The relation between experiencing Low-Frequency Noise and Memory Functioning

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Abstract

Only few studies have focused on the impact of Low-Frequency Noise (LFN) on health, while cognitive problems and sleep difficulties are often associated with LFN experience. The goal of this study was to provide insight regarding objectively assessed memory functioning associated with experiencing LFN in daily life. Additionally, this study aimed to explore the role of quality of sleep on memory functioning. Adults experiencing LFN in their daily life (*N* = 74) and a control group (*N* = 46) completed memory tasks in a neuropsychological assessment, and a questionnaire regarding the subjective quality of sleep. Memory tasks, aimed at assessing short- and long-term memory functioning, verbal and non-verbal memory functioning, and recognition, were used for this study. Results on these tasks were compared between groups and regression analyses were performed to explore the role of sleep quality. The results of this research suggest reported experience of LFN in daily life not to be associated to reduced memory functioning in a neuropsychological examination and reported quality of sleep does not seem to affect this relation. This study had a limited sample size and future research should focus on clarifying the relation between cognition and LFN, and the possible role of quality of sleep in this relation, by including a larger sample size. Annoyance could be affecting the difference between reported cognitive problems and the absence of changes in cognition in this study. Future research should explore the role of annoyance, thereby possibly providing directions for appropriate support for individuals experiencing LFN.

Keywords: Low-frequency noise, memory functioning, quality of sleep

Samenvatting

Slechts weinig onderzoek heeft zich gericht op de impact van laagfrequent geluid (LFG) op gezondheid, terwijl cognitieve problemen en slaapproblemen vaak worden geassocieerd met LFG-ervaring. Het doel van deze studie was inzicht te verkrijgen in de objectieve geheugencapaciteiten in relatie tot LFG-ervaring in het dagelijks leven. Bovendien was deze studie gericht op het onderzoeken van de rol van de kwaliteit van slaap op het functioneren van het geheugen. Volwassenen die LFG ervaren in hun dagelijks leven (*N* = 74), en een controlegroep (*N* = 46), voltooiden geheugentaken in een neuropsychologisch onderzoek en een vragenlijst over de subjectieve kwaliteit van slaap. Geheugentaken, gericht op het beoordelen van het korte- en langetermijngeheugen, het verbale en non-verbale geheugen, en herkenning, werden voor dit onderzoek gebruikt. Resultaten op deze taken werden vergeleken tussen groepen en regressieanalyses werden uitgevoerd om de rol van slaapkwaliteit te onderzoeken. De resultaten van dit onderzoek suggereren dat gerapporteerde ervaring van LFG in het dagelijks leven niet geassocieerd is met verminderde geheugencapaciteiten in een neuropsychologisch onderzoek en de gerapporteerde kwaliteit van slaap lijkt deze relatie niet te beïnvloeden. Toekomstig onderzoek zou zich moeten richten op het verduidelijken van de relatie tussen cognitie, LFG en mogelijk slaapkwaliteit, door een grotere steekproefomvang op te nemen. Ergernis zou van invloed kunnen zijn op het verschil tussen gerapporteerde cognitieve problemen en de afwezigheid van veranderingen in geheugencapaciteiten in deze studie. Toekomstig onderzoek zou de rol van ergernis moeten onderzoeken, waardoor mogelijk aanwijzingen worden gevonden voor passende ondersteuning/hulp voor personen die LFN ervaren.

Trefwoorden: Laagfrequent geluid, geheugenfunctie, slaapkwaliteit

Introduction

The WHO has ranked noise as a prominent environmental stressors impacting public health (Fritschi et al., 2011). On a worldwide scale, a great amount of studies has focused on the impact of environmental noise on health. However, only few studies have focused on the impact of Low-Frequency Noise (LFN) on health and wellbeing. This gap should be addressed, especially since an increasing amount of people are expected to be exposed to LFN, due to the increase in density in the urban regions and the increase in machinery in our daily life environment.

Low Frequency Noise

LFN refers to sound waves around or just below the hearing threshold (ranging from 10Hz – 200Hz) (Leventhall et al., 2003) and is often described as a humming or rumbling sound, but it is on occasion also perceived as a bodily vibration (Baliatsas et al., 2016). LFN is produced by natural sources (e.g. sea waves, wind turbulence) but is often a by-product of manmade machinery (e.g. industrial installations, transportation, wind turbines) (Berglund et al., 1996). Only a proportion of the population experiences problems with LFN, since the auditory system of must humans is relatively insensitive to it. As a consequence, the effects of LFN have not been given much research attention. However, according to the National Institute for Public Health (RIVM), at least 8.1% of the population experiences problems due to LFN, and 2.1% of the population experiences severe health related problems resulting from LFN experiencing (National Institute for Public Health, 2016).

LFN-related complaints

The problems reported following LFN exposure show a great variety, but the most prominent and often first complaint is annoyance (Kaczmarska & Łuczak, 2007; Baliatsas et al., 2016; Pawlaczyk-łuszczyńska et al., 2005). Annoyance can be defined as a comprehensive term for all negative feelings like dissatisfaction, displeasure, nuisance and disturbance, negatively impacting the individual experiencing annoyance (Bhattacharya, 2012). In addition to annoyance, experiencing LFN has been found to be associated to physical and psychological problems like depression, headaches, shortness of breath and sleep-related problems, with the latter being one of the most reported problems after annoyance (Baliatsas et al., 2016; Leventhall et al., 2003). Besides psychological and physical problems, individuals experiencing LFN frequently report cognitive complaints like problems with memory and attention, which are crucial cognitive domains for activities of daily living (ADL) (Leventhall et al., 2003; Møller & Lydolf, 2002). Especially memory has been shown to be of importance for ADL, as it has been found by De Paula et al. (2015) that the effect of memory problems is one of the factors most strongly associated with functional performance in daily living. Since memory problems are frequently reported by LFN experiencing individuals, it is important to clarify the nature and extent of the reported memory problems in this group.

LFN and memory functioning

The cognitive domain of memory functioning is frequently regarded as multiple systems interacting in order to facilitate useful memory functioning. One of the most influential models of memory functioning is the multistore model of Baddeley and Hitch (1974) (Figure 1). According to this model, short-term memory is regarded as part of a more complex working memory system. In this model, short term memory includes a phonological loop (assumed to hold speech-based representations for a few seconds), a visuospatial scratchpad (associated with the short term memory of visuospatial information), and an episodic buffer (which is thought to be responsible for temporary storage and for binding representations across multiple modalities). These components of short term memory are controlled by an attentional control system, often referred to as the central executive. The central executive and the components of short term memory together constitute the working memory (Norris, 2017). Finally, according to the model of Baddeley and Hitch, long-term memory is suggested to be the result of information from the working memory being stored. This information can later be retrieved, which involves activity of the working memory again (Baddeley et al., 2019). Following this model, multiple aspects of memory should be measured, including short- and long-term memory, verbal and nonverbal memory, as well as recognition, in order to get a thorough understanding of memory functions.

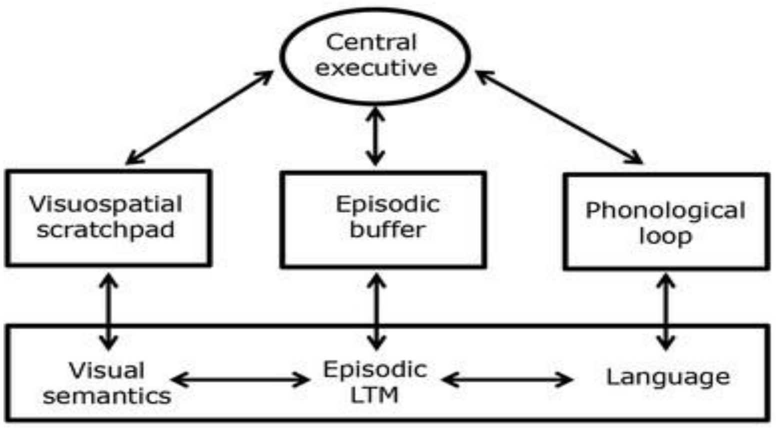
Objective memory functioning, and the components of memory functioning outlined in the model of Baddeley and Hitch (1974), should not be assessed using only reports of memory functioning. Objective memory functioning should be measured using neuropsychological tests developed to assess the multiple parts that make up the cognitive domain of memory functioning and is thereby different from subjective memory functioning, which is reported by individuals (often assessed through self-report questionnaires). Since the relationship between subjective memory problems and objective memory problems is generally weak, the presence or absence of memory problems should not be assumed based solely on self-reports of memory functioning, but should rather include objective measures of memory functioning (Schmidt et al., 2001; Newson & Kemps, 2006).

Interestingly, current literature investigating the association between LFN and memory functioning focused either on objectively assessing memory functioning while being exposed to LFN, or consisted of self-report questionnaires after experiencing LFN (Weichenberger et al., 2015; Abbasi et al., 2018; Waye et al., 2001; Leventhall et al., 2003; Møller & Lydolf, 2002; Gomes et al., 1999). To the author's knowledge, even though memory problems are often reported in LFN experiencing individuals, no studies have focused on objectively assessing memory functioning in individuals reporting to be affected by experiencing LFN in their daily lives. Moreover, the results put forward by experimental studies focusing on memory functioning in relation to LFN range from better to worse memory performance after LFN.

Finally, besides LFN, other factors, like sleep, are thought to affect memory functioning and should be considered when investigating the relation between LFN and memory functioning. Interestingly, sleep problems are often reported in LFN and are also thought to affect memory functioning (Walker, 2008). Therefore, sleep might play a role in the possible relation between LFN and objectively assessed memory functioning (Baliatsas et al., 2016).

Figure 1

Model for memory functioning by Baddeley and Hitch (2019)



Sleep in LFN and memory functioning

Sleep is essential for optimal memory functioning, with sleep being important prior to learning (necessary for initial coding of memories), as well as after learning (required for consolidation of memory) (Walker, 2008). While general noise, specifically intermittent noise, is usually reported to be more annoying and disturbing of sleep, it has been found that LFN (e.g. from the source of a ventilation system) led to a significant increase in time to fall asleep (Waye et al., 2003), resulting in a shorter period of sleep. Supporting the proposition that LFN is associated with sleep problems, Myllyntausta et al. (2020) found worse scores on both, objective and subjective measures of sleep when being exposed overnight to LFN compared to a control group. Therefore, the additional role of quality of sleep in individuals experiencing LFN might aid in understanding the association between experiencing LFN and memory problems.

Aim

The main goal of this study was to provide insight into objectively assessed memory problems associated with experiencing LFN. Current findings focusing on the impact of LFN on memory functioning are limited, inconsistent, and most research has an experimental set-up, where participants are exposed to LFN before or during their performance on a memory task (Weichenberger et al., 2015; Pawlaczyk-łuszczyńska et al., 2005; Waye et al., 2001; Gomes et al., 1999).

Earlier research either made use of an experimental set-up, in which individuals were exposed to LFN, or used self-report questionnaires in order to assess memory functioning. The current study does not make use of an experimental set-up, but recruited participants reporting to be affected by LFN in their daily living, as well as a control group of participants not reporting to be affected by LFN. Given the estimation that a proportion of the population is more prone to the effects associated with experiencing LFN, focusing on a group reporting problems after exposure to LFN may additionally provide more insight into the problems associated with LFN for people more sensitive to the effects.

This study is an observational study, using group comparisons between the LFN experiencing group and a control group. Neuropsychological tests focusing on memory storage of different modalities were used to assess objective memory functioning for both groups. The 15 word test (15WT) and the WAIS-IV Digit Span (DS) were used for testing verbal short term memory. The Location Learning Test (LLT) was used for testing short term visuospatial memory. Additionally, the delayed LLT and 15WT recall task were used respectively to assess visuospatial and verbal long term memory. Lastly, the 15WT recognition task was used to assess memory recognition, which is different from free recall memory tasks by the requirement of effortful search through and retrieval from memory in free recall tasks (Rich, 2011). Based on earlier research, no clear expectations were formed regarding the association between LFN experience and objectively assessed memory functioning, as earlier research was limited and inconsistent (Weichenberger et al., 2015; Pawlaczyk-łuszczyńska et al., 2005; Waye et al., 2001; Gomes et al., 1999).

Finally, this study aimed to explore the role of quality of sleep on memory functioning associated with LFN perception. Given the importance attributed to sleep for optimal memory functioning and the often present sleep disturbances reported in LFN experiencing individuals, a role of quality of sleep was expected, where worse reported quality of sleep was expected to be associated with worse performance on memory tasks. The quality of sleep was measured using self-reports on the Pittsburgh Sleep Quality Index (PSQI) questionnaire. Prior to analyzing the role of sleep-disturbance on the association between memory problems and LFN, this study first identified whether there was an association between LFN experience and memory functioning. Thereafter, it explored the effect of sleep problems for the relation between LFN and memory functioning.

Method

Participants

120 participants (54% women), with a mean age of 58.18 years (range: 28-83, *SD* = 11.13), were included in this study. From this group, 74 participants (62% women), with a mean age of 57.77 years (range: 33-83, *SD* = 10.39), were LFN experiencing individuals. Participants included in the LFN experiencing group reported difficulties attributed to LFN on a daily basis, and reported to be restricted by these difficulties. The LFN experiencing

individuals were contacted through the Stichting Laagfrequent Geluid, a Dutch volunteer organization established in 2017 that supports affected individuals and informs about the topic, and from the personal environment of the members of Stichting Laagfrequent Geluid. Individuals with a diagnosis of a psychiatric or neurological disorder were excluded, based on their self-reported answer on a question whether they suffered from a psychiatric or neurological disorder. This exclusion criterion was used in order to minimize the assumed confounding effects of sound effects or cognitive impairments not related to LFN (Sheehan et al., 1998; Van Vliet & De Beurs, 2007). Disorder with assumed low confounding effects on the outcome of the neuropsychological assessment, or disorders possibly related to experiencing LFN were included (e.g. depression). The focus of this study is on the effects of complaints attributed to LFN rather than focusing on the cause of the LFN experience. Therefore, participants who experienced LFN and also suffered from tinnitus were included. Since, although difficult to separate, the phenomenon are distinct from each other and are therefore not mutually exclusive.

The control group consisted of 46 participants (41% women), with a mean age of 58.85 years (range: 28-77, *SD* = 12.32), who did not experience LFN, and who did not meet the psychiatric and neurological disorder exclusion criteria. The control participants were contacted from the personal environment of the LFN participants, the researchers and from earlier research at the Department of Clinical and Developmental Neuropsychology of the University of Groningen.

Materials

During the neuropsychological assessment, participants performed a series of standardized neuropsychological tests (See Appendix A for the complete list of neuropsychological tests included in the assessment). For this study, the 15WT, the DS and the LLT were included since these tests assess memory functioning. Additionally, participants filled out a set of questionnaires prior to the neuropsychological assessment, from which only the PSQI was used for the current study.

The 15 word test (15WT) is a test designed to measure verbal memory (Saan & Deelman, 1986). During this test, a list of fifteen everyday words was read out to participants via an audio recording five times. After each repetition, the participant was given as much time as required to name as many words as possible. After each repetition, the participant had to name all words he/she can remember, including the words already said in an earlier repetition. The participants were told that double responses (saying the same word twice within the same repetition) and wrong answers (naming words not included in the list) were not corrected by the examiner, but they were registered. In addition, participants were not told beforehand how many words were included in the list. After the fifth repetition, participants performed other tasks not requiring memory capacity for approximately thirty minutes, before starting the 15WT delayed recall task. In the recall task, participants were asked to once more name as many words from the word list as they could remember. After having done the delayed recall task, the 15WT recognition task started. In this task, thirty words were read out to the participant, one at a time. Half of these words were included in the word list, and the participants had to tell whether they were included in the word list or not. The score on the immediate recall task was calculated by the addition of the total words said in the five trials. The score of the delayed recall task consisted of the amount of words remembered in the delayed trial. The score on the recognition task was the total amount of words correctly identified as being either in the list of words or not. Finally, the scores on the 15WT immediate and delayed recall were converted to percentile scores based on age, gender and education in order to control for these factors (Mitrushina et al., 1991; Bolla-Wilson & Bleecker, 1986). The 15WT is a translation of the English Rey Auditory Verbal Learning Test. No reliability for the 15WT was found, but the Rey Auditory Verbal Learning Test had a sufficient validity (Soble et al., 2021) and reliability (α = .80) (de Sousa Magalhães et al., 2012)

The DS tasks together form a subtest of the WAIS-IV test battery (Weiss et al., 2010). The DS consists of three tasks in which a sequence of numbers was being read out by the examiner, which were then to be repeated by the participant. In the first task, the participant had to repeat the numbers in the same order as they were read out by the examiner. In the second task of the DS the participant had to repeat the numbers in a backwards order as they were read out by the examiner. In the final task of the DS, the participant had to repeat the numbers sorted from smallest magnitude to largest, while also including multiple times the same numbers that were read out multiple times within the trial. The sequence of numbers started with a length of two numbers, and was increased after every two sequences. When a participant answered incorrect on both sequences of a certain length (for instance on both rows of five numbers), the test was stopped. When participants correctly answered one of the two sequences of a certain length, the test regularly continued. The score for each individual subtest of the DS consisted of the amount of trials properly answered. The Digit Span has been found to have a sufficient validity (Varela et al., 2022) and a good reliability (α = .90) (Groth-Marnat & Baker, 2003).

The LLT is a task thought to rely mainly on visual memory (Thompson et al., 2021). In this task, participants were shown a grid existing of five rows and five columns (making up 25 cells). In this grid, ten drawings of everyday objects were shown (e.g. glasses, wallet). The participant was shown the grid for fifteen seconds, after which an empty grid was presented to the participant. The participant received the ten drawings in a random order one after another and had to place them on the place of the grid where the participants remembered them to be shown earlier. After the participant had placed the ten drawings, the grid was emptied and the participant was shown the correct grid for another fifteen seconds. This procedure continued for a maximum of five times. When a participant placed all drawings in the correct place two times in a row, the test was stopped. The participant was then informed that this task would come back later in the assessment. After approximately thirty minutes, the delayed recall task started, in which the participant was shown only the empty grid. The participant was then asked to place the ten drawings at the place where they were shown in the example grid. The scoring of the LLT consisted of adding up the amount of cells each object is misplaced, both on the horizontal and vertical axis, to give an error score per drawing. The errors per individual drawing placed on the grid were then added up per repetition. The results from the immediate recall trials could then be used to calculate the total amount of drawings correctly placed in the complete task as well as the learning index in the LLT. The learning index was calculated by subtracting the score of the errors made in each repetition from the errors made in the previous repetition. This total was then divided by four to get the learning index (Kessels et al., 2006). The learning index reflects the increase of objects correctly remembered over the five immediate recall trials, where a higher learning index meant a steeper learning curve. The scoring for the delayed recall consisted of the same procedure as for the immediate recall trials, where the amount of errors made (expressed in cells misplaced per object) was added up. The Location Learning Test is a well validated, reliable neuropsychological test for visual memory functioning (Thompson et al., 2021).

The Pittsburgh-Sleep-Quality-Index (PSQI) was used as a subjective measure for sleep disturbance, which measures self-described sleep quality over the month prior to assessment (Ji & Liu, 2016). The PSQI consists of four questions asking participants about general estimations regarding their sleep (e.g. ‘In the past month, at what time did you usually go to bed?’), followed by five items (consisting of multiple sub-items, on a scale from ‘not during the past month’ to ‘Three or more times a week’) where participants had to score how often certain events or experiences occurred. The results on the questionnaire provided 7 component scores that were then combined into a global score ranging from 0 to 21. This global score was used in this study. Finally, the PSQI defines individuals with more than 5 points on the global score as poor sleepers (Smyth, 1999; Buysse et al., 1991). The PSQI has been found to be a reliable measure of reported sleep quality (α = .85) (Lu et al., 2014).

Design

This study used an observational controlled-trial between-subjects design. The outcome of a neuropsychological assessment of participants who reported to be affected by LFN in their daily life was compared to a not-affected control group who completed the same neuropsychological assessment. Only standardized neuropsychological tests providing quantitative data were included in the assessment. The researchers were trained in order to minimize the influence of different administers of the assessment, thereby collecting the data with optimum reliability.

Procedure

After distribution of an information letter to possibly interested participants, individuals could show interest to participate in this research via email. The LFN experiencing participants filled out the questionnaires and could indicate interest to partake in the neuropsychological assessment. The control participants filled out the questionnaires after the neuropsychological assessment. All individuals willing to participate were invited to complete the assessment at the Department of Clinical and Developmental Neuropsychology at the University of Groningen, the Netherlands. All participants read and agreed to an informed consent before participating. The subjects received both written and verbal instructions about the tests and procedures and written consents were collected prior to the neuropsychological examination. Both, the LFN experiencing individuals and the unaffected controls were tested individually and were given a compensation for the travel costs. Participants completed the test battery in about 4 hours, with at least two pauses and more if requested by the participant. From the total assessment, the neuropsychological tests used in this study took approximately 30 minutes to complete. The sequence of the tests was the same for all participants.

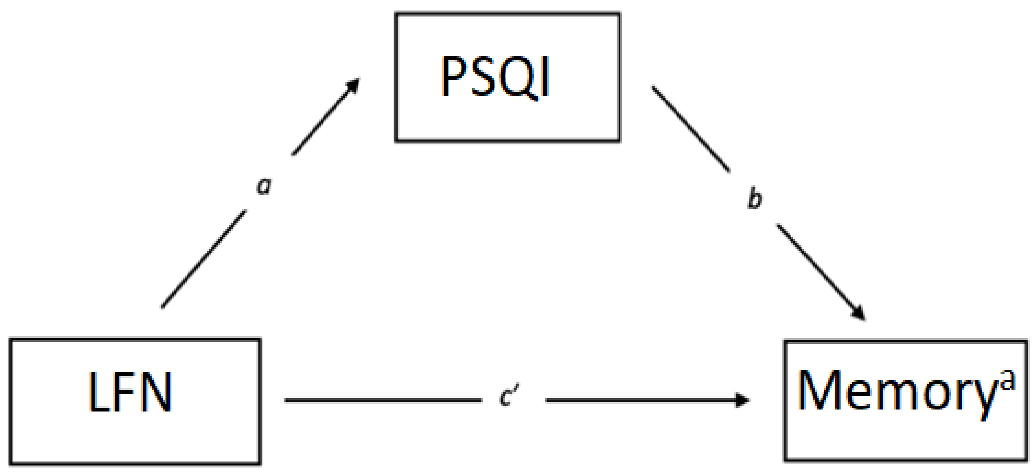
Statistical analysis

The scores on the different tests measuring memory functioning (15WT, DS, LLT) were compared between the LFN experiencing group and the unaffected control group to investigate whether a relation was present between experiencing LFN and memory disturbances. Both the assumptions of equal variances and of normality were examined. Since tests for normality may lack power to identify violations of the normality assumption in small participant groups, P-P plots and histograms were used alongside the Kolmogorov-Smirnov test in order to gain insight in the distribution of the test scores. The normality assumption was rejected for the 15WT, DS and LLT as well as for the scores on the PSQI. Using Levene’s test, the equal variances assumption was rejected for the 15WT recognition task and the LLT learning index. Therefore, Mann-Whitney U tests were used and effect sizes were computed based on these results. The effect sizes were calculated using Cohen’s *d* in line with the manner proposed by Rosenthal et al. (1994). The effect sizes were interpreted based on Sawilowsky’s categorization of very small ($d < .01$), small ($.01 < d < .2$), medium ($.2 < d < .5$), large ($.8 < d < 1.2$) and very large ($d > 1.2$) effects (Sawilowsky, 2009). All statistical tests were done with an assumed level of significance at a value of below .05. In addition to the analysis of the memory tasks, a Mann-Whitney U test was used to investigate whether the LFN experiencing group reported more sleep problems than the control group.

A mediation analysis was conducted for the memory task(s) for which a significant difference in performance between the LFN experiencing and the control group was found (Figure 2). Multiple regression analyses, using a stepwise forward-entry, were performed to explore the role of quality of sleep for the relation between LFN and memory functioning. A full mediation effect was regarded when experiencing LFN or not was a significant predictor for a memory measure when LFN was entered in the model alone, but was no significant predictor when quality of sleep was added to the model. A partial mediation effect was regarded when experiencing LFN or not was a significant predictor for a memory measure when LFN was entered in the model alone, and when quality of sleep was added both quality of sleep and experiencing LFN were significantly related to the measure of memory functioning. No mediation effect was regarded when, after adding quality of sleep to the model, quality of sleep was not significantly related to the measure of memory functioning. The statistical analysis employed SPSS version 27 software for Windows (Chicago, IL, USA).

Figure 2

Mediating role of sleep for the relation between LFN and memory functioning



Note: LFN – Either low frequency noise experience or not. PSQI – Sleep quality as measured by the Pittsburgh Sleep Quality Index.
[a]:Memory functioning as found in the 15 word test, location learning test and the WAIS-IV digit span.

Results

Results from the Mann-Whitney U test for the memory tasks are shown in Table 1. No significant difference was found between the LFN experiencing group and the control group for the 15WT immediate recall raw score (see Appendix B, Figure 1). The same was found for the delayed recall raw score and for the recognition task. However, the difference in mean rank scores between the LFN experiencing group and the control group was much larger in the recognition task than in both of the recall tasks. This is also reflected in the effect sizes. The effects for the immediate recall task and delayed recall task were very small, while a small effect size was found for the recognition task (Table 1).

No significant difference was found between the LFN experiencing group and the control group for the DS forward task (see Appendix B, Figure 2). For the DS forward recall the LFN group had a lower mean rank score than the LFN group, with a very small effect size. Similarly, no significant differences were found between the groups for both, the DS backwards task, with a very small effect size, and for the DS sorting task, with a very small effect size.

No significant difference was found between the LFN experiencing group and the control group for the LLT immediate recall score (see Appendix B, Figure 3). The effect size was very small. In addition, no significant difference was found between the two groups for the learning index, with a small effect size. Finally, no significant difference was found between the LFN experiencing group and the control group for the LLT delayed recall task, with a very small effect size.

The Mann-Whitney U test showed no significant difference on the PSQI score between the LFN experiencing group and the non-affected group (Table 1). The mean rank score for LFN experiencing groups was higher than for the control group, with a small to medium effect size (Appendix B, Figure 4).

Although no significant differences were found between the groups for the memory tasks, a trend was observed of the LFN group having lower scores on the memory tasks than the control group. This was found for seven out of the nine variables derived from the memory tasks (Table 1). In addition, only two tasks (the 15WT recognition and the LLT delayed recall) showed a small effect while all others tasks showed a very small effect size (Table 1).

Table 1

Group differences on memory tests and the sleep questionnaire

	LFN		CG					
Score	*M*	Median	*M*	Median	*U*	*SD*	*p*	*r*
15WT-IR	55.81	47	56.31	47	1416.0	161.77	.94	.01
15WT-DR	55.73	10	55.07	10	1351.0	158.28	.92	.01
15WT-RS	51.64	29	62.82	30	1646.0	146.31	.06	.18
DS-F	53.63	8	60.38	9	1575.0	159.44	.28	.10
DS-B	58.18	9	51.97	8	1247.0	160.02	.33	-.09
DS-S	54.76	8	58.29	8	1493.5	159.59	.58	.05
LLT-IR	55.92	12	57.51	13	1497.0	165.47	.80	.02
LLT-DR	54.46	0	58.29	0	1022.5	113.87	.14	.25
LLT-LC	23.17	.8	31.32	.9	278.5	39.80	.08	-.14
PSQI[a]	14.64	10	7.25	4	19.0	14.02	.08	-.35

Notes. LFN – Low Frequency Noise experiencing group. CG – Control Group. *M* – Mean rank. *U* – Mann-Whitney U test. *SD* – Standard deviation. *p* – Significance. *r* – Effect size. 15WT – 15 Words Test. IR – Immediate recall. DR – Delayed recall. RS – Recognition score. DS – Digit Span. F – Forward. B – Backward. S – Sorting. LLT – Location Learning Test. LC – Learning index. PSQI – Pittsburgh Sleep Quality Index.
[a]: Different sample size from the other Mann-Whitney U tests ($N = 26$).

No difference was found between the scores on the different memory tasks. Therefore, a forward-entry regression analysis to explore the influence of the PSQI score in addition to the influence of experiencing LFN with regards to the memory tasks yielded no significant results. For the memory tasks, an overview of the standardized beta coefficients and their significance of both, experiencing LFN and/or the PSQI score was found using a forced-entry regression analysis (Appendix C). Notably, for the LLT learning index, a significant effect of the PSQI ($F(1,15) = 10.775$, $p = .005$) was found in the absence of an effect of experiencing LFN. The standardized beta coefficients across the different memory tasks showed no tendencies for either PSQI or experiencing LFN to be of greater influence on the performance on the tasks.

Discussion

The aim of this study was to gain a better understanding of the relation between reported experience of LFN in daily life and memory functioning. Three standardized neuropsychological tests (15WT, DS, LLT) were used to explore this relation, investigating both, verbal and nonverbal memory, short-term and long-term memory, and recognition ability. A further objective was to explore the potential role of sleep problems for the relation between LFN and memory functioning. The results of this research suggest that reported experience of LFN in daily life is not associated to reduced memory functioning in a neuropsychological examination and that reported quality of sleep does not affect this relation. It was found that the LFN experiencing group had similar results to the control group on tasks dependent on both, visual and verbal memory functioning, as well as on the reported quality of sleep. This is in contrast with self-reports of memory functioning in the presence of LFN, where memory is reported to be one of the cognitive domains most affected (Leventhall et al., 2003; Møller & Lydolf, 2002). The results imply that, despite reports of worse memory functioning, reported experience of LFN in daily life is not reflected in memory capacity as measured by neuropsychological tests.

Considering the results regarding memory functioning, it is interesting that, although memory complaints were often reported (Waye et al., 2001; Leventhall et al., 2003; Gomes et al., 1999), the neuropsychological assessment for memory capacity did not show any differences from the control group. At least three points of interest might contribute to the difference between the reported complaints and the results of the neuropsychological assessment for memory capacity. The first point of interest is annoyance. Annoyance is related to stress and is the most prominently reported complaint in experiencing LFN (Rylander, 2004; Kaczmarska & Łuczak, 2007; Baliatsas et al., 2016; Pawlaczyk-łuszczyńska et al., 2005). Österberg et al. (2014) found participants scoring higher on stress scales to report more memory deficits, even in the absence of objectified cognitive deficits. Similar results were found by Nivison & Endresen (1993), where a strong correlation was found between noise annoyance and reported health. Accordingly, it could be that annoyance from LFN, rather than the reported LFN experience, influences subjective memory functioning.

The second point of interest is the difference between reported problems in daily life and assessed cognitive problems in a neuropsychological examination. The relationship between subjective and objective memory problems is generally weak (Schmidt et al., 2001; Newson & Kemps, 2006). As was the case for the current study, neuropsychological tests are usually administered to a single person, in a quiet environment, with very few distractors and only assess performance during a short period of time. Therefore, the neuropsychological tests are thought to reflect an estimate of a person's peak level cognitive performance but may not adequately reflect cognitive capacities in daily living (Boyle et al., 2012). Subsequently, one interpretation of the current findings is that the cognitive performance of the LFN experiencing group in the context of a structured environment such as a neuropsychological examination may thus be sufficient, but problems may be present in a setting, which is less structured and calm and of a longer duration.

Thirdly, there may be a difference between performance while being exposed to LFN, and when not being exposed to LFN. In a study by Abbasi et al. (2018), 35 adult participants were exposed to LFN (55-70dBA) while performing memory tasks. These participants reported LFN to negatively affect memory functioning and showed worse results on memory tasks than a control group. However, in the study presented in the present paper, participants were recruited who experienced LFN in their daily life, and these participants were not actively exposed to LFN during the neuropsychological examination. Therefore, the findings might be explained by the hypothesis that the reported cognitive complaints reflect worse cognitive performance only when LFN is present.

Although no significant differences on the memory tasks were found between the LFN experiencing and the control group, a tendency was observed where the LFN experiencing group scored lower than the control group. No conclusions can be drawn from these results, but the results could reflect subtle effects of experiencing LFN on memory functioning. These effects on cognitive functioning are important to clarify, since small differences found in the structured and organized setting of a neuropsychological assessment are associated with functional difficulties in activities of daily living, where less structure and a higher amount of distractors is often present (Kotwal et al., 2015; Salthouse, 2012). It should be noted that this research did not include objective measures of daily life functioning. Therefore, in terms of future research, it would be useful to extend the current findings by examining memory functioning in a larger sample size in order to clarify whether experiencing LFN is associated with a subtle effect in memory functioning. Additionally, since the relationship between subjective and objective memory problems is generally weak, no evidence for the presence of cognitive complaints in daily life and for the possible relation of these possible cognitive complaints in daily life to experiencing LFN could be derived from the results of the current study.

Similarly to the performance on the memory tasks, no significant difference was found for the reported sleep problems between the LFN experiencing and the control group. Although this effect was not significant, a small to medium effect size was found for the relationship between LFN and reported quality of sleep, with the LFN experiencing group reporting worse quality of sleep as reflected in higher mean rank scores. Additionally, the median score for the LFN experiencing group was above the cut-off score for bad sleepers, while the median for the control group was below the cut-off score. The current study only used measures of subjective (self-reported) sleep quality but is inconsistent with the research done by Myllyntausta et al. (2020), where worse scores were found on both objective and subjective measures of sleep when being exposed overnight to LFN compared to a control group. However, in the current study, participants were not actively exposed to LFN during their sleep but rather reported LFN in their daily life. This difference might be reflected in the different results put forward by the studies. Moreover, the current study had a limited amount of participants (N = 26) who completed the neuropsychological test battery and also filled out the PSQI questionnaire. Therefore, the results of the current study are of low statistical power. So, although the current results of this study oppose earlier research of subjective reports of sleep (Myllyntausta et al., 2020) and are not in line with research in terms of objective quality of sleep (Waye et al., 2003; Myllyntausta et al., 2020), the most important contribution of the present study may be that these results raise questions for future study. It would therefore be useful to extend the current findings by examining the relation between LFN and reported quality of sleep in a study with a larger sample size, thereby clarifying whether experiencing LFN in daily life significantly affects the subjective quality of sleep.

Earlier research found sleep to be essential for optimal memory functioning (Walker, 2008) and problems with sleep to be more often reported in individuals experiencing LFN (Scullin & Bliwise, 2015). A significant role of PSQI for the relation between experiencing LFN and memory functioning was expected. However, a stepwise forward-entry regression analysis using these variables yielded no significant results (Appendix C). The only exception to this was the score on the LLT learning index, which was found to be significantly related to the PSQI score. Since no significant relation was present between LFN and the LLT learning index, both prior to and after adding PSQI to the model, the association between PSQI and the LLT learning index was considered to be an association in itself, rather than a (partial) mediating effect. It was found that those reporting worse quality of sleep had a worse learning index and thus a flatter learning curve. However, this result has low statistical power, given the very limited number of participants (N = 16) for whom a LLT learning index and a PSQI score was known.

The findings regarding the role of the reported quality of sleep are in line with research done by Nivison and Endresen (1993), where no negative correlations were demonstrated between objective noise levels, health and sleep, but oppose the results put forward by Myllyntausta et al. (2020), where LFN was found to be associated with worse subjective and objective quality of sleep. Like the present study, the research of Nivison and Endresen (1993) included participants who experienced noise in their daily living, but both studies did not actively expose participants to noise during their sleep. It could therefore be reasoned that the participants in both studies were exposed to sounds overnight that they were, to some degree, accustomed to, since participants most likely spent the nights surrounding the study in their usual sleeping place. This is different from the work done by Myllyntausta et al. (2020), where participants were actively exposed to sounds overnight in an experimental setting. One possible explanation for the difference in results regarding quality of sleep between these studies might be that individuals exposed to a new or unfamiliar sound are more affected than those exposed to similar sounds over a longer period of time. However, future research is needed to shed more light on this hypothesis. In addition, it should be noted that, like self-reported and objective cognitive problems, self-reported and objective sleep measures are weakly associated (Jackowska et al., 2016), and therefore this study only provides information regarding the subjective quality of sleep of LFN experiencing individuals.

Limitations

Various limitations have to be recognized when interpreting the results of this research. First of all, the current study is an observational study, meaning that participants were not actively exposed to LFN during the neuropsychological assessment. It is therefore possible that differences in memory functioning could be present when participants are exposed to LFN, but not in the absence of LFN. However, the current results are valuable in showing that although complaints are reported in daily living, no differences are found between the LFN experiencing group and the control group when a neuropsychological assessment is completed in a controlled environment. It might therefore be possible that, should changes be present when exposed to LFN, this effect may be restricted to a limited period after exposure to LFN.

Secondly, the current study focused on the relation between experiencing LFN and memory functioning. Thus, participants included reported to experience LFN in their daily life, but no research was done regarding the origin or the presence of LFN in their daily life. Therefore, the implications of this study do not provide insight into the specified case of being directly exposed to LFN, but should be limited to those reporting experience of LFN. Individuals reporting LFN have been found to report many and severe complaints (van Poll et al., 2018; Kaczmarska & Łuczak, 2007; Pawlaczyk-łuszczyńska et al., 2005; Baliatsas et al., 2016; Leventhall et al., 2003; Møller & Lydolf, 2002). It is thus important that this group and the complaints reported by this group receive proper research attention. Therefore, this study is valuable in providing insight in the association between LFN experience and memory functioning, rather than in the investigation of a possible direct causal relation between LFN and memory problems. An additional advantage of including participants reporting experience of LFN in their daily living is that individuals more prone to the effects of LFN are more likely to be included in the current study. This is especially important given the relatively limited part of the population being more susceptible to the effects of LFN and the lack of research into the effects of LFN on this specific group (van Poll et al., 2018).

Finally, the current study had a limited sample size (*N* = 120), with the analysis of sleep as a mediator having a smaller sample size (*N* = 26). Therefore, the statistical power is low and subtle differences that might be present between the groups may not yield significant results, while a small difference in cognitive capacity may be related to an increased amount of difficulties in daily life (Kotwal et al., 2015; Salthouse, 2012). The small sample size for the relation between the LLT learning index and the PSQI score resulted from not all participants having filled out the PSQI-questionnaire, combined with not all participants having a learning index of the LLT available, due to some of the participants aborting the neuropsychological assessment prematurely. The results of this explorative analysis regarding the mediating role of sleep showed no significant difference, but a medium effect size was present for quality of sleep. Moreover, the LFN experiencing group showed a median score above the cut-off score for bad sleepers while the control group did not. Since these results were based on a very limited sample size and subtle effects might not have been revealed, no conclusions should be drawn from this analysis, and these results might rather be valuable in raising questions than they are in providing answers.

Implications

The results of this study suggest that experiencing LFN in daily life is not associated with changes in memory functioning in a neuropsychological assessment. Rather, other factors could be relevant for explaining memory complaints found in previous literature, like annoyance and the difference between peak cognitive performance and daily life cognitive performance. Annoyance may have implications for LFN experiencing individuals. Annoyance in experiencing LFN might affect the way in which cognitive functioning is perceived, as it was found that annoyance is associated with more reported problems in health, cognition and specifically in memory functioning, even in the absence of objectified cognitive deficits (Österberg et al., 2014). This could mean that an underlying psychological process, rather than cognitive changes, play a role in the perceived problems in daily living. This would yield implications for the assistance and treatment individuals experiencing consequences of LFN should receive, a psychological approach may be more appropriate than an approach based on cognitive deficits. It would be useful for future studies to investigate the potential role of the factors described above (annoyance and the difference between daily life cognition and optimal cognitive performance) in order to provide directions for appropriate support/treatment for those affected by experiencing LFN.

Another factor which might be of influence is the difference between peak cognitive performance and daily life cognitive performance. The results of this study may imply that while maximum cognitive performance is not affected by experiencing LFN, daily life cognitive functioning may be affected. The cognitive performance in a structured environment such as a neuropsychological examination may be sufficient, but problems might still be present in a setting which is less structured and calm and more time restricted. It may therefore be important to provide support to those experiencing cognitive problems related to LFN in daily living. This support could address coping strategies to aid in functioning optimally in daily living, for instance by providing strategies to best deal with complex or time limited situations (Wilson et al., 2017).

The implications above shed light on the value this study may have for those experiencing negative consequences following LFN experience. However, future research would do well to first aim at clarifying whether (subtle) cognitive changes are associated to experiencing LFN in daily life, by assessing cognitive functioning in a larger sample size. Additionally, it would be useful to gain insight into the daily life cognitive performance of those reporting to be affected by LFN. Finally, there is need for extensive research investigating the role of sleep quality for the relation between LFN and memory functioning, as the present study lacks statistical power.

Conclusion

On a worldwide scale, a great amount of studies have focused on the impact of environmental noise on health. However, only few studies have focused on the impact of LFN on health and cognition, while cognitive complaints and sleep difficulties are often reported following LFN experience. The main goal of this study was to provide insight into objective memory problems associated to experiencing LFN in daily life. Additionally, this study aimed to explore the role of quality of sleep on memory functioning in LFN. This study included participants experiencing LFN in their daily life, as well as a control group, who took part in a neuropsychological assessment and filled out questionnaires. Group comparisons, between individuals experiencing LFN in their daily life and a control group on neuropsychological memory tests, suggested no association between LFN perceptions and memory restrictions. In addition, reported quality of sleep was not found to affect this relation. Multiple factors like annoyance and the structured environment of a neuropsychological assessment might underly the difference between the reported cognitive problems in previous literature and the absence of a difference in objectively assessed memory functioning found in this study. The current study had a limited sample size, and future research should extend the current findings by including a larger sample size to clarify whether cognitive changes are associated to experiencing LFN in daily life. Furthermore, the role of reported quality of sleep for the relation between LFN and memory functioning should be clarified in a more extensive study. Finally, it would be interesting for future research to investigate the potential role of annoyance and daily life cognition in LFN experience, in order to provide directions for appropriate support/treatment for those affected by LFN in their daily lives.

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Appendix A

List of neuropsychological tests included in the assessment

Mini International Neuropsychiatric Interview

Test of Memory Malingering (TOMM) Trials 1 and 2

Groningen Effort Test

Trail Making Test

Stroop Word Color Test

TOMM Retention

Visuospatial working memory test

Tower of London

Paced Auditory Serial Addition Test

Dutch reading test for adults (‘Nederlandse leestest voor volwassenen’)

Location Learning Test: immediate recall

Vienna Test System (VTS) – WAFA (Alertness)

VTS – WAFS (Selective Attention)

VTS – WAFG (Divided Attention)

VTS – DT (Stress Tolerance)

Location Learning Test: Delayed recall

Dutch Fluency Test Letters D, A, and T

WAIS-IV Digit Span

15 Words Test: immediate recall

VTS – Go/No-go (Inhibition)

VTS – WAFV (Vigilance)

15 Words Test: Delayed recall

15 Words Test: Recognition

Appendix B

Results of the Scores on Multiple Memory Tasks.

Figure 1

Results of performance on the 15WT immediate recall

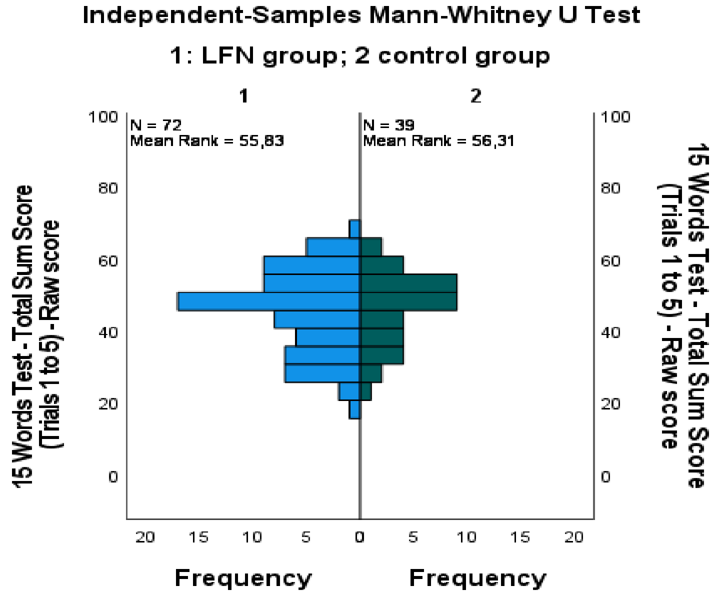


Figure 2

Results of performance on the DS forward

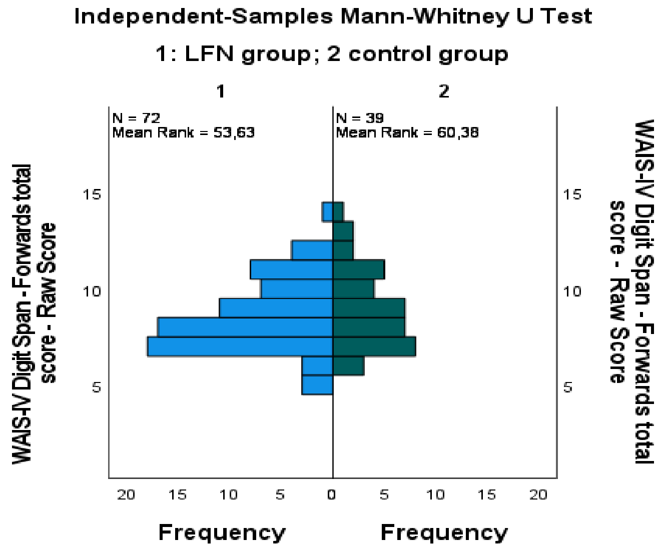


Figure 3

Results of performance on the LLT immediate recall

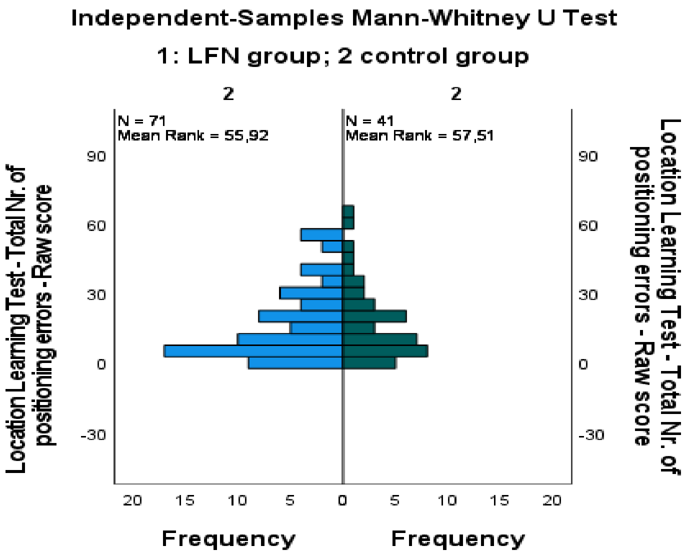
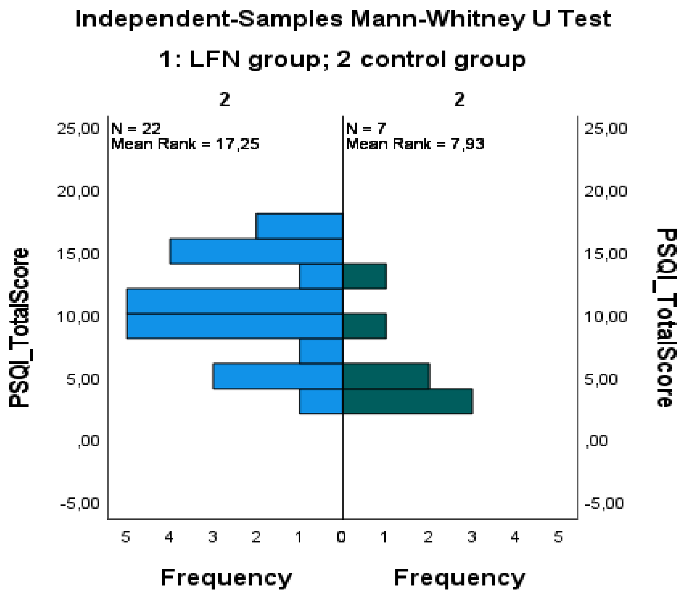


Figure 4

Results of the PSQI score



Appendix C

Table of Regression Analysis for Memory Tasks.

Table 1

Regression analysis using LFN and PSQI for the memory tasks.

Task	Variable	*β*	*p*	R^2
15WT-IR				0.060
	Constant		<.001	
	LFN	.11	.61	
	PSQI	-.18	.41	
15WT-DR				0.13
	Constant		<.001	
	LFN	.12	.61	
	PSQI	-.30	.41	
15WT-RS				0.02
	Constant		<.001	
	LFN	.14	.54	
	PSQI	.02	.93	
DS-F				0.04
	Constant		<.001	
	LFN	.18	.43	
	PSQI	.18	.41	
DS-B				0.16
	Constant		<.001	
	LFN	-.10	.64	
	PSQI	.36	.09	
DS-S				0.03
	Constant		<.001	
	LFN	.18	.42	
	PSQI	-.10	.65	
LLT-IR				-.01
	Constant		.10	
	LFN	-.21	.33	
	PSQI	.11	.61	

LLT-LC				.42
	Constant		<.001	
	PSQI score	-.65	**.01**	
LLT=DR				.11
	Constant		.67	
	LFN	.14	.54	
	PSQI	.24	.29	

Notes. β – Standardized beta coefficient. p – Significance. R^2 – Explained variance by the model. 15WT – 15 Words Test. IR – Immediate recall. DR – Delayed recall. RS – Recognition score. DS – Digit Span. F – Forward. B – Backward. S – Sorting. LLT – Location Learning Test. LC – Learning curve. LFN – Low Frequency Noise experiencing. PSQI – Pittsburgh Sleep Quality Index.