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Napping after complex motor learning enhances juggling performance

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A B S T R A C T

The present study examined whether a nap after complex motor learning enhanced the following day's physical performance. Eighteen volunteers met the inclusion criteria and were assigned to either a nap (n=9; men=5; mean age=21.0 ± 1.5) or no-nap group (n=9; men=5; mean age=21.9 ± 0.3). Participants practiced juggling in the morning and were tested immediately afterwards. Participants of the nap group were given a 70-minute nap opportunity after juggling practice, while the no-nap group stayed awake. Juggling performance was then tested in the evening (retest-1) and the next morning (retest-2). Two-way analysis of variance (group: nap, no-nap × time: test, retest-1, retest-2) found there was a significant effect of test time and a significant group × time interaction. The juggling performance of both groups improved from test to retest-1, respectively. However, the juggling performance level of the nap group was higher than that of the no-nap group at the retest-1. As predicted, a nap promptly after learning motor skills was associated with subsequently improved performance. Moreover, the juggling performance of the nap group showed additional significant improvements in the retest-2. In the no-nap group, however, there were no significant improvements in the juggling performance after nocturnal sleep. These results demonstrate that the benefits of a nap following learning were further enhanced after nocturnal sleep. The present results may provide justification for introducing nap periods into daily athletic training as an active method to improve performance.

1. Introduction

Sleep after learning has reportedly contributed to enhancing the consolidation of various memories in the two main memory systems, declarative and procedural memory [1–7]. This beneficial effect is expected to contribute to the improvement of skill-related performance, because the process of skill learning is related to procedural memory. A previous study has reported that the performance of sequential finger tapping improved when sleeping occurred after skill learning. Subsequent motor speed increased without a loss of accuracy [7]. Some additional findings about the details of this sleep-dependent learning have been demonstrated using the same task. The performance improvement occur not only after nocturnal sleep, but also after a daytime nap [8,9]. The effect of sleep-dependence in the complex sequence task was greater than that in the easy sequence task [10]. Recent reports indicate that the performance of whole body movements, that are closest to a real sports performance, similarly improve after sleep [11,12]. The number of catches while three-ball juggling increased after a 2-hour nap.

Consequently, the effects of modest sleep intervention are expected to improve motor learning and sports training of athletes. However, it is still unknown if the benefits seen after a nap endures or further enhances the following day's performance after a full night's sleep. Regardless of whether napping after motor learning benefits performance, if the following day's performance does not maintain the improvement, there would be little practical benefit in napping if only a brief performance improvement is gained. The purpose of the present study is to determine if the benefits obtained by a nap after motor learning is further enhanced on the following day. We hypothesized that the following day's physical performance for those who took a nap after motor learning would be better on the following day than the performance of participants who did not nap.

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2. Methods

2.1. Subjects

The present study was approved by the ethics committee of the Waseda University. It was reviewed and carried out according to the Helsinki Declaration. Subjects with the following characteristics were included in the study: (1) 20–30 years old, (2) university or graduate students of the sport sciences, (3) three-ball cascade novices, and (4) ability to maintain a regular sleep-wake schedule (bedtime during 22:00–1:00 and rise time during 6:00–9:00). We excluded those who were: (1) smokers; (2) with a history of neurological, psychiatric or sleep disorders; (3) used hypnotics, psychotropic, or other medications; or (4) had exercise limitations as prescribed by their by medical doctor. Eighteen volunteers met the above inclusion criteria and were assigned to either the nap ($n=9$, men$=5$, mean age$=21.0\pm1.5$) or no-nap group ($n=9$, men$=5$, mean age$=21.9\pm0.3$).

2.2. Procedures

All subjects confirmed that they had abstained from caffeine, alcohol, and naps for 24 h before the start of the study. Subjects kept to their accustomed daily schedules, as indicated by entries in a sleep diary, which were confirmed by wearing a motion logging Actiwatch (model-AWL, Mini Mitter Co., Inc.) for a week prior to the experimental day. Subjects in the nap group came to the laboratory individually and attempted to nap for approximately 70 min (to allow an anticipated 60 min of sleep after 10 min to fall asleep) beginning at 14:00, in order to become familiar with the sleep environment before the experimental day (adaptation). One week after the adaptation visit, each subject's experimental day began at our laboratory at 10:00 (Fig. 1). The subject watched the instructional DVD, then practiced three-ball cascade juggling for 15 min before the practice test session. Testing consisted of five trials lasting for 3 min each, during which subjects continued juggling for as long as possible. All practice and test trials were video recorded. Subsequently, each subject in the nap group took a nap for around 70 min starting at 14:00, whereas the no-nap group subjects remained awake reading books or watching videos on TV. At 17:30, 7 h after the juggling test, each subject's juggling performance was re-evaluated (retest session-1). The next morning, subjects again performed the three-ball cascade at 10:30 (retest session-2).

We used the 70-minute nap protocol in order to increase the likelihood of obtaining NREM sleep, particularly slow wave sleep (SWS), which has been shown to have the greatest relevance for juggling performance improvements in a previous study [12]. To get sufficient SWS, in cases of subjects who require a long time before SWS, the time in bed was, if necessary, extended by up to 10 min. Actigraphic recordings of nocturnal sleep on the nights immediately before and after the experiment were recorded in order to measure sleep quality (sleep onset and offset, total sleep, wake and sleep times as well as sleep efficiency and latency). Actiwatch produces results that are highly correlated with polysomnography [13].

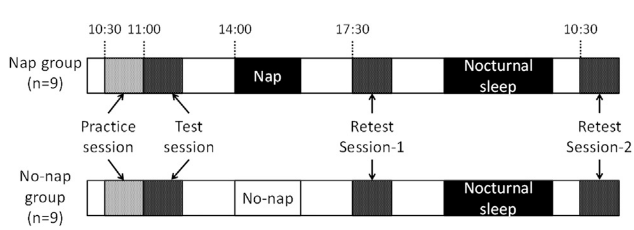

Fig. 1. Experimental design practice session: subjects practiced three-ball cascade juggling after watching an instructional DVD. Test session: juggling performance was evaluated in five 3 min trials, during which subjects continued juggling for as long as possible. After the test session, subjects in the nap group took a 70-minute nap starting at 14:00, while the control subjects stayed awake. Retest-1 session: juggling performance re-tested at 17:30. Retest-2 session: juggling performance re-tested at 10:30 the following morning.

2.3. Measurements

Three-ball cascade juggling was selected because it requires training and engagement of complex motor skill activities that are similar to a real sports performance. Training for juggling was done systematically by having the subjects follow video recorded instructions presented in a commercially prepared training DVD (NARANJA, Inc. JAPAN). The standard for evaluating subjects' practice was the number of ball catches after a subject threw a ball from one hand and caught it with the other. One cycle of juggling consists of a series of three ball throws and catches, which was counted as a three-time catch and explained as follows. The first ball is thrown from the right to the left hand (the first catch), and the second ball from the left to the right hand (the second catch) before the first ball reaches the left hand. Then, the third ball is thrown from the right to the left hand (the third catch), starting before the first ball comes back to the right hand. If the subject fails to catch the third ball, the catch number is recorded as two. We counted the number of catches for each subject in 3-min long trials. The methods for learning the three-ball cascade were defined based on a previous study [12].

Electroencephalograms (EEG) were recorded from 4 scalp sites (Fz, Oz, C_3, C_4, referenced to linked mastoids A2 and A1), which were placed in accordance with the International 10–20 system [14]), recorded using a Polymate recording system (AP1000, TEAC), and filtered with a time constant of 0.3 s. Horizontal and vertical electrooculograms (EOG) were recorded from the outer canthi of both eyes, and from above and below the left eye, with time constants of 0.03 s. The electromyogram (EMG) was recorded from electrodes taped to the skin above the mentalis muscles, using a time constant of 0.03 s. Electrode impedances were initially below 5 kΩ at bedtime, and the sampling rate was 500 Hz for each channel. A high-cut filter of 30 Hz was used for all channels.

Subjective fatigue, concentration, and sleepiness were measured using 100 mm visual analog scales. In the subjective fatigue scale, a 0 score indicated "vigorous," and 100 indicated "tired." In the subjective concentration scale, a 0 score indicated "distracted" and 100 indicated "concentrated." In the sleepiness scale, 0 indicated "alert" and 100 indicated "sleepy."

2.4. Statistical analysis

Juggling performance was quantified as the mean number of successful catches that were made during the five 3 min test trials. Analyses used a two-way analysis of variance (ANOVA) (group: nap, no-nap $\times$ time: test, retest-1, retest-2), with Bonferroni post-hoc testing of significance differences.

Polysomnography was scored using standardized criteria and analyzed using 30 s epochs (Rechtschaffen & Kales, 1968 [15] and the supplements and amendments to these criteria developed by the Sleep Computing Committee of the Japanese Society of Sleep Research [16]). Scored sleep stages were NREM stages 1–4, REM sleep stages, awake, and movement time. SWS consisted of both stage 3 and stage 4 NREM sleep. Total bed time, total sleep time, sleep efficiency, sleep latency, number of awakenings, and durations were calculated for each stage.

Using the Actiware version 5.0 software, the following nocturnal sleep variables were calculated from the Actiwatch data for the nights preceding and following the experimental day: sleep onset, sleep offset, total bed time, wake time, total sleep time,