RUNNING HEAD: SLEEP STAGES AND EXPLICIT KNOWLEDGE GENERATION

Shifting from implicit to explicit knowledge: Replication of Yordanova et al. (2008)

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Author Note

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The outline, research design, and data in this article were generated based on the Yordanova et al. (2008) research results. The sample size was doubled from the Yordanova et al. research to make the expected values in most cells of chi-square analysis greater than 5.

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Abstract

Previous research studies revealed the role of sleep in shifting from implicit to explicit memory. However, the different sleep stages might have different roles in shifting these memories. To test the different roles, I classified participants into early-night sleep, which was rich in slow-wave sleep (SWS) and late-night sleep groups, which was rich in rapid eye movement (REM). The research results revealed that participants had more explicit knowledge after sleeping in early-night compared to late-night. When comparing percentage of sleep stages, people who had explicit memory had REM stage sleep highly significantly less than one who had implicit memory, $F(2, 104) = 8.84$, $p = .000$, but not significantly different in SWS, $F(2, 104) = 0.07$, $p = .93$. The possible explanations of unexpected results were discussed.

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Cognitive and brain sciences research revealed that there were two levels of processing in perception, memory, and action: implicit and explicit processing (Bargh & Chartrand, 1999). Implicit processing referred to unaware or automatic processing and explicit processing referred to aware or intentional processing. There were links between these levels of processing. The role of sleeping in shifting from implicit memory, which people were not aware of its presence, to explicit memory, which people were aware of its presence, was one of the examples of these links. Different stages of sleep played different roles in shifting the types of memory. Wagner, Gais, Haider, Verleger and Born (2004) suggested that slow-wave sleep (SWS) might have a critical role in shifting from implicit to explicit memory, but REM sleep might have a critical role in maintaining implicit memory. This research would test the roles of SWS and REM sleep stages in restructuring memories. The research hypothesis was that REM would maintain the implicit knowledge but the SWS would shift the implicit to explicit knowledge, according to Wagner et al. (2004).

Method

Participants

Participants were 120 healthy undergraduates (51% women and 49% men; 18-28 years old) without any history of sleep disturbances. All participants received partial course credit and gave informed writing consent prior to the study.

Task

The memory task in this experiment was number reduction task (NRT), as shown in Figure 1. In this task, participants saw the computer screen which showed the sequence of numbers which were only three possible digits: 1, 4, or 9. Participants had to make the new set of seven numbers from the provided sequence. The first answer in the new sequence would use the first two number of the provided sequence. The second to seventh answers would use the previous answer, which were the first to sixth answers, respectively, and the next number of the provided sequence that had not used in determining the previous answers, such as the third number for determining the second answer. Participants had to answer until reaching the seventh answer. The answers which participants had to press on the keyboard of computer were based on two rules: identity and difference rules. When the two numbers were the same, such as 1 and 1, the identity rule was used; participants had to answer the same number, which is 1. However, when the two numbers were different, such as 1 and 4, the difference rule was used; participants had to answer the rest of possible numbers, such as 9 in this example. After answering the seventh answer of the set, the new set would appear on the computer screen. Also, researchers asked participants to respond as quickly as possible and the reaction times in each respond after appearance of the question were measured.

All sets of answers were generated in the underlying common regularity. The fifth, sixth, and seventh answers in each set were the same as the fourth, third, and second answers. In other words, there was a mirror structure of answers for each sequence. The last three responses mirrored the preceding three responses. If participants had already known the regularity of this task either implicitly or explicitly, the response time of last three answers would decrease from the response time of the previous four answers.

Procedure

The experimental design was illustrated in Figure 2. Participants were equally randomly classified in two groups: early- and late-night sleep. Participants in the early-night sleep group would practice the NRT before sleeping. After sleeping for three hours, which was rich in SWS stage, researchers woke the participants up and asked them to redo the NRT again. Participants in the late-night sleep group would sleep for three hours. After that, participants were waken up and practiced the NRT. Next, they slept for additional three hours, which was rich in REM stage. After that, participants were woken up again and retested the NRT.

In practicing periods, participants in both groups practiced in 90 sets of questions, which were classified in three blocks. After practicing, participants answered a questionnaire that asked whether they noticed hidden task structures. Next, based on the reaction time of NRT and the answer from questionnaire, participants were classified in three categories: no knowledge (NoK), implicit knowledge (ImK), and explicit knowledge (ExK). In dividing between the NoK and others groups, I used the sixth and seventh responses from answer sets compared to the third and fourth responses. I classified participants in the NoK group if the sixth and seventh reaction times were not highly significantly greater than the second and third time, or $p > .01$. The reason why I did not use the second and fifth reaction times was that these positions were transition phases which made high variability in participants' reaction times. Besides, participants were classified as ExK if they answered that they were aware of the regularity in the sequential task. The participants who classified as ExK were excluded from data analysis because I could not study the shifting memory phenomenon. Thus, only participants in NoK and ImK groups were used in data analysis.

In sleeping periods between practicing and retesting, both early- and late-night groups of participants were recorded their sleeping stages by electroencephalogram (EEG) and electro-oculogram (EOG). Sleeping periods were classified as waking, stage 1, stage 2, SWS (stage 3 and stage 4), and REM. These periods were recorded as percentage of time that could be classified as each stage of sleeping. Only percentages of SWS and REM in sleeping period were used in data analysis.

In retesting period, participants in both groups answered 300 sets of sequences, which were divided into ten blocks. After the retesting period, participants answered the same questionnaire as the practicing period and classified into three groups: NoK, ImK, and ExK. In sum, there are five variables involved in this experiment: sleeping conditions (early- or late-night sleep), practicing knowledge (NoK or ImK), retesting knowledge (NoK, ImK, or ExK), and percentages of SWS and REM period in sleep duration.

Result

In this analysis, ten participants, two from the early-night group and eight from the late-night group, were excluded from the analysis because they showed the explicit memory on NRT in practicing period. Therefore, there were 58 and 52 participants in the early- and late-night groups, respectively. Next, I divided the data analysis into two major sections. First, I provided the manipulation check section to see whether there were desired conditions, before the retesting phase. Second, I provided the main analysis that showed the effect of different sleeping stages in shifting memories. All SPSS outputs were shown in Appendix.

Manipulation check

In this section, I would show whether the research design in this experiment was on the right way. First, early- and late-night groups revealed the different sleeping patterns. The SWS percentage in early-night sleeping (M = 24.04, SD = 12.41) was highly significantly greater than the percentage in late-night sleeping (M = 11.60, SD = 10.46), $t(108) = 5.66$, $p = .000$. Also, the REM percentage in early-night sleeping (M = 6.56, SD = 4.87) was highly significantly less than the percentage in late-night sleeping (M = 21.51, SD = 7.16), $t(108) = -12.66$, $p = .000$. Secondly, I found that the percentages of SWS and REM in sleeping period were highly significantly negative correlated, $r(108) = -.36$, $p = .000$. Finally, as shown in the last column of Table 1, the knowledge results in the practicing period of both early- and late-night groups were not significantly different from each other, $\chi^2(1, N = 110) = 0.29$, $p = .59$.

Main Analysis

In research hypothesis, I expected that the REM would maintain the implicit knowledge but the SWS would shift the implicit to explicit knowledge. From this hypothesis, I hypothesized the research results in two directions.

First, I hypothesized that if participants had acquired the implicit knowledge already before sleep, the different phases of sleep would show different patterns of knowledge in the retesting period. The participants in the early-night group would show more percentage of participants who acquired explicit knowledge than the participants in late-night group. However, if participants had not received the implicit knowledge before sleeping, the participants in both groups would not differ in percentages of participants in any types of memory in retesting period. This research hypothesis showed the three-way interaction of practicing knowledge, sleeping periods, and retesting knowledge. In testing the three-way interaction, I divided participants to two groups based on practicing knowledge, which were NoK and ImK, and analyzed the two-way interactions of sleeping periods and retesting knowledge in both groups by chi-square statistic.[1] The frequencies of each group were shown in Table 1. In the NoK group of practicing knowledge, which showed in the first layer of Table 1, the sleeping periods were not significantly associated with the retesting knowledge, $\chi^2(2, N = 110) = 3.77$, $p = .15$. However, in the ImK group of practicing knowledge, which showed in the second layer of Table 1, there was the highly significantly association between sleeping periods and retesting knowledge, $\chi^2(2, N = 110) = 12.31$, $p = .002$.[2] The participants in early-night groups showed higher percentage of participants who acquired ExK and lower percentage of participants who acquired ImK than the participants in late-night groups.

Second, I wondered whether the SWS, REM, or both caused the shifting from ImK to ExK. From the research hypothesis, I expected that, in both NoK or ImK groups in the practicing period, participants in the ExK group had an average of percentage of SWS in sleeping period more than participants from the other groups. Also, the participants in the ImK group had an average of percentage of REM in their sleep periods more than the participants from the other groups. Therefore, ignoring the sleeping groups, I designed practicing knowledge (NoK or ImK) x retesting knowledge (NoK, ImK, or ExK) factorial ANOVA with the percentages of SWS and REM in the sleeping period as dependent variables.[3] The averages and standard deviations of each cell and marginal in percentages of SWS and REM during the sleep period showed in Table 2, and were illustrated in Figure 3 and 4, respectively. In the percentage of SWS, there was not a significant interaction from both factors, $F(2, 104) = 0.06$, $p = 0.94$, not a significant main effect of practicing knowledge, $F(1, 104) = 0.06$, $p = .80$, and not a significant main effect of retesting knowledge, $F(2, 104) = 0.07$, $p = .93$. In the percentage of REM, there were not a significant interaction of both factors, $F(2, 104) = 0.37$, $p = 0.69$, as well as not a significant main effect of the practicing knowledge, $F(1, 104) = 1.34$, $p = .25$. However, there was a highly significantly main effect of the retesting knowledge, $F(2, 104) = 8.84$, $p = .000$. Tukey HSD post-hoc comparisons revealed that ImK and ExK groups were highly significantly different ($p = .000$), that ExK and ImK groups were marginally different ($p = .065$), and that ImK and NoK groups were marginally different ($p = .096$).

Discussion

The previous research studies have suggested that SWS sleep related to shifting from implicit memory to explicit memory and REM sleep related to maintain implicit memory. Supporting the research hypothesis, early-night sleep, which was rich in SWS, made participants, who already had implicit memory before sleeping, aware of their memory. The late-night sleep made participants maintain their implicit memory. However, when comparing percentage of SWS and REM during sleep, we found that the result was inconsistent with the research hypothesis. People who had explicit memory did not have SWS less than people who had implicit memory or people who did not have any memory. However, people who had explicit memory have REM less than people in other groups.

These research results suggested that, although SWS did not have any role in shifting from implicit memory to explicit memory, people really shifted from implicit memory to explicit memory in early-night sleep. There are two possible explanations for this finding. First, REM might have a critical role in blocking shifting from implicit to explicit memory. In early night sleep, people would sleep in relatively less REM period. Thus, their memory would shift from implicit to explicit, because of lack of blocking. Another possible explanation was that people might have different strategies in organizing their memory between practicing periods between both groups. In early-night sleep, people did not sleep before practicing the NRT, but people in late-night sleep had slept for three hours before practicing the task. This difference might affect the dependent variables.

The limitations of this research were confounding variables and dichotomizing variables. First of all, although the early- and late-night sleep were used for manipulating SWS and REM sleep stages, there were some confounding variables that made the dependent variables differences, which were not attributed to difference in SWS and REM sleep stages, such as time of practicing and retesting periods. Second, the implicit memory were grouped by statistical difference between means of answer 6 combined with 7 and answer 3 combined with 4 in all sets of sequences. In spite of clarity, the dichotomization destroyed the details of information. For example, the degrees of strength of implicit memory were destroyed into a group of participants who had implicit memory.

For suggestion, the statistical analyses those were appropriate for continuous independent variables, such as regression or logistic regression, might be used for avoiding dichotomization of independent variables. Furthermore, the clearer manipulation of SWS and REM, such as waking participants up when presenting REM sleep in the SWS group or consuming alcohol to reduce SWS in the REM group, might be appropriate to detect the causal relationship of sleep stages and memory shift. Finally, in future research, the role of implicit memory strength and explicit knowledge should be clarified more. In previous research, researchers dichotomized the implicit knowledge, although the implicit knowledge varied in their strength. Therefore, researchers might find that the strength of implicit knowledge had critical role in shifting to explicit knowledge.

Reference

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Wagner, U., Gais, S., Haider, H., Verleger, R., & Born, J. (2004). Sleep inspires insight. *Nature, 427*, 352-355.

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Table 1

The cross-tabulations of sleeping conditions, practicing phase knowledge, and retesting phase knowledge from 110 participants.

Practicing Phase knowledge	Sleeping Condition	Retesting Phase Knowledge			
		NoK	ImK	ExK	Total
NoK	Early-night	18	8	6	32
	Late-night	8	10	8	26
	Total	26	18	14	58
ImK	Early-night	4	10	12	26
	Late-night	2	22	2	26
	Total	6	32	14	52

Note. NoK = No Knowledge; ImK = Implicit Knowledge; ExK = Explicit Knowledge.

Table 2

The 2 practicing phases x 3 retesting phase conditions' descriptive statistics of the percentages of slow-wave sleep (SWS) and rapid eye movement (REM) sleep during sleeping period between practicing and retesting phase.

Practicing Phase Knowledge	Retesting Phase Knowledge	*N*	% of SWS sleep		% of REM sleep	
			M	*SD*	*M*	*SD*
NoK	NoK	26	18.46	13.11	13.04	10.74
	ImK	18	18.53	14.12	17.27	9.01
	ExK	14	17.15	11.32	7.81	5.83
	Total	58	17.72	13.56	12.11	9.01
ImK	NoK	6	18.46	13.11	13.04	10.74
	ImK	32	18.53	14.12	17.27	9.01
	ExK	14	17.15	11.32	7.81	5.83
	Total	52	18.65	12.60	15.33	10.08
Total	NoK	32	18.46	13.11	13.04	10.74
	ImK	50	18.53	14.12	17.27	9.01
	ExK	28	17.15	11.32	7.81	5.83
	Total	110	18.16	13.06	13.63	9.62

Note. NoK = No Knowledge; ImK = Implicit Knowledge; ExK = Explicit Knowledge.

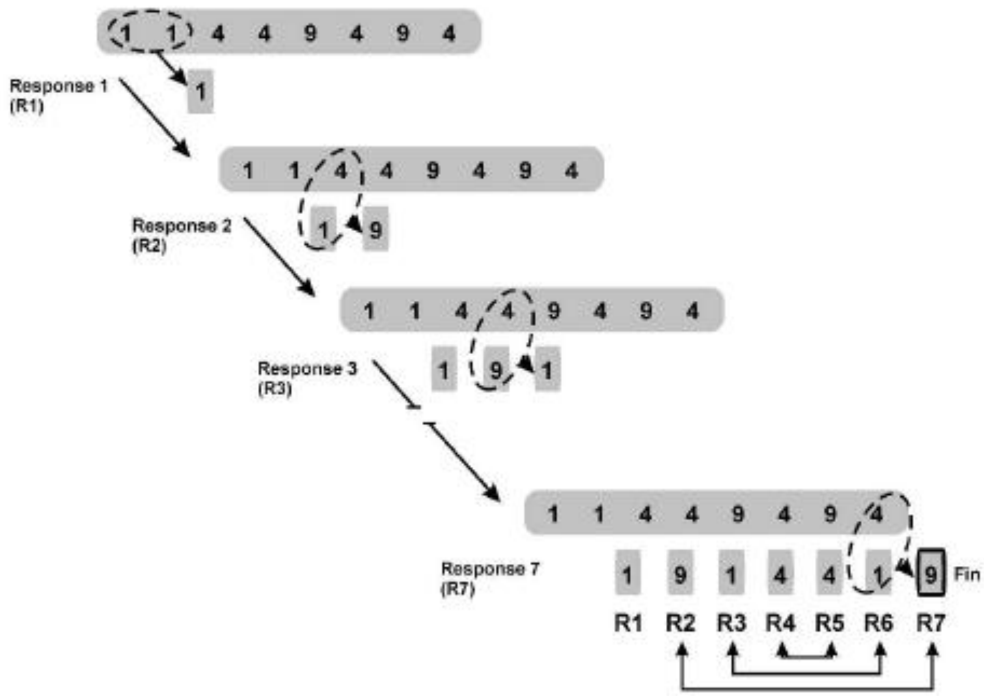

Figure 1. The number reduction task (NRT) procedures were illustrated by an example trial. Participants were seen a sequence of numbers (with only three possible digits: 1, 4, and 9) and had to make the new sequence, which contained seven numbers, paralleled to sequence shown. The answers were based on two rules: identity and difference rule. The identity rule was used when participants saw the two same numbers, such as the response 1 shown above; participants had to press the same number from the questions in the sequence, which was 1 in the response 1. However, the difference rule was used when participants saw the two different numbers, such as response 3 shown above; participants had to press the digit to make three numbers fulfilling 1, 4, or 9, which was 1 in the response 3. The hidden regularity is that the responses of answers 5, 6, and 7 were as same as the responses of answers 4, 3, and 2, respectively. Source: Yordanova et al. (2008)

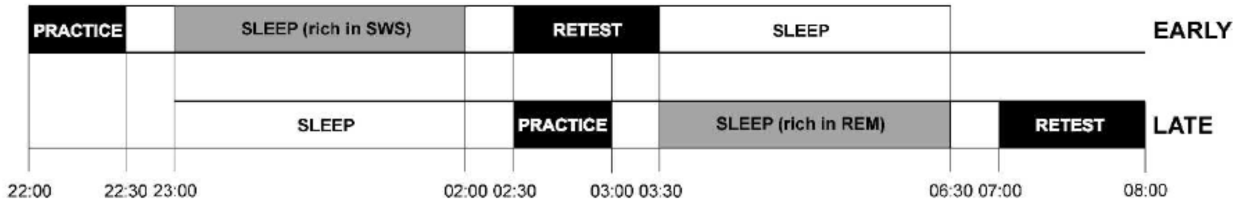

Figure 2. Participants were classified into two groups: early- and late-night groups. The participants in early-night group would practice the number reduction task (NRT) before sleeping for three hours. After sleeping, they were woken up and did the NRT again, as retesting period. However, participants in late-night group would sleep for three hours before being woken up for practicing. After practicing NRT, they slept for another three hours. Next, they were woken up again and retested the NRT.

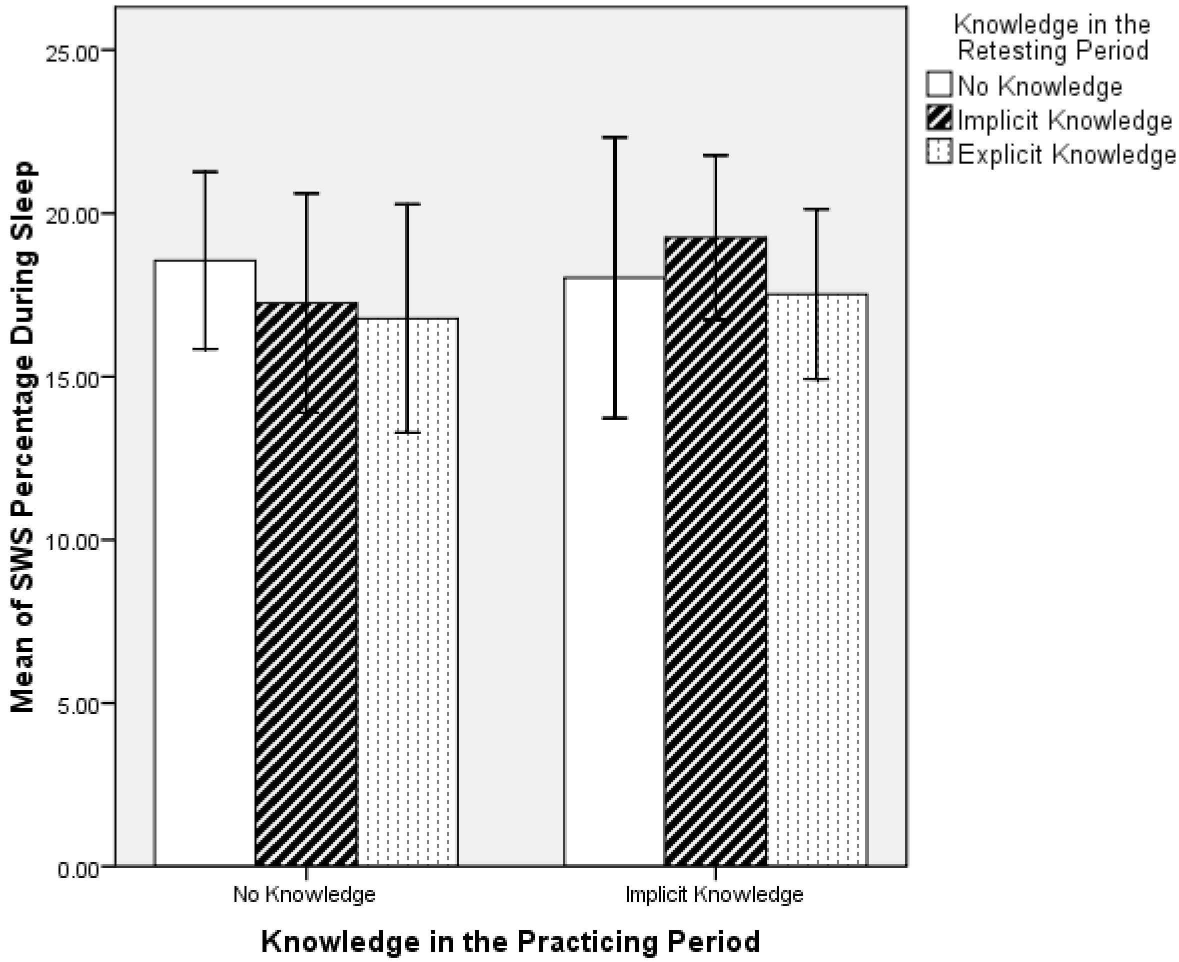

Figure 3. The bar graph showed the average of slow-wave sleep (SWS) during sleep period in each group of knowledge in the practicing period and knowledge in the retesting period. The line in each bar showed the standard error of group mean.

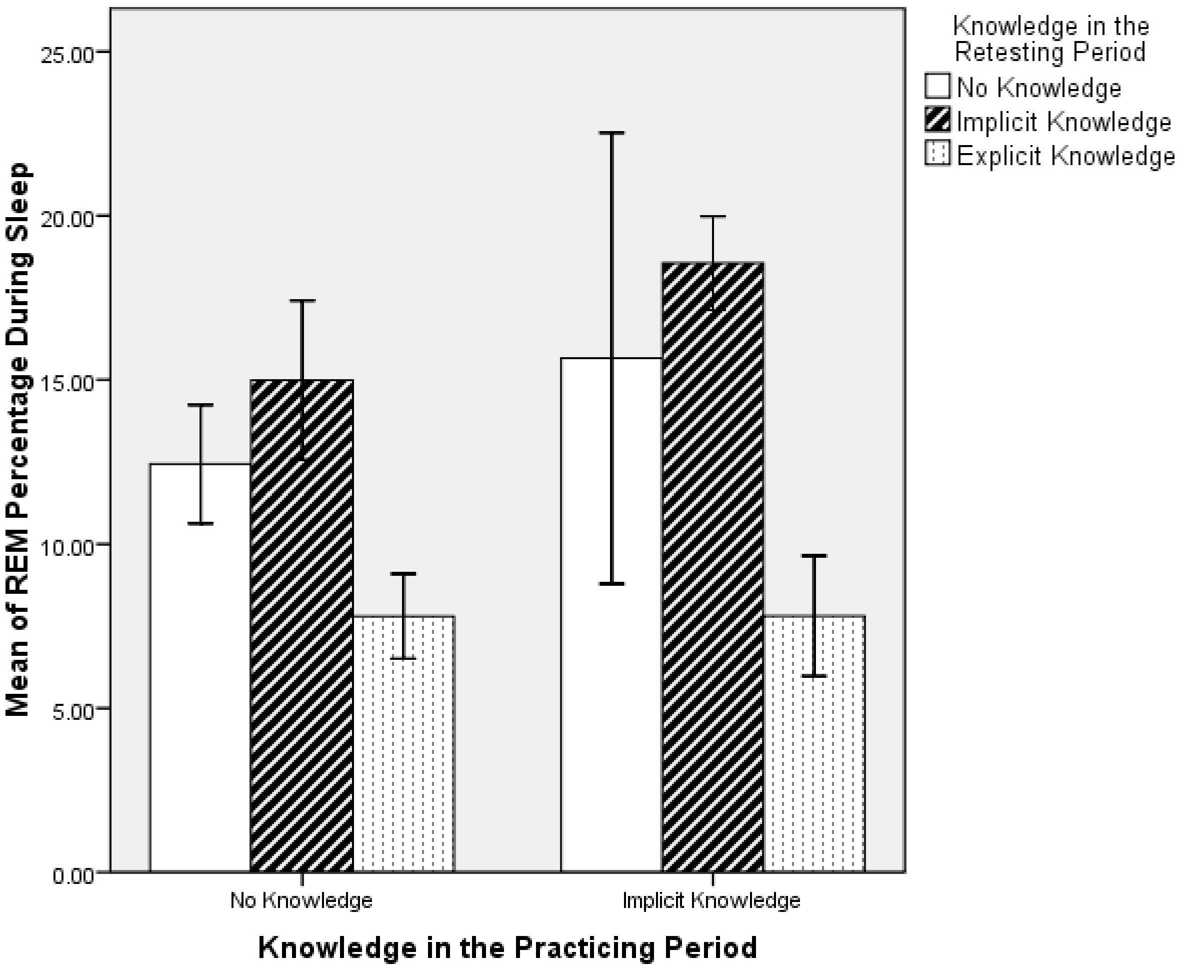

Figure 4. The bar graph showed the average of rapid eye movement (REM) period during sleep period in each group of knowledge in the practicing period and knowledge in the retesting period. The line in each bar showed the standard error of group mean.

Footnotes

1. In fact, the log-linear model revealed the three-way interaction of these three factors, $\chi^2(2, N = 110) = 6.42$, $p = .040$.

2. This significant value might be biased because the expected values of two out of six cells were less than 5.

3. I decided that I would not use the three-way factorial ANOVA that included the factor of sleeping conditions because the number of participants of some cells would be only two. These few numbers of participants caused the imprecise parameter estimation of cell means