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The Contribution of the Cerebellum on Working Memory Volume with Patients with a Mild Cognitive Impairment

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Abstract

The present study aims to investigate the relationship between cerebellar volume and cognitive performance in patients with Mild Cognitive Impairment (MCI), using data from the Dutch COGMAX study. Working memory (WM) performance was assessed using the average hit rate and d-prime of average performance from the n-back (2-back) task. T1-weighted structural magnetic resonance imaging data of thirty-one patients (male: M = 73.1, SD, = 5.1; female: M = 73.4, SD, = 14.1) were analysed to assess volumes of cerebellar subregions. Voxel-based morphometry with the SUIT toolbox was used to measure brain structure at the voxel level. A general linear model analysis was used to examine the relationships between cerebellar volumes and cognitive performance, controlling for education and age. The analysis revealed a significant association between lobule 7 and WM performance on the 2-back task. No significant association was found between lobule 8 and WM performance. Additionally, higher education levels were associated with better WM performance, and an interaction effect was identified between education level and cerebellar volume, suggesting that the influence of cerebellar volume varies depending on education level.

Keywords: Cerebellum, Working Memory, Cognitive Reserve, Cerebellar Grey Matter, Mild Cognitive Impairment

The Contribution of the Cerebellum on Working Memory Volume with Patients with a Mild Cognitive Impairment

The understanding of the cerebellum's role in cognitive functioning has undergone a great transformation. While it was traditionally seen as a region primarily responsible for motor coordination and speech, emerging research reveals that its involvement higher-order processes include working memory (Jacobs et al., 2008; Marvel & Desmond, 2010). This shift in perspective is particularly relevant for patients with Mild Cognitive Impairment (MCI) who often show noticeable decline in memory and other cognitive domains. By exploring the cerebellum's contribution to these deficits, we can gain valuable insights into the underlying mechanisms of cognitive decline in MCI.

MCI is a disease which is characterized by decline in memory, language, executive function or other cognitive domains. These impairments are characterized by a subtle but not noticeable decline in cognitive functioning. On a neuropathological basis, the progression of MCI is associated with presence of amyloid-beta plaques and neurofibrillary tangles, which are characteristic neuropathological indicators of Alzheimer's Disease (AD) (Dubois et al., 2007). MCI is considered a prodromal stage of AD and is viewed as a transitional stage (Peterson et al., 2001). An important difference with AD is that the symptoms do not significantly interfere with activities of daily living.

A subtype of MCI is Amnestic Mild Cognitive Impairment (aMCI) and is characterized by the subjective experience of memory decline (Petersen et al., 1999). Diagnostic criteria for aMCI, outlined by Petersen et al. (2001) include impaired memory function relative to age and education norms, preserved general cognitive function, intact activities of daily living and the absence of dementia. Patients presenting with a clinical dementia rating (CDR) score of 0.5 (questionable dementia/MCI) are clinically classified as having MCI. It is estimated that the majority of patients are expected to progress to AD at a

rate of 8% to 15% per year (Petersen, 2016). The identification of aMCI and the application of the diagnostic criteria outlined by Petersen and colleagues (2001) are important in recognizing individuals at risk of progressing to AD.

Furthermore, exploring the cognitive mechanisms underlying MCI the shows impactful working memory deficits, which is a crucial cognitive domain implicated in MCI progression. Working memory (WM) is the ability to hold information in memory while performing another mental operation (Economou et al., 2007). Thus, it involves temporary storage of information. According to Baddeley (1992), it is defined as the cognitive capacity required for the temporary storage and manipulation of the information necessary to perform complex cognitive tasks, such as language comprehension, learning and reasoning.

The cerebellum is commonly perceived as playing a central role in coordinating motor functioning and speech (Marvel & Desmond, 2010). To better understand these functionalities, it is essential to consider the cerebellum's anatomical structure. The cerebellum can be distinguished into different lobules, which are organized into three main regions: the anterior lobe (lobules I through V); posterior lobe (lobules VI through IX); and flocculonodular lobe (lobule X). This study will focus on the posterior lobe of the cerebellum, specifically on the lobules VIIB, VIIIa and VIIIb and we will refer to these lobules as 7 and 8. Evidence shows that these lobules are an important component of WM, particularly active during the retention of information over a delay period (Marvel & Desmond, 2010; Stoodley & Schmahmann, 2009).

Further evidence suggests that the cerebellum is involved in progressing deterioration of memory performance, such as monitoring, accuracy, progressing speed, and cognitive performance (Jacobs et al., 2018). Results from a study of Lin and colleagues (2020) demonstrate a negative correlation between cerebellar volume and cognitive function in patients with MCI, specifically highlighting that increased cerebellar volume is associated

with poorer cognitive function. This negative correlation is particularly evident in the cerebellar grey matter. Furthermore, patients diagnosed with Alzheimer Disease (AD) have a smaller cerebellar volume which is associated with worse execution function. However, this was not the case for patients with MCI. This suggests that cerebellar involvement in cognitive processes may differ across the different stages of cognitive impairment. Lin and colleagues (2020) also suggest that cerebellar volume plays a role in executive function in AD, but it does not in MCI. Therefore, these findings imply that the cerebellum besides being important for movement, gait, posture and speech it is also linked to memory.

In addition to its role in cognitive impairment, a study of Tabatabaei-Jafari and colleagues (2017) showed that the rate of atrophy acceleration in the cerebellum is lower than the average rate of atrophy in the cerebrum and is not influenced by AD moderators such as education. Further evidence by Kim and colleagues (2021) demonstrated that grey matter volume (GMV) loss in the cerebellum among patients with MCI, is associated with cognitive impairment. They propose that cerebellar volume may serve as a potential imaging biomarker for predicting dementia. While these findings contribute to the understanding of the role of the cerebellum in cognitive dysfunction, thereby helping its understanding of its role in cognitive impairment. Further research is necessary to clarify how cerebellar changes impact cognitive decline and to assess potential biomarkers for the early detection and progression of MCI.

WM capacity can be assessed through behavioural tasks that provide a quantitative measure of memory span. These tasks often require participants to encode lists of stimuli, such as words, digits, letters or pictures. Additionally, some tasks may involve selective attention during encoding or divided attention, further challenging WM capacity. In magnetic resonance imaging (MRI) studies of WM, the n-back task is frequently used (Hautzel et al., 2009; Küper et al., 2016). In this task, participants are presented with single stimuli

sequentially and must determine if the current stimulus matches the one presented before (1-back) or two stimuli before (2-back). Volumetric variations in the cerebellum may be correlated with individual performance on the n-back working memory task, as measured both by average hit rate and d-prime. The average hit rate, defined as the proportion of correctly identified targets relative to the total number of presented stimuli, provides a fundamental measure of WM success by assessing the accuracy of target detection. D-prime reflects the sensitivity or discriminative ability of an individual, separating true ability to identify targets form the tendency to guess or respond randomly. This offers a more nuanced understanding of WM performance.

Another test which is a measure of short-term verbal memory, is the Digit Span Forward (Kessels et al., 2015). This task requires a participant to retain phonological and verbal information from a series of numbers (1-9) in their memory and reproduce them immediately after presentation. Additionally, the Rey Auditory Verbal Learning Test (RAVLT; 15 words test) is employed to assess working and long-term memory. The RAVLT is an effective neuropsychological tool designed to evaluate the nature and severity of memory dysfunction investigating verbal memory (Andersson et al., 2006; Moradi et al., 2017).

Understanding the role of the cerebellar volume and cognitive performance in patients with MCI requires a multifaceted approach. Research suggests that cerebellar atrophy may influence cognitive functions such as WM, short-term memory, and long-term memory. To enlighten the cerebellum’s role in cognitive decline, it is important to contrast the score from various cognitive tests. By comparing volume differences and the performance on the N-back task with the Digit Span Forward and the RAVLT scores, a comprehensive understanding can be gained of how cerebellar atrophy impacts various memory systems and cognitive domains.

Furthermore, the relationship between cerebellar atrophy and cognitive performance can be influenced by several moderating factors. One of these factors, is age which affects both brain structure and cognitive function (Deary et al., 2009). Another factor is cognitive reserve, which refers to the brains ability to improvise and find alternative ways of completing tasks. Cognitive reserve is influenced by factors such as education and has been demonstrated to have a protective effect on the risk of dementia (Scarmeas et al., 2001; Scarmeas et al., 2003; Stern, 2009; Stern et al., 2020; Valenzuela & Sachdev, 2006)

The primary objective of this study aims to investigate volume differences of the cerebellum in relationship to cognitive performance in patients with Mild Cognitive Impairment. Specifically, this study aims to investigate to what extent volume differences in lobules 7 and 8 correlate with WM among patients with MCI.

The following hypotheses will be tested:

Hypothesis 1: Cerebellar volumes are significantly associated with working memory performance in patients with MCI, indicating that greater cerebellar atrophy is associated with poorer cognitive function. I hypothesize this relationship to be stronger for working memory (n-back task) than for short-term (Digit Span forward) or long-term verbal memory (RAVLT).

Hypothesis 2: I hypothesize that a specific region of the cerebellum (lobules 7 and 8) shows a stronger association with working memory than other cerebellar regions.

Hypothesis 3: The relationship between cerebellar volume changes and cognitive performance in patients with MCI is moderated by other factors such as age or education.

Method

Participants

Thirty-one patients aged 51-92 have been derived from the data set of the Dutch COGMAX study. One patient has been excluded due to not finishing the assessment. This

sample consists of Amnestic Mild Cognitive Impairment (aMCI) patients and patients were recruited from the memory clinic of the University Medical Centre Groningen (UMCG). 24 males; mean age = 73.1 ± 5.1 years; 24 right-handed, 0 left-handed and 7 females; mean age = 73.4 ± 14.1 years; 5 right-handed and 2 left-handed. Males had an average level of education of HAVO/VWO/HBO (*M* = 6, *SD* = 1) and females had an average level of MAVO/MBO (*M = 5*, *SD*, = 2). Handedness was assessed using The Edinburgh Handedness Inventory (Oldfield, 1971) questionnaire, which consist of 10 questions regarding hand preference for various manual activities (e.g., lighting a match). The diagnosis of aMCI was confirmed through neurologist evaluation, yielding a verbal memory score of 1.5 standard deviations below the normative control values (Petersen et al., 2001). Sources of recruitment included advertisement through Alzheimer Nederland and NoNe-Gon network.

Exclusion criteria

The exclusion criteria were assessed through questionnaires filled by the patients. Patients were excluded when the following criteria were met: history of psychiatric or neurological illness other than MCI, metal implants, risk of having metal particles in the eyes, tattoos containing iron oxide, (suspected) Pregnancy or breast feeding, claustrophobia, alcohol or drug abuse, Recent use of alcohol (2 days before EEG and/or fMRI measurement), refusal to be informed of structural brain abnormalities that could be detected using MRI during the experiment.

Procedure/design

This study uses a cross-sectional design to investigate the relationship between cerebellar volume and WM performance in patients with MCI. Data was collected using two primary methods: cognitive functions were assessed through questionnaires (N-back WM task) and brain morphometry analysis through Magnetic Resonance Imaging (MRI). The independent variable in this study is cerebellar volume, with the covariates age and education level. The

dependent variable is the n-back task performance, assessed through cognitive function questionnaires.

As previously mentioned, data collection was conducted using two methods: questionnaires to assess cognitive functions and Magnetic Resonance Imaging for brain morphometry analysis. The independent variable that has been measured is the volume of the cerebellum.

Cognitive Assessment

An n-back WM task was employed to measure WM performance. The two-letter delayed task is a form of the 2-back task, where letters and masked letters are used. Participants monitor a series of presented stimuli (e.g., letters or numbers) during encoding and are asked to recall whether a specific stimulus in a sequence matches one presented n trials previously. The n-back task has previously been used in MCI patients and when compared with elderly participants with normal cognition, the MCI patients were less accurate and had larger reaction times (López Zunini et al., 2016; Yeung et al., 2016).

To measure short-term memory the Wechsler Adult Intelligence Scale Revised (WAIS-R; (Wechsler, 1981) was used: The Forward Digit Span in this task participants needed to recall a string of numbers immediately after presentation. The third test that was used measuring verbal WM is the Rey Auditory Verbal Learning Test (RAVLT) consisting of five trials in which two sets (set A and set B) of fifteen words. First set A was read aloud to the patient, and then the patient is immediately asked to recall these words, with the direction to memorize as much as possible. After the second set (the ‘inference set’) the patient needed to recall the words from set A. After a 20-minute delay, the participant is asked to again recall the words from set A. Different summary scores are derived from the raw RAVLT scores. This includes RAVLT immediate, delayed (corrected).

Neuroimaging

All scans were obtained on a 3 Tesla (Siemens Magnetom Prisma) MRI scanner equipped with a 32-channel head coil. T1-weighted anatomical images were obtained with a 3D magnetization-prepared rapid gradient-echo with the following parameters: TR/TE = 2300/2.98 ms, field of view = 256 mm × 256 mm × 256 mm, 176 continuous axial slices., voxel sizes = 1 mm × 1 mm × 1mm and the flip angle = 9◦.

Preprocessing

Voxel-based morphometry analysis was used to measure the brain structure at each voxel. It has been used to measure regional GMV in the cerebellum. SPM12 was used running on MATLAB 2020b. For the normalization of the cerebellar data, the T1 Anatomical images were pre-processed using the Spatially Unbiased Infra-Tentorial template (SUIT) toolbox specifically developed for the cerebellum (Diedrichsen et al., 2009; Diedrichsen, 2006) which is implemented in SPM12. These were initially segmented into grey matter, white matter, and CSF. The cerebellum was processed using the high-resolution atlas of the SUIT toolbox which maintains the anatomical detail of the cerebellum and provides more precise spatial registration (Diedrichsen et al., 2009; Diedrichsen et al., 2011). The procedure was as followed: The cerebellum's position varies among patients, therefore T1 anatomical images were first realigned, cropped and isolating the cerebellum from the rest of the brain and using SUIT. Furthermore, the cerebellum images were resliced into SUIT space. A Montreal Neurological Image (MNI) T1 template was used to normalize the structural images 1 mm × 1 mm × 1mm and modulated GM images were then smoothed with a 5 mm full-width half maximum Gaussian smoothing kernel. At last, to summarize the data, a region of interest (ROI) analysis was used. Cerebellar areas were identified using the probabilistic cerebellar atlas in MRIcron (Diedrichsen et al., 2009).

Statistical analysis

Statistical analyses were performed with SPSS version 28.0 and MATLAB 2020b. Descriptive statistics were first calculated to summarize data form the questionnaires. A general linear model (GLM) analysis was employed to examine the relationships between cerebellar volumes, demographic variables (education level and age), and cognitive performance measured through the N-back WM task, Digit Span Forward, and RAVLT.

Before conducting the GLM analysis, the data was checked for normality using the Kolmogorov-Smirnov tests. These results indicated that the assumption of normality was violated. Homoscedasticity was evaluated by examining residual plots, and this indicated that the assumption was not met. However, the GLM was chosen for handling non-normally distributed data and for its robustness against violated assumption of homoscedasticity.

Multicollinearity was assessed by examining the Variance Inflation Factor (VIF) scores. Initial analyses revealed that the VIF scores exceeded five when including three predictors, indicating multicollinearity. To address this, the predictor with the highest VIF (lobule 7a) was removed, resulting in VIF scores below 5 for all remaining predictors, suggesting no further multicollinearity concerns. Due to this separate GLM analyses were performed for the lobules. This approach allowed for a more detailed examination of the effects of specific cerebellar regions on cognitive performance.

First, a correlation analysis was conducted to examine the relationships between GMV and both hit rate and average performance on the WM task. These results were used to contrast this to the scores of short-term (Digit Span Forward) and long-term verbal memory (RAVLT). Following this, a series of GLM analyses were performed to examine the relationships between GMV, and average performance on the WM task, as well as short-term and long-term verbal memory scores. Age, gender, and education level were entered as covariates of no interest. A significance threshold of $p < .05$ was used throughout the study. To address potential confounding effects between the n-back scores and average scores of the

RAVLT and Digit Span Forward, additional correlation analyses were conducted. In these analyses, RAVLT and Digit Span Forward scores were added as covariates of no interest, one ate time, when analyzing the correlations between GMV, n-back, RAVLT, and Digit Span Forward scores. The analysis focused solely on significant differences in cerebellar GMV, as the primary objective of the current study was to investigate the relationship between cerebellar GMV and WM performance. At last, a multivariate GLM analysis was conducted to examine moderation effects of cerebellar volume on WM performance, while controlling for age and education level.

Results

Correlation of GMV with WM, short-term memory and verbal long-term memory

The results of the correlation analysis are presented in *table 2*. There was a significant moderate positive correlation between GMV in lobule 7 and average hit rate on the 2-back task r (29) = .466, $p < .01$. There also was a significant moderate positive correlation between GMV in lobule 7 and d-prime 2-back task r (29) = .399, $p < .05$. There was a significant moderate positive correlation between GMV in lobule 7 and the Digit Span Forward r (29) = .473, $p < .01$ and significant positive correlation was found between GMV in lobule 7 and RAVLT delayed recall corrected. Additionally, A positive correlation was found between GMV in lobule 8a and the Digit Span Forward, RAVLT Delayed recall and RAVLT Delayed Recall Corrected. Furthermore, a positive correlation was found between GMV in lobule 8b and the Digit Span Forward. *Figure 1* shows scatter plots presenting the correlations between GMV, WM scores and short-term memory scores and *table 1* presents the volumes of cerebellar lobules for the entire sample.

Regression of cerebellar lobules 7 and 8, compared to other lobules in WM association

Results of the multivariate GLM show that no effect was found between lobules 7 and 8. But an effect was found between Lobule Right V and average hit rate 1-back task $F(1, 24) = 4.909$, $p = .036$, $\eta 2 = .170$, d-prime 1-back task $F(1, 24) = 5.226$, $p = .031$, $\eta 2 = .179$. Lobule Right Crus I and average hit rate 1-back task $F(1, 24) = 5.566$, $p = .027$, $\eta 2 = .188$, d-prime 1-back task $F(1, 24) = 4.521$, $p = .044$, $\eta 2 = .159$. Right Crus II and average hit rate 1-back task $F(1, 24) = 5.095$, $p = .033$, $\eta 2 = .175$, average 2-back task $F(1, 24) = 5.366$, $p = .029$, $\eta 2 = .183$, d-prime 1-back task $F(1, 24) = 4.349$, $p = .048$, $\eta 2 = .153$, d-prime 2-back task $F(1, 24) = 4.251$, $p = .050$, $\eta 2 = .150$. No effect was found for the other lobules.

Moderating effects of age and education on the relationship between cerebellar volume and cognitive performance

Results of the multivariate GLM to examine the effects of cerebellar volumes, age, educational level, and their interactions on cognitive performance indicate that the model explained a significant portion of variance in the dependent variables. There was a significant main effect of education level on the average hit rate in the 1-back task $F(3, 14) = 4.616$, $p = .019$ $\eta 2 = .497$, average hit rate in the 2-back task $F(3, 14) = 3.446$, $p = .046$, $\eta 2 = .425$, d-prime 1-back task $F(3, 14) = 3.720$, $p = .013$, $\eta 2 = .444$, and d-prime 2-back task $F(3, 14) = 5.450$, $p = .011$, $\eta 2 = .539$. Additionally, there were significant interaction effects between education level and lobule 7 on average hit rate in 1-back task $F(3, 14) = 4.357$, $p = .023$, $\eta 2 = .483$, average hit rate in 2-back task $F(3, 14) = 3.504$, $p = .044$, $\eta 2 = .429$, d-prime 1-back task $F(3, 14) = 4.058$, $p = .029$, $\eta 2 = .465$ and d-prime 2-back task $F(3, 14) = 6.226$, $p = .007$, $\eta 2 = .572$. This indicates that the relationship between lobule 7 and cognitive performance varies by education level. No Significant main effects or interactions were found for age for lobule 7 and education level and age for lobule 8.

Discussion

The present study aimed to investigate volume differences of the cerebellum in relationship to cognitive performance in patients with Mild Cognitive Impairment. This study aimed to investigate to what extent volume differences in lobules 7 and 8 correlate with WM among patients with Mild Cognitive impairment. Positive correlations were found between lobule 7 and performance on the 2-back task. Additionally, positive correlations were observed between lobule 7 and short-term memory, and long-term verbal memory. Furthermore, lobule 8 showed positive correlations with short-term and long-term memory. These findings support the hypothesis that cerebellar atrophy is associated with poorer cognitive functioning in MCI patients. It does not confirm the findings of Lin et al (2020), where cerebellum volume is negatively associated with cognitive function. But it does correspond with the literature that the cerebellum is besides being important movement, gait posture and speech, it is also linked to memory (Jacobs et al., 2018; Lin et al., 2020).

We hypothesized that lobules 7 and 8 would show a stronger association with WM compared to the other cerebellar lobules. Contrary to the hypothesis, results did not show significant outcomes for lobules 7 and 8. Instead, it shows significant associations in lobule V, Crus I and Crus II. The associations found in these lobules suggest that these regions may play a more crucial role in WM than previously thought. Literature indicates that Crus I is involved in preparing for complex motor patterns and covert speech as part of WM (Marvel & Desmond, 2010). Interestingly, an earlier study by Stoodley and colleagues (2010) found that Crus I and Crus II to be active during the n-back task, though Crus II showed no association in the current study. Further research could investigate these discrepancies.

A significant effect of education level on cognitive performance was found for lobule 7. This suggests that higher levels of education are associated with better performance on WM tasks. Furthermore, significant interaction effects were found between education level and lobule 7 volume on the measures of WM performance. This suggests that the influence of

lobule 7 volume on cognitive performance varies depending on education level of the patients. Interestingly, no main effects or interaction effects were observed for lobule 8, involving education level and age. This suggests that lobule 8 may not play a significant role in cognitive performance, or its impact is not moderated by education level or age in this study. This is in line with recent research that cognitive reserve is a protective factor for WM (Gutiérrez-Zamora Velasco et al, 2021; Li et al., 2021) and it suggests that education has a protective effect on the clinical presentation of MCI. Higher educated patients often maintain higher levels of GMV, and the effect of education can be explained by the brain reserve capacity and cognitive reserve theories (Stern et al., 2019). These theories suggest that higher education contributes to both cognitive reserve and brain reserve, helping to maintain cognitive function and delay the pathological effects of MCI. Research by Ye and colleagues (2013) indicates that protective effects of education against cognitive decline persist in the early stage of aMCI but diminish in late-stage aMCI. This suggests that the varying levels of education may influence the progression of aMCI. Further research could investigate this.

Theoretical and practical implications

These results give better evidence for clinical approaches for patients with MCI. Interventions aimed at enhancing cognitive reserve, such as cognitive training might particularly be beneficial. Furthermore, understanding the specific contribution of different cerebellar regions could help further improve rehabilitation strategies.

Limitations and further research

There are several limitations that should be considered. First, the sample size of this study was relatively small, which limits the generalization of the findings. Second, due to the design of the study casual implications cannot be made about the relationship between the cerebellar volumes and WM performance. Another limitation that has been encountered is the violation of the assumption of normality. Despite applying various transformation techniques,

the data remained skewed. This could be due to the small sample size and the presence of outliers. Small sample sizes inherently increase the likelihood that outliers will have a more pronounced impact on statistical analyses, potentially skewing results and affecting overall data interpretation (Osborne & Overbay, 2004; Wilcox et al., 2018).

Given the small sample size of this study, acknowledging the potential effect of outliers, excluding outliers could significantly reduce the statistical power and potentially ignore important variations that are relevant to the research question. According to Frost's (2019) guidelines of dealing with outliers, we followed the three rules: correcting or removing errors caused by data or measurement errors, excluding non-representative data that do not belong to the population, and retaining outliers that naturally belong to the population being studied. We concluded that there was no justifiable reason to exclude the outlier, as it represents a natural variation within the MCI population this study is investigating.

From a statistical standpoint, the GLM has been used due to its robustness to ensure that the findings were not influenced by extreme values. The GLM analysis helps mitigate the influence of outliers, ensuring that the findings are not disproportionately affected by these values. Therefore, including the outliers provide a more comprehensive understanding of the data, capturing the full range of cognitive performance among patients with MCI.

The decision to include the outlier was also supported by the literature. Havlicek and Peterson (1976) have noted that while skewed data can impact statistical assumptions, the overall effect on the obtained distribution may be minimal. This perspective reinforces the approach taken in this study, emphasizing the importance of retaining naturally occurring data points to maintain the integrity and representativeness of the sample.

Further research with larger sample sizes could further investigate the impact of outliers and provide additional insights into the relationship between cerebellar volume and cognitive performance. Longitudinal studies tracking changes over time would also be

beneficial in understanding the directionality and causality of these associations, thereby offering a clearer picture of the cerebellum's role in cognitive decline among patients with MCI.

The last limitation is that the time constraint of this study. It must be taken into account that this master thesis was restricted to a limited deadline and a certain level of knowledge. This could have restricted the depth of the subject of this study.

Conclusion

This study investigated the relationship between cerebellar volume and cognitive performance on WM tasks in patients with MCI. Contrary to the primary hypothesis, while finding a link between lobule 7 and performance on the 2-back task, no significant associations were found for lobule and 8 with WM. Instead, significant results were observed in Lobule V, Crus I, and Crus II, suggesting that these regions play a bigger role than previously thought. Additionally, data showed that education level has a significant effect on cognitive performance, indicating that education may be associated with better WM performance.

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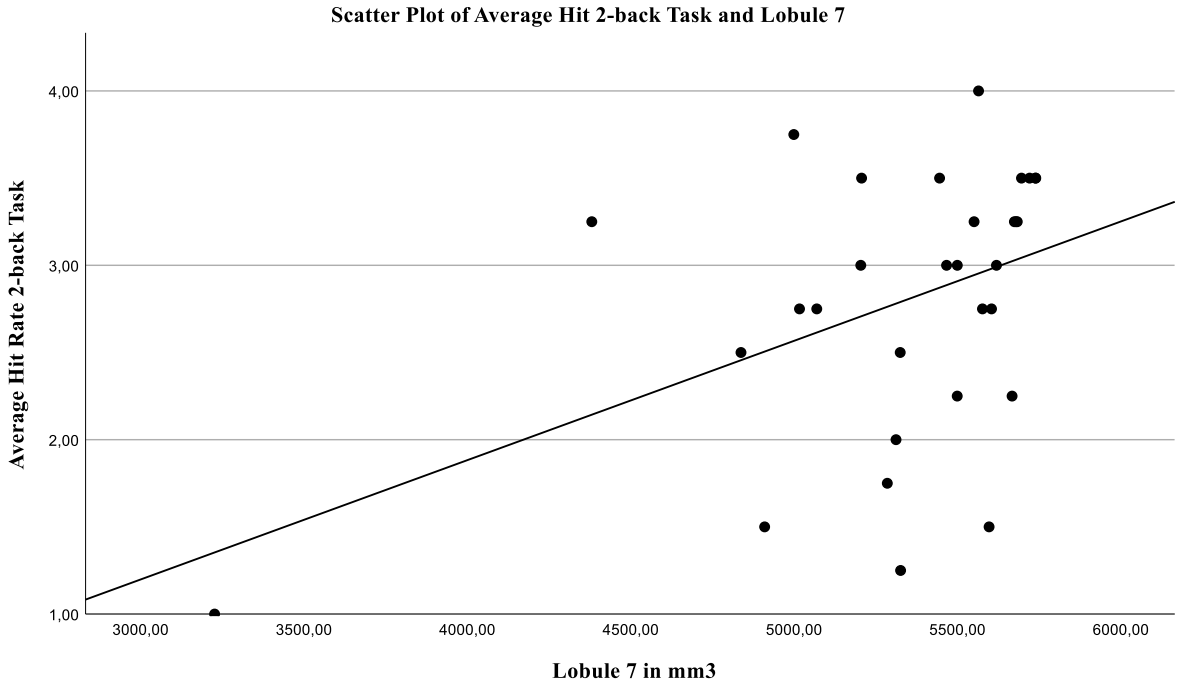
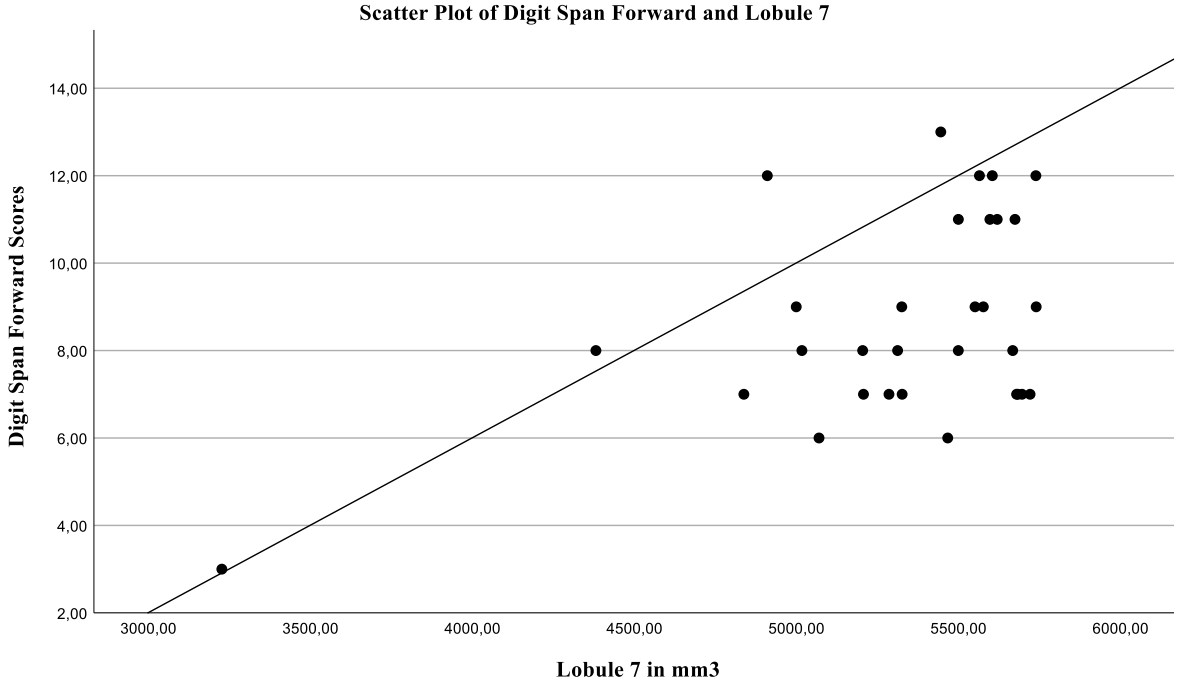
Appendix

Figure 1

Scatter Plot of Lobule 7 and Average Hit 2-back Task



Scatter Plot of Lobule 7 and Scores of The Digit Span Forward



Note. Scatter plots of the GMV of lobule 7 and the scores of the n-back and Digit Span Forward. The upper figure demonstrates the correlation of cerebellar GMV and the N-back task. The figure below demonstrates the correlation of cerebellar GMV and Digit Span Forward test. $N = 31$.

Table 1

Cerebellar lobes GMV in mm3

Cerebellar lobules	Mean (SD)	Median (IQR)
Lobule VIIb	5328.06 (504.56)	5500.88 (463.06)
Lobule VIIIa	4777.37 (515.74)	4970.35 (504.08)
Lobule VIIIb	3885.44 (461.87)	3983.09 (588.21)

Note. Values are expressed as mean, standard deviation, median and interquartile range. *N* = 31

Table 2

Cerebellar lobules in which GMW was correlated with performance on cognitive tests.

Variable	M	SD	1	2	3	4	5	6	7	8	9	10	11
1. Lobule VIIb	5328	504	-										
2. Lobule VIIIa	4777	516	.897**	-									
3. Lobule VIIIb	3885	462	.815**	.920**	-								
4. Average Hit 1-back	3.39	0,92	.287	.164	.173	-							
5. Average Hit 2-back	2.79	0.78	.466**	.297	.278	.770**	-						
6. D-prime 1-back	1.35	0.59	.255	.129	.136	.978**	.741**	-					
7. D-prime 2-back	0.95	0.45	.399*	.258	.227	.724**	.961**	707**	-				
8. Digit Span Forward	8.68	2.29	.473**	.425**	.332*	.198	.280	.157	.308*	-			
9. RAVLT Immediate Recall	33.32	9.89	.264	.152	-.037	.222	.206	.189	.312*	.470**	-		
10. RAVLT Delayed Recall	29.48	8.98	.263	.317*	.234	.263	.156	.274	.199	.269	.297	-	
11. RAVLT Delayed Recall Corrected	39.16	15.02	.318*	.347*	.278	.299	.230	.305*	.253	.353*	.471*	.950**	-

Note. $N = 31$. *$p < .05$. **p < .01