Dream Drill: A Bedtime Learning Application

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Abstract. There is considerable evidence that sleep supports memory consolidation. Items studied before going to sleep are memorized more efficiently than on other occasions. Consequently, we propose a learning application based on these findings. The system includes an alarm clock, which alarm is set only if a user answers a few questions. We implement a prototype and conduct a field test to evaluate the effectiveness of the system.

Keywords: Memory consolidation, CAI, sleep, learning application, smartphone application.

1 Introduction

Since David Hartley proposed in 1971 that memory consolidation is enhanced by dreaming [1], many studies have been conducted on the relationship between sleep and memory. In recent years, the importance of sleep in memory reactivation has been borne out by neuro-scientific and cognitive-scientific research [2].

Memory is generally classified into sensory memory, short-term memory, and long-term memory [3]. Sensory memory stores sound and image information. The duration of short-term memory is in the order of seconds. In contrast, information can retain in long-term memory until one's death, barring impairment of the brain's function. Long-term memory is classified into declarative and non-declarative memory. The former contains facts and knowledge that we can consciously recall, and the latter contains unconscious skills, procedures, and techniques that we have learned. It is well-known that both declarative and non-declarative memories are consolidated by sleep [2].

Research shows that sleep consolidates declarative memory, but no systems have yet utilized this finding to help with everyday life. Setting an alarm before going to sleep is one of the routines of our daily lives. To utilize this for effective learning, we make a ubiquitous learning system, Dream Drill. The alarm clock application designed for Dream Drill provides a learning opportunity when a user sets the alarm at night and turns it off in the morning. To test the effectiveness of our application, we have conducted preliminary English-language word

P. Zaphiris and A. Ioannou (Eds.): LCT 2014, Part II, LNCS 8524, pp. 138–145, 2014.

Fig. 1. Dream Drill usage scenario

memorization experiments on several Japanese participants [4]. In this paper, we carry out more precise experiment with larger number of subjects in longer period of days. We also present results of learning effect data from a wide variety of users, gathered by making our learning application public through Google Play[1]. These results indicate that learning before bedtime is more effective than at any other time of the day, and also show that our learning system successfully encourages the consolidation of memory.

2 Related Work

Some alarm clocks are employed not only to wake the user up but also to help him/her learn. The TWIST Desktop Digital Alarm Clock [5] displays a formula on the LCD when its alarm sounds. To stop the alarm, the user has to complete the formula by twisting the wheel on the clock. This technique is based on the idea that forcing a user to use his/her brain and body will help him/her wake up easily. However, this technique does not employ sleep effects to promote memory consolidation. This device does not provide any systematic way to make users practice memory enhancement before sleeping.

Various devices and applications have been developed for learning support. For example, MicroMandarin [6] is a location-based application program for language learners whose first language is not Chinese. It provides Chinese word quizzes that correspond to the location of users. However, such devices and applications do not provide any systematic way of making users exercise their memory before sleeping. In this paper, in order to effectively promote memory consolidation by sleep, we propose Dream Drill, a ubiquitous learning system that uses the time before sleep for this purpose.

3 Design of Dream Drill

Dream Drill is a system that supports daily learning before sleep for people whose first language is not English. We used smart-phones as mobile terminals

[1] A smart-phone (Android) applications and contents distribution service by Google.

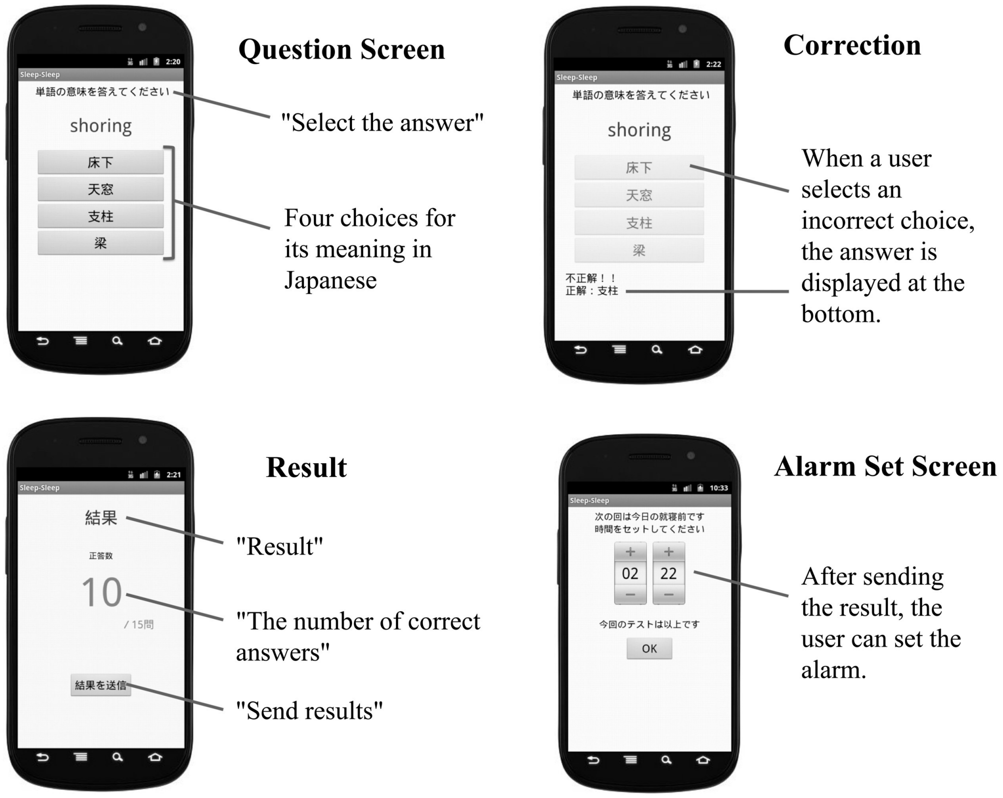

Fig. 2. Question, correction, result and alarm set screens

and built the server using the Google App Engine. The system includes an alarm clock function and the opportunity to perform language exercises before and after sleep. Figure 1 shows the typical scenario for the use of the system. It offers English language word quizzes to users before they set alarms and after they turn them off. We chose an English word quiz, because a lot people want to learn English and memorize English words. The screenshots of the quiz on a smart-phone are shown in Figure 2. The system displays one English word and four options for its meaning in Japanese. Users select one of these words as answer. The system displays ”correct” in response to a correct answer and ”incorrect” in response to an incorrect one, along with the correct answer to the question. At the end of a turn, the system shows the number of correct answers. Users are able to set the alarm after the completion of the quiz.

On the server side, the database of the system stores information for each user, such as his or her name, a list of question words, correct response rate, the choices, the time taken to answer, and the date and time of each turn (Figure 3). At the beginning of each turn, mobile terminals fetch the words from the server. At the conclusion of each turn, the mobile terminals send data to the server. The server selects words at random for each user in the first version. In the later version, word-sets are selected according to the user's language skill as selected in the setup menu.

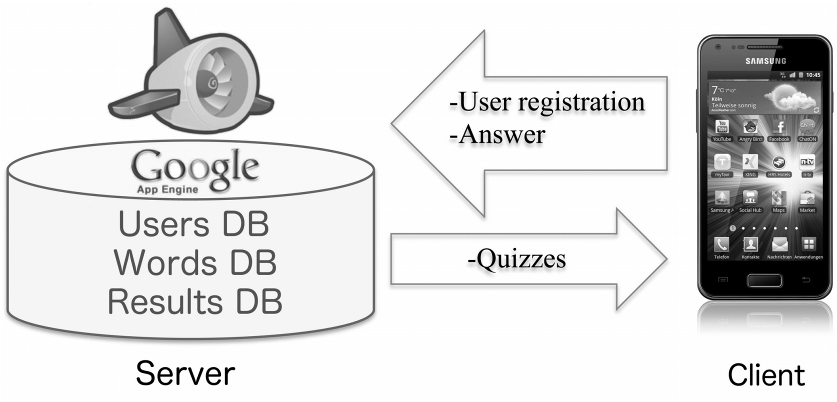

Fig. 3. Server and client configuration

4 Experimentation

Using the system described above, we performed a weeklong experiment with 10 participants to explore an effective way to learn before sleep. We selected difficult English words that were new to all participants. The participants learned the words simply by answering the questions asked by the system. We asked the participants to take these tests three times a day – upon waking up, in the daytime, and before bedtime – and compared the results. We know that a few trials in the experimental log can be noise, such as taking the quiz before a short nap instead of prior to going to sleep for the night, or waking up and taking the quiz only to fall back to sleep, or taking the quiz at an unscheduled time. We consider such data to be noise and remove it manually by referring to our survey questionnaire, which was filled out by each participant.

Table 1 is the trial schedule of the experiment and shows when a subject challenges each word group. The first column represents the name of the word group, the first row represents the days of the experiment while the second row records the time of the experiment (morning, afternoon, and evening). Each word group contains five words and is posed to the users at the scheduled time marked by a capital letter, as shown in Table 1. The letter 'O' (for once) shows a learning trial that poses a questions only once, while 'R' (for repeat) shows a learning trial that will be repeated until the user correctly answers each question two times. 'T' (for test) indicates the final test to measure the effectiveness in each word group. At the beginning of each trial, a questionnaire screen is shown to survey the condition of sleep, such as time elapsed between learning and bedtime, whether the user takes a nap after the last trial, etc. Although not shown in Table 1, this experiment also has dummy word groups to adjust the amount of learning.

Table 2 shows the results of measurement effectiveness. The numbers show normalized scores of the final tests (out of 100). EMD (Evening Morning Double), AED (Afternoon MD), and MAD are the word groups with four trials. EMS

Table 1. Trial schedule for the word groups

	Day1			Day2			Day3			Day4			Day5			Day6			Day7		
	M	A	E	M	A	E	M	A	E	M	A	E	M	A	E	M	A	E	M	A	E
EMD									O	O		O	O					T			
AED											O	O		O	O					T	
MAD							O	O		O	O					T					
EMS															O	O					T
AES														O	O					T	
MAS													O	O					T		
EMR			R	R					T												
AER					R	R					T										
MAR	R	R					T														

Table 2. Average score of effect measurements (out of 100)

EMD	AED	MAD	EMS	AES	MAS	EMR	AER	MAR
89	73	80	73	65	70	87	78	85

(EM Single), AES, and MAS are groups with two trials. EMR (EM Repeat), AER, and MAR are word groups that are repeated until the user successfully answers correctly. In all categories, evening-morning pairs (EMD, EMS, and EMR) recorded the highest scores. Therefore, we concluded that learning before going to bed and upon waking up leads to higher learning effects than at any other time.

5 Field Test

5.1 Method

We released our learning application on Google Play and gathered learning effect data from a wide variety of users. We also offered three courses with different levels of difficulty so that users with varying English language skills could be involved. Users in each skill level can learn 100 English words using our application. During the two-month field test period, 45 Android users downloaded our program, and attempted our 10-word-quiz 170 times.

The program advises users to answer the quiz regularly in the morning, during the day and in the evening. We recommended that learning activities be evenly spread out during the day, i.e., a quiz be taken every eight hours. We also recommended that users take the evening quiz just before bedtime.

In the release version of our application, the quiz schedule has been designed to be much simpler than in the experimental version in order to obtain more useful data. The simplification is also intended to make our application more user-friendly, since we realize that the average Internet user is likely to be less

Table 3. Scheduling word groups (A, B, C,...)

Time	Day1/A	Day1/E	Day2/M	Day2/A	Day2/E	Day3/M	...
Word groups	A & B	B & C	C & D	D & E	E & F	F & G	...

patient than our volunteer subjects. While we tried to evaluate effects in multiple learning trials in the previous experiment, we designed the quiz schedule in the release version to evaluate effects using a single session. Each English word is sequentially presented twice. That is, if a user takes the test regularly, each word is posed in evening-and-morning, morning-and-afternoon, or afternoon-and-evening sessions. The regular quiz schedule is shown in Table 3. Each word group – A, B, C, D, E, F and G – consists of five words, and users try two word groups (10 words) in each quiz. There are 20 word groups for each of the three skill levels, so that each skill level contains 100 words. As shown in Table 3, 10 English words are presented to the user, half of which are new and the other half are words from previous quizzes. The word group A is a dummy group and not used in later analyses. In case a user has missed a quiz, the relevant score is excluded from the analysis.

5.2 Analysis

The words presented to each user can be categorized into the following two groups:

- words of which the user remembers the meaning even before starting the first quiz, and always answers 100% correctly
- words of which the user does not remember the meaning perfectly, and answers with an accuracy of less than 100%

Let X be the number of words in the second group – the words that the user needs to learn and does not answer perfectly in the quiz. Note that even if the user does not know these words, he/she can select the correct answer in 25% of all cases. This is because each question on the quiz offers four options to choose from, and thus, the probability that the user gets the correct answer is 0.25, even when he/she is completely ignorant of the meaning of the word at hand. Given that the total number of the words is N, the number of words that the user remembers 100% correctly even before starting the first quiz is $(N - X)$. We claim that the learning effect of a quiz trial can be measured by the improvement of the rate at which words belonging to the second group above are answered correctly. In the following analysis, we try to calculate the improvement of the rate using the number of correctly and incorrectly answered words.

Firstly, we calculate the number of correctly and incorrectly answered words in the first quiz as shown, respectively, in Formulas 1 and 2 below. Here, we assume that perfectly memorized $(N - X)$ words can be answered correctly, and that inaccurately memorized X words are answered correctly with percentage of α. Formulas 1 and 2 describe the user's initial knowledge of the words in the quiz.

$$C = (N - X) + \alpha X \tag{1}$$

$$I = (1 - \alpha)X \tag{2}$$

Secondly, we calculate the number of correctly and incorrectly answered words in the second quiz. We also assume that inaccurately memorized words, from the second group above, are answered correctly with percentage of β in the second trial. We categorized the words used in the quiz as follows:

- $\boldsymbol{CC}$ words that are correctly and correctly answered
- $\boldsymbol{CI}$ words that are correctly and incorrectly answered
- $\boldsymbol{IC}$ words that are incorrectly and correctly answered
- $\boldsymbol{II}$ words that are incorrectly and incorrectly answered

The two letters in each category refer to the user's performance, respectively, in the first and second quiz. The respective numbers of words in each category is represented by formulas 3, 4, 5 and 6.

$$\boldsymbol{CC} = (N - X) + \alpha\beta X \tag{3}$$

$$\boldsymbol{CI} = \alpha(1 - \beta)X \tag{4}$$

$$\boldsymbol{IC} = (1 - \alpha)\beta X \tag{5}$$

$$\boldsymbol{II} = (1 - \alpha)(1 - \beta)X \tag{6}$$

Using Formulas 4 and 6, the rate α of correct answers in the first quiz trial is calculated as shown in Formula 7:

$$\alpha = \frac{\boldsymbol{CI}}{\boldsymbol{CI} + \boldsymbol{II}} \tag{7}$$

Similarly, using Formulas 5 and 6, the rate β of correct answers in the second quiz trial is calculated as shown in Formula 8:

$$\beta = \frac{\boldsymbol{IC}}{\boldsymbol{IC} + \boldsymbol{II}} \tag{8}$$

Additionally, using α, β, and Formula 3, X is calculated as follows.

$$X = \frac{N - \boldsymbol{CC}}{1 - \alpha\beta} \tag{9}$$

Table 4 shows the results of the field test. The rows labeled by "Evening-Morning", "Morning-Afternoon" and "Afternoon-Evening" represent,

Table 4. Word-learning effect. α and β denote rates (%) of correct answer for uncertain words in the first and second trials. The learning effect is calculated by $\beta - \alpha$.

Timing	$\boldsymbol{CC}$	$\boldsymbol{CI}$	$\boldsymbol{IC}$	$\boldsymbol{II}$	$N(words)$	$X(words)$	α(%)	β(%)	**Effect(%)**
Evening-Morning	58	11	38	23	130	90.2	32	62	**30**
Morning-Afternoon	43	13	25	24	105	75.5	35	51	**16**
Afternoon-Evening	55	20	33	17	125	109	54	66	**12**

respectively, records in the quiz trials of the times before going to bed and after-waking-up, after waking up and daytime, and daytime and before bedtime. The columns labeled $\boldsymbol{CC}$, $\boldsymbol{CI}$, $\boldsymbol{IC}$ and $\boldsymbol{II}$ represent the total number of words answered correctly and incorrectly in the first and second quiz trial, as explained above. The column labeled N represents the total number of words use in the trial. The columns labeled X, α, and β represent, respectively, the number of uncertainly remembered words and the rate (%) of correct answers, calculated formulas 9, 7, and 8. The last column shows the learning effect of the first quiz trial: that is, the improvement in the percentage for answering uncertainly memorized words. These are calculated by $(\beta - \alpha)$. By calculating the difference of the percentages, we can accurately evaluate the learning effect by canceling factors arising out of the difficulty of the quiz and questions correctly answered by chance. The results in Table 4 show that using our application before bedtime is two times more effective for learning than using it in the morning or during the day.

6 Conclusion

We proposed a smart-phone application based on findings that sleep supports memory consolidation. From the results of the experiment and the field test, we found that learning before bedtime is the most effective in memory consolidation. This result indicates the usefulness of our alarm clock design, which provides an opportunity to learn while setting the alarm just before going to sleep. We will continue to improve the functionality and user-interface design of our application to innovate more practical computing devices that support everyday learning activities.

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