the resting state was a significant predictor of deficits in lexical processing [41] and verbal memory [42] in individuals with schizophrenia. A positive association between this activity and deficits in the ability to initiate a consistent and coherent cognitive task during a verbal fluency test in this population was also identified [43]. These data corroborate the findings of the present study.

The evaluation of system revealed a high level of satisfaction among participants, which is a positive indicator of acceptance of this type of technology by elderly individuals. The NPS score suggests that the test is not only considered helpful by participants but is also well-received, which may facilitate its implementation and adoption in clinical and research settings. This acceptance is crucial for the viability of new cognitive assessment technologies, especially in populations that may be less familiar with digital technologies.

However, some limitations must be considered. Although adequate for initial experimental comparison, the sample in this study is relatively small, which may limit the generalization of the results. Additionally, the direct comparison between the DMLT and the RAVLT was conducted in a controlled environment, and future studies are needed to explore the effectiveness of the test in broader and more diverse clinical settings. As another limitation, the divisions of each word were not maintained during the recording of the experiment, which made it impossible to analyze the prediction of specific memory performance for each word, based on the EEG recording. Future tests could be carried out with this modification, combined with the use of machine learning, for this prediction analysis.

Conclusion

This study has demonstrated that the DMLT is a promising tool for assessing cognitive domains in elderly individuals. The results suggest that the test can provide measures comparable to those of an established instrument like the RAVLT, while offering additional insights into brain activity during task performance. In the EEG analyses, higher levels of Theta activity were associated with lower scores in the memory and digital learning test. On the other hand, higher levels of Gamma activity were associated with higher scores on the same test. In addition, higher levels of Alpha activity at the start of the test were associated with lower scores in word recognition in the late phase of the test. This result points to the potential use of continuous biosignals monitoring, with registration of brain electrical activity in real-time, during the application of cognitive tests to the elderly people. The high acceptance of the test by elderly participants indicates its potential for use in clinical and research evaluations, contributing to early detection and monitoring of cognitive decline in this population.

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Data availability
The datasets used and analyzed in the current study are available from thecorresponding author on reasonable request.

Declarations

Competing interests
The authors declare no competing interests.

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