Relationship between Sleep Quality and Visual Short-Term Memory in Young Adults

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Abstract: Modern studies have indicated an active role of sleeping in memory consolidation. To further explore the relationship between them, the present study tested the relationship between sleep quality and visual short-term memory (VSTM) function. The study was conducted via online surveys and targeted at people aged 18 to 30 years old. The survey contained three main sections, basic information, sleep quality questionnaire, and VSTM tests. There are three questions asking age, gender, and education level of the basic information section. The Pittsburgh sleep quality index (PSQI) questionnaire was utilized to assess sleep quality, and global PSQI score was calculated according to the given PSQI calculation model. VSTM tests contain questions with pictures showing squares of different colors and randomly ask the color of a specific square. A total of 82 responses were used for data analysis. Most participants included are college students. A few of them are grad students. The results implicate that no association between sleep quality and VSTM function in younger adults was found in the present study. After comparison between good and poor sleepers, no significant difference in VSTM performance was discovered. Furthermore, after comparing the VSTM performance between females and males, no significant difference was found in the present study. The results from the present study might offer new insight for the relationship between sleep quality and short-term memory and thus suggests new direction for clinical treatment to certain mental diseases.

1 INTRODUCTION

Sleeping plays an important role in many aspects. It is believed that sleeping allows our body and mind to recharge, helping us to stay healthy. Studies have shown that sleep deprivation could cause enormous problems in human healthy. From basic level, sleep deprivation could increase response time, slowing down the reaction speed. Regarding to higher level cognition function, such as memory, perception, and executive functions, even though there are disagreements on how sleep loss could affect them, emerging evidence have suggested that sleep loss would impair certain functions, including learning, memory, and especially cognitive systems that rely on emotions (Killgore 2010). In human bodies, we have a circadian rhythm, an internal 24-hour clock that regulates our sleep cycle. For young adults, it's recommended to have 7 to 9 hours for sleep. According to National Sleep Foundation, sleep quality is defined as the measurement of how well you are sleeping. There are several factors used to determine sleep quality, including sleep latency, sleep waking, wakefulness, and sleep efficiency. In the present study, the Pittsburgh sleep quality index (PSQI) used to assess sleep quality contains all factors mentioned above.

Memory is the ability to both preserve and recover what we have learned and experienced. There are three general steps of memory: encoding, storage, and retrieval. There are two main kinds of memory, short-term memory which lasts seconds to hours and long-term memory which could last for years. The present study mainly focuses on short-term memory, especially VSTM. Short-term memory (STM) could be considered as a temporary storage system which usually lasts about 20 seconds and only holds a small amount of information. It's commonly believed that for human, the STM capacity is 7±2. VSTM is defined as the memory system that stores visual information for seconds. Previous studies have suggested that the capacity of VSTM is 4 items, but newer findings have indicated that the capacity could be set by both the information contained and the number of objects (Alvarez, Cavanagh 2004). In the present study, pictures with 8 squares of different

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colors were presented for a few seconds as visual stimulus, and a random square will be asked about its original color to test VSTM function.

The relationship between sleeping and memory has been studied for a long time. Early studies believe sleeping functions as a passive role in memory consolidation by protecting them from external stimulus, modern studies have shown sleeping plays an active role since memory undergoes processes for consolidation (Rasch, Born, 2013). Previous study has suggested that sleep deprivation could impair short-term memory of normal objects (Li, Wu, Shao, Liu 1991).

Inspired by all these information, the current study wants to further examine the association the effect of sleep quality on visual short-term memory (VSTM). The hypothesis is that there is association between sleep quality and VSTM function, and poor sleep quality would result in worse VSTM performance. The current study uses Pittsburgh sleep quality index (PSQI) questionnaire to test sleep quality and 12 questions containing squares of different colors to test VSTM function among around 80 Chinese young adults. It's hoped that by studying the relationship between sleep quality and VSTM, this study could help better answer the question that if sleep could improve STM. In addition, from clinical aspect, this study might have potential for developing more effective treatment to mental diseases. Sleeping disturbances are more common among patients with mental diseases that have symptoms of memory disorder than in general population. One such disease is schizophrenia, as data has shown that about 50-80% patients reported sleep problems while in general population, the number is approximately 30% (Cohrs 2012). Currently, many treatments of schizophrenia thus usually tend to increase total sleep time and sleep efficiency (Cohrs 2012). The result of the present study might provide new insight into clinical treatment.

2 METHODS

In this study, I conducted online survey designed through Qualtrics to test the sleep quality and VSTM function. The online survey contained three main parts: basic information, sleep quality questionnaire, and VSTM tests. The whole survey is anonymous. For the basic information part, participants were asked three questions: age, gender, and education level. The PSQI questionnaire is used to test the sleep quality. The Pittsburgh sleep quality index (PSQI) questionnaire is a self-rated questionnaire that covers a 1-month time interval (Buysse, Reynolds, Monk, Berman, Kupfer 2002). The final global PSQI score was calculated based on the given PSQI calculation model. A lower global PSQI score indicates a better sleep quality. The last part of the online survey is the VSTM function tests. There is a total of 12 questions in each survey. For each question, there will first be a picture with 8 squares at different positions with different colors. This colorful picture would appear for 5 seconds. After the 5 seconds, the picture would automatically disappear according to the design of the survey, and another picture will be shown with a multiple-choice question to the participants. The second picture has the same 8 squares at the same positions but with no color. An arrow points at a random square in the second picture, and the participants will be asked to choose the color of the indicated square. All positions and color of the squares and the indicated square in each question are random. Details of those pictures are shown below (Figure 1). Each question is counted as 1 point for the final performance score. For example, if a participant gets 4 questions right, his or her performance score will be 4 out of 12 points.

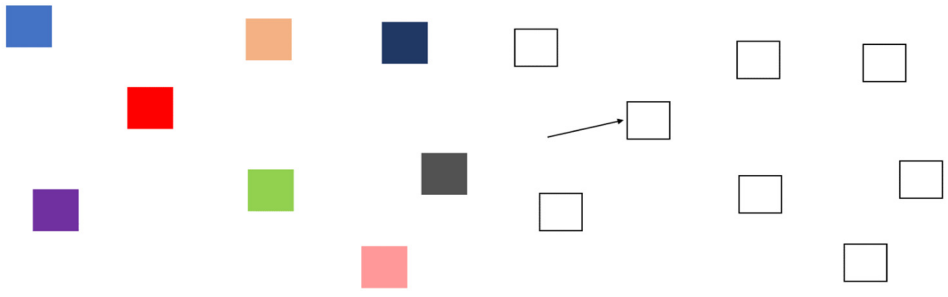

Figure 1: A sample of the pictures used in the VSTM test. The first picture (on the left) will first appear for 5 seconds. After this short time, the second picture (on the right) will appear with the question asking about the original color of the pointed square.

The link to this survey was published online through social media. In order to better control the noises of other factors that could potentially influence the short-term memory function, only people aged between 18 and 30 years old were allowed to complete the survey. In the end, this survey got a total of 86 responses. But for the final data analysis, only 82 responses were used. This is because some responses had very ambiguous answers so that their global PSQI score could not be accurately determined. Some responses were incomplete. There was also one response that has 0 scores for the performance score, and it is doubted that this person didn't seriously take the survey. Therefore, to make the research more powerful, only 82 responses were utilized in the analysis.

In terms of the data analysis, descriptive data, mean and standard deviation, were calculated for the age, PSQI score, and performance score. Shapiro test was used to test the distribution of the PSQI score and performance score. Spearman correlation test was used to determine if there's a significant association between sleep quality and VSTM function. To better determine if certain parameter could affect the VSTM function, a two-sided Mann-Whitney test was used to test the significance of difference in the VSTM performance. The threshold is set at $p = 0.05$ for the significance. All these tests were performed using R.

3 RESULTS

The survey finally got 82 complete responses. Based on their answers to the question of their education level, most participants are undergraduate students. Several of them are grad students. One participant is currently working. For all responses, mean and standard deviation of the age, the global PSQI score, and the performance score were calculated. The results are shown in the below table (Table 1).

Table 1: mean and standard deviation of age, PSQI score, and performance score for the whole dataset.

	mean	sd
age	21.57 (yrs)	2.84 (yrs)
PSQI score	5.21	2.96
Performance score	7.59	2.55

Shapiro test was performed on the PSQI score and the performance score to test the distribution of these data. The p-values from this test are shown in the table below (Table 2). Both p-values are smaller than the threshold, 0.05, therefore the distributions of these data are not normal. This indicates that spearman test should be used for the correlation test and Mann-Whitney test should be used to test the significance of difference.

Table 2: p-values from the Shapiro test on the PSQI score and the performance score of the whole dataset.

	p-value
PSQI score	5.268E-5
Performance score	0.01192

The main goal of the study is to determine if sleep quality is related to the VSTM function. Therefore, a correlation test was performed to examine if there's any association between them. Since the Shapiro test gave p-values smaller than 0.05, indicating that the distributions of the PSQI score and the performance score are not normal, the spearman method was used for the correlation test. The correlation coefficient is -0.0839, and the p-value is 0.4536. The correlation coefficient is slightly negative, implicating that a lower PSQI score might be associated with a better performance score. This is expected since a lower PSQI score means a better sleep quality. However, the p-value is larger than 0.05, indicating a non-significant correlation between sleep quality and VSTM performance. A scatterplot of VSTM performance vs. PSQI score was also drawn (Figure 2). From the scatterplot, we can that the distribution is relatively random, which could further support the conclusion from the correlation test.

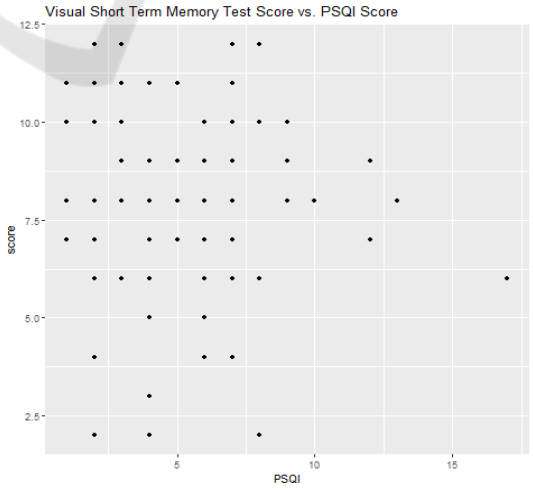

Figure 2: scatterplot of visual short-term memory performance score vs. PSQI score. The distribution in this scatterplot is relatively random.

To better determine if sleep quality could affect VSTM function, I separated the data into two groups based on the PSQI score. According to Buysse et al., a global PSQI score greater than 5 yielded both high diagnostic sensitivity and specificity (both over 80%) in distinguishing good and poor sleep quality (Buysse, Reynolds, Monk, Berman, Kupfer 2002). Thus, I categorized participants with a PSQI smaller than 5 into the good sleep quality group and participants with a PSQI greater than or equal to 5 into the poor sleep quality group. After categorizing the data, good sleep quality group has 37 participants, and the poor sleep quality group has 45 participants. Then I ran the Shapiro test on the PSQI score and performance score of both groups. The p-values of the PSQI score of both groups are smaller than 0.01, way smaller than the threshold. The p-value of the performance score of the good sleep quality group is 0.01485, and the p-value of the poor sleep quality group is 0.5213. Based on the p-values, most data are not normally distributed, thus the Mann-Whitney test should be performed to compare the performance difference between the two groups.

In order to examine the significance of the difference, mean and standard deviation of the performance score were first calculated. The good sleep quality group has a mean of 7.65 with a standard deviation of 2.93, while the poor sleep quality group has a mean of 7.53 with a standard deviation of 2.22. The Mann-Whitney test gave a $p = 0.5019$, larger than 0.05. Therefore, the difference in the VSTM performance between the two groups is not significant.

To test if gender could be a factor affecting the VSTM function, data were separated into the female and male groups based on their answers. There are 64 females and 18 males. The mean and standard deviation of the PSQI score and the performance score of these two groups were calculated as shown in the table below (Table 3&4). Since the group sizes differ greatly, the Mann-Whitney test was performed to test the significance of the performance difference. The test gave a $p = 0.7052$, greater than 0.05. Therefore, no significant performance difference was found between the two genders.

Table 3: mean and standard deviation of the PSQI score and the performance score for the female group.

Female group	mean	sd
PSQI score	5	3.07
Performance score	7.67	2.54

Table 4: mean and standard deviation of the PSQI score and the performance score for the male group.

Male group	mean	sd
PSQI score	5.94	2.51
Performance score	7.28	2.63

4 DISCUSSION

Based on the results from the data analysis, three conclusions could be reached. First, there's no association found in this study between sleep quality and VSTM function. Second, sleep quality might not affect VSTM function. Third, gender might not be a factor that influences VSTM function. Some previous studies have reached a similar conclusion as the present study. One study conducted by several undergraduate students at Georgia college tested 25 individuals for their sleep quality short-term memory function. Their study also used the PSQI for testing sleep quality and word recall tasks for the short-term memory function. They found no correlation between sleep quality and the number of words recalled and no significant difference in the number of words recalled by males and females (Holcomb, Raisin, Gravitt, Herrick, Mitchell 2016). This could reflect the results of the present study.

In another study conducted by Xie et al. (2019), sleep quality, working memory, and depressed mood were assessed. They used a short-term recall task and measured both the capacity and the precision of the working memory. They found that poor sleep quality could reduce the short-term memory capacity but not the precision (Xie, Berry, Lustig, Deldin, Zhang 2019). This conclusion could mirror the results in the present study. In the present study, the performance score of the VSTM tests is the number of questions the participant answered correctly. This could be considered as a measurement of the precision of short-term memory. In other words, the conclusion of the present study could be interpreted as no association found between the sleep quality and the precision of VSTM and no significant influence in the VSTM precision by sleep quality found based on the data, which is the same result as the previous study. This might also indicate that for future interest, the relationship between sleep quality and short-term memory capacity could be studied.

Even though there are some studies indicating that there might not be association between sleep quality and short-term memory function, many previous studies have suggested the opposite. An early study

conducted by Li et al. (1991) examined the sleep quality and short-term memory with several tasks and proved the importance of sleep in short-term memory function. The results from their short-term memory tests showed that sleep deprivation caused obvious drops in the score (Li, Wu, Shao, Liu 1991). They further conducted REM sleep deprivation using rat model and found the duration of the deprivation is potentially related to the strength of the impact on the short-term memory function by sleep deprivation. In addition, the team assessed the sleep quality and found that good sleepers had remarkably higher scores on digit span test than poor sleepers (Li, Wu, Shao, Liu 1991). However, for digit symbol, cube figure, and digit cancellation tests, no significant differences were found between the two groups (Li, Wu, Shao, Liu 1991). This finding might to some extent support the results found in the present study. The VSTM test in the present study only contains squares, which is similar to the cube figure test. Thus, it might be reasonable that no significant relationship between sleep quality and short-term memory was found. However, it might be worthy for future studies to investigate the reason why certain tests do not reveal the relationship.

The current study found no significant difference in VSTM function between two genders. One early study about gender difference and short-term memory function somehow provided similar result. The study tested on 1279 individuals, 637 males and 642 females, aged from 5 to 19 years old and performed 14 subsets of the Test of Memory and Learning (TOMAL) on all individuals (Lowe, Mayfield, Reynolds 2003). With this large sample size, the study revealed similarities between two genders on the VSTM tests. Even though a few tests showed minor differences, there were no consistent pattern found, and the magnitude of those differences are small, indicating there might be no gender difference in VSTM function (Lowe, Mayfield, Reynolds 2003). However, the study revealed that gender difference might play a role in other kinds of short-term memory. The study concluded that females scored higher on two verbal memory tests while males scored higher on spatial memory tests. These findings might offer new future directions in terms of gender effect on certain short-term memory function.

The main goal of the present study is to determine the relationship between sleep quality and VSTM function. The conclusion rejected the original hypothesis which proposed that worse sleep quality might be associated with poor VSTM function. However, as stated above, many previous studies have found such effect on short-term memory function. One potential reason for this mix might be age. Many studies have illustrated that age could affect short-term memory function, and usually the short-term memory function peaks at young adulthood. One such study tested on younger children (10 to 12 years), teenagers (13 to 15 years), younger adults (20 to 25 years), and older adults (70 to 75 years) and concluded that item-bindings, closely related to short-term memory function, are functioning better in teenagers and young adults than children and older adults (Fandakova, Sander, Werkle-Bergner, Shing 2014). Some studies also have shown similar conclusion and proved from neurobiology aspect. One such early study claimed that the binding process and the top-down control, related to posterior and frontal brain regions and their interactions with the whole neural network, experience large changes across the lifespan as both grow mature until young adulthood and decline as age increases, leading to the peak of short-term memory function in young adulthood (Sander, Lindenberger, Werkle-Bergner, 2012). In the present study, most participants could be considered as young adults. According to the above findings, the participants included in the present study might exert ceiling effect, all performed high short-term memory function regardless of sleep quality. Therefore, the effect of sleep quality might be reduced so that no association was found.

There are certain limitations in the present study as well. First, all participants are aged 18 to 30 years old. Most of them are college students. As discussed above, these participants could exert a ceiling effect on the study, reducing the power of sleep quality on short-term memory function. This also constrains the scope and the application of this study, limiting it to be only applicable to young adults. This also introduces the second limitation of the present study. The survey of this study took place during the summer break, during which students' sleep quality might not strongly influence students' behavior due to many other factors. This "summer break" limitation can potentially decrease the association between sleep quality and short-term memory function. To improve it, future studies could conduct at another time period to avoid summer break. The third limitation is due to the accessibility of research tools. All data of the present study were collected via an online survey, and no monitor was conducted when participants finished the survey. Therefore, if participants cheated, for example, taking pictures during the VSTM tests to help them remember the color, researchers could not know the truth. Thus, their performance score might not reflect their real

VSTM function. Improvement could be made by giving the survey in person to better control environmental influence. In addition, since the VSTM tests were designed personally by the researcher, the professionality might not be fully guaranteed. For future studies, if possible, more professional tests should be utilized. Fourth, there might be response bias in the present study. The link to the survey was published online through social media. As a result, only people who have social media and are interested in the survey would complete the survey, resulting in response bias. Therefore, the result of the present study might not be able to apply generally. Finally, self-response bias might appear in the present study. The PSQI questionnaire utilized to assess sleep quality is a self-rated questionnaire. The global PSQI score is calculated only based on the response from the participant. Even though the calculation model usually counts component scores based on a range of the answer to be more general, the inaccuracy of responses still could affect the global PSQI score, thus further affecting the conclusions.

For future study, the relationship between age, sleep quality, and short-term memory function could be studied by increasing the age range of the sample. Researchers could also have several groups of different ages and make comparisons between them. In addition, despite the fact that no relationship between sleep quality and VSTM were found, there might be relationship between sleep quality and other kinds of short-term memory. Thus, those relationships could be studied due to interest by including various kinds of short-term memory tests, such as auditory word recall tasks. Finally, understanding the relationship between sleep quality and short-term memory function might shed light on future treatment for mental diseases. As mentioned in the introduction section, some mental diseases have symptoms of sleeping disturbances associated with memory disorder. Thus, future studies could explore which factor of sleeping is related to the disease in order to develop clinical treatment.

5 CONCLUSIONS

The present study mainly investigated the relationship between sleep quality and VSTM function among young adults and included analysis of gender effect as well. Three conclusions are reached in the present study. First, there's no association found in this study between sleep quality and VSTM function. Second, sleep quality might not affect VSTM function. Third, gender might not be a factor that influences VSTM function. These results might indicate that further examinations are required to determine the relationship between sleep quality and VSTM. Based on findings from previous studies, future studies could also investigate sleep quality and other kinds of short-term memory, gender effect, and effect of different factors of sleep on short-term memory function to develop clinical treatments for mental diseases. Since sleep and memory are closely related to many mental diseases, results from the present study might suggest new direction in future effective clinical treatment.

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