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## Short Communication

## Re-examining sleep's effect on motor skills: How to access performance on the finger tapping task?

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## ABSTRACT

Here our goal was to determine the magnitude of sleep-related motor skill enhancement. Performance on the finger tapping task (FTT) was evaluated after a 90 min daytime nap ( $n=15$ ) or after quiet wakefulness ( $n=15$ ). By introducing a slight modification in the formula used to calculate the offline gains we were able to refine the estimated magnitude of sleep's effect on motor skills. The raw value of improvement after a nap decreased after this correction (from  $\sim 15\%$  to  $\sim 5\%$ ), but remained significantly higher than the control. These results suggest that sleep does indeed play a role in motor skill consolidation.

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Daily activities such as riding a bike, knitting, typing, playing a musical instrument or playing a sport, collectively known as motor skills, characteristically require repeated practice until they can be performed automatically [1]. Inside the lab, motor skills are probed through a variety of tasks, such as the finger-to-thumb opposition task [2], the serial reaction time task [3] and the finger tapping task [4].

The finger tapping task (FTT) consists of typing a numeric sequence with the non-dominant hand as fast and as accurately as possible. It is commonly used to probe explicitly learnt motor sequences, that is, the subject is aware of the sequence underlying the motor output he is asked to produce [4]. On the other hand, tests like the serial reaction time task

are used to probe implicitly learnt motor sequences since, unbeknown to the participant, there is a hidden structure behind the movements he is required to perform while pushing a collection of buttons in response to a given cue [3].

Performance on the FTT has been shown to improve by 20% after a night of sleep, but not after an equal period of wakefulness [4]. Additionally, the magnitude of improvement was correlated with the amount of time spent in non-rapid eye movement (NREM) sleep stage 2 [4]. According to Nishida and Walker (2007), a similar offline gain on the FTT (approximately 15%) can also be obtained after a 90 min daytime nap. The authors reported not only a positive correlation with time in NREM 2 but also with the spindle density specific to

Abbreviations: NREM, non-rapid eye movement; SWS, Slow Wave Sleep; TST, total sleep time; WASO, wake after sleep onset; MEQ, Morningness–Eveningness Questionnaire; ESS, Epworth Sleepiness Scale; KSS, Karolinska Sleepiness Scale; EEG, electroencephalogram; FTT, finger tapping task; OL, offline improvement

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the learning hemisphere [5]. Similar benefits from sleep were observed when motor skills were probed with related tasks across a large number of studies [2,6,7].

However, a growing number of investigations are starting to paint a different picture [8–13]. Explicitly learnt motor sequences seem to profit from sleep, but not implicitly learnt ones [12]. When explicit motor sequences were further examined, it has been shown that their spatial representation is strengthened by sleep, but not their motoric representation [13]. A particular case of motor sequence learning (probabilistic sequence learning) has been shown to consolidate independently of sleep [8]. While reviewing the literature, Rickard and colleagues noticed 4 aspects of data analysis that could erroneously lead to sleep-dependent enhancement findings: (1) masked learning effects in the averaged data; (2) masked reactive inhibition effects in the averaged data; (3) time-of-day and time-since-sleep confounds; and (4) a gradual build-up of fatigue across training. Next, they designed 2 experiments where these effects were either controlled for or attenuated. Under these circumstances, sleeping did not lead to performance enhancements. Instead, sleep's role was more consistent with protection from forgetting [9]. Later on, these results were reproduced by an independent group and further extended to include the hypothesis that the stabilization elicited by sleep is an active process, rather than a mere protection from interference [11].

Here we aim at improving the estimate of sleep-related skill enhancement by reducing the influence of unrelated sources of variance. In order to address this issue, 30 right-handed subjects (6 males, 3 on each of the two experimental groups) aged 18–30 ( $23.4 \pm 3.8$  years) were invited to take part in this study. They signed an informed consent to voluntarily participate in this experiment, approved by the local ethics committee. Individuals were asked about sleep habits and health status by questionnaires. Exclusionary criteria were smoking, history of mental illness, diagnosed sleep disorders, use of psychotropic medication and experience in playing musical instruments. Subjects were instructed to maintain their habitual sleep schedules throughout the week previous to the experimental day. They were also asked to refrain from caffeine, stimulants and alcohol for 24 h prior to the experiment.

Participants completed the Horne–Ostberg Morningness–Eveningness Questionnaire (MEQ) [14] to assess circadian preference and the Epworth Sleepiness Scale (ESS) [15] to evaluate trait daytime sleepiness. Next, subjects were prepared for polysomnography recordings and performed the training session of the finger tapping task. A light meal was served and participants were assigned to either the nap group ( $n=15$ ) or the wake control ( $n=15$ ), both lasting 90 min. Finally, all subjects performed the test session of the FTT. To assess state sleepiness, the Karolinska Sleepiness Scale (KSS) [16] was administered before the training session (KSS 1) and the test session (KSS 2) of the FTT.

Nocturnal sleep data were collected using sleep logs and an activity monitor (Mini-Motionlogger, Zero Crossing Mode, Ambulatory Monitoring Inc., USA) placed on the non-dominant wrist for seven consecutive days, starting one week before the experiment. Actigraphy data were scored using Action W version 2.6 9801 software (Ambulatory Monitoring

Inc.). Variables analyzed were total sleep time (Nocturnal TST) and sleep efficiency, averaged over the 5 nights before the experiment. Data from three subjects (nap=1, wake=2) were unavailable because they failed to wear the wristwatch in one of the 5 nights.

Polysomnography data were acquired with Alice 5 (Respiro-nics), digitalized at a sampling rate of 200 Hz and filtered at 0.3 Hz and 75 Hz. Scalp EEG (10–20 system, F3, F4, C3, C4, O1 and O2 channels) and electrooculogram electrodes were referenced to opposite mastoids (M1/M2) and submental electromyogram electrodes were attached under the chin. Impedances were kept under 5 k $\Omega$ . Sleep was scored offline in 30 s-epochs according to the 2007 American Association of Sleep Medicine Manual [17]. Nap architecture variables analyzed included total sleep time (Nap TST), sleep latency, time spent awake after sleep onset (WASO) and percentage of sleep stages non-rapid eye movement 1 (NREM 1), NREM 2, Slow Wave Sleep (SWS) and REM.

Motor memory was probed with the finger tapping task, which requires subjects to explicitly learn to type a numerical sequence on a regular keyboard [4]. The sequence was displayed on the computer screen, to reduce the working memory component to a minimum and it was always the same: 4-2-3-1-4. After every key press, a white dot appeared on the screen and feedback was given at the end of each trial. The learning session consisted of 12 trials of 30 s each, interspersed with 12 blocks of 30 s of rest, while the retrieval session consisted of 3 trials and 3 rest blocks.

The conventional formula for calculating the offline improvement (OI %) takes into account the difference in percentage between the average number of correctly typed sequences on the testing session and the average number of correctly typed sequences on the 3 last trials of the training session (OI% 3L). In order to decrease the influence of unrelated sources of variance near the end of the training session (such as, for example, fatigue and/or boredom), we propose a slight modification to this formula: instead of using the 3 last trials, we suggest using the 3 best trials of the training session (OI% 3B). We argue that **best possible performance before** the retention interval should be the baseline against which any future *additional* gains will be compared to. Therefore, we believe this procedure is more suitable to estimate the *true* offline gains, especially if the average of the 3 best trials proves to be significantly higher than the average of the 3 last trials.

Data are presented as mean (standard error of the mean (SEM)). Descriptive and actigraphy data as well as the offline improvement were compared between groups with unpaired *t* tests. The 2 variables used to determine end-training performance (3 last vs. 3 best, both in absolute number and in the OI (%)) were compared within groups with paired *t*-tests, as well as performance results from training to testing sessions. Nap architecture variables were correlated with both measures of OI % with Spearman's coefficients. The *p* value for significance was set to 0.05.

Subjects from the nap and wake groups did not differ significantly in age, circadian preference (MEQ), trait sleepiness (ESS), state sleepiness (KSS 1 and KSS 2), nocturnal sleep duration or sleep efficiency during the week before the experiment (Table 1).

Performance on the FTT before the retention interval was similar between groups, regardless of the formula used, thereby ensuring that the individuals from both groups learned the task and achieved similar levels of performance before the retention interval. When considering the 3 last trials, the nap group typed 14.4 (0.4) and the wake group typed 14.1 (0.6) correct complete sequences ( $p=0.614$ ). When considering the 3 best trials, the nap group typed 15.5 (0.5) and the wake group typed 15.3 (0.6) sequences ( $p=0.805$ ). Comparing these 2 variables (3 last vs. 3 best) within groups yielded significant differences for both the nap ( $p=0.001$ ) and the wake ( $p=0.009$ ) groups, thus confirming that the end of the training session *does not* necessarily reflect the highest possible speed before the retention interval.

After the retention interval a significant increase in speed was observed in the nap group (Fig. 1A and B) but not in the

wake group (Fig. 1C and D), despite the formula used to calculate the baseline performance (3 last or 3 best).

As for the offline improvement, when the conventional formula was used, a 14.86 (3.2)% improvement was depicted in the nap group and a 7.0 (3.4)% in the wake control. No difference between groups was found ( $p=0.104$ ) (Fig. 2A). On the other hand, when the unrelated sources of variance were attenuated, (i.e., by using the '3 best' formula) a 6.9 (2.8)% improvement was still detected in the nap group, while the wake control exhibited a 2.3 (2.2)% decrease in speed. In this case, the nap group significantly outperformed the wake control ( $p=0.016$ ) (Fig. 2B). The offline gains in the nap group decreased significantly when the formula was adjusted to account for unrelated sources of variance (nap 3 last vs. nap 3 best), but an improvement in performance was still detected ( $p=0.002$ ) (Fig. 2C). A significant decrease in performance was also detected in the wake controls (wake 3 last vs. wake 3 best); however, after the correction this group no longer presented an improvement, but rather a worsening of performance ( $p=0.008$ ) (Fig. 2D).

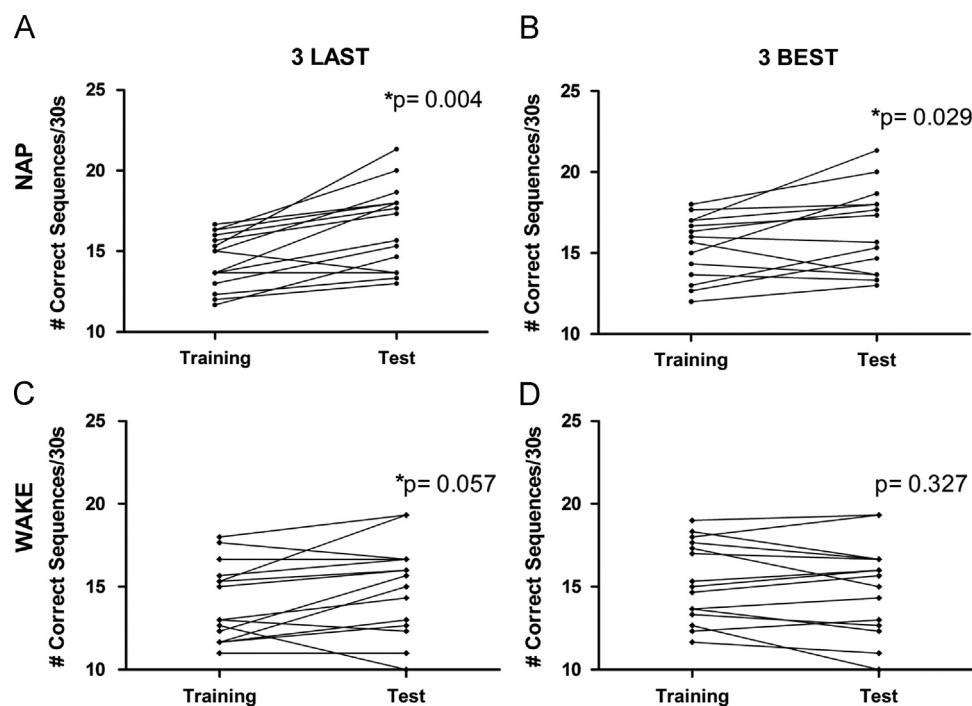
Nap architecture parameters were correlated with the offline improvement based on the 3 last trials and a positive significant correlation with total sleep time was found ( $r=0.578$ ,  $p=0.024$ ), but not with NREM 1(%), NREM 2 (%), SWS (%) or REM (%) (all with  $p>0.05$ ). However, no significant correlations were found for the offline improvement calculated with the 3 best trials ( $p>0.05$ ) (Table 2).

A great deal of evidence has accumulated in the past decades to support the view that sleep has a role in the consolidation of declarative memories (for a review, see [18]). On the other hand, sleep's role on procedural memories, particularly motor skills, is still a matter of debate in the literature due to conflicting results and inconsistencies [10].

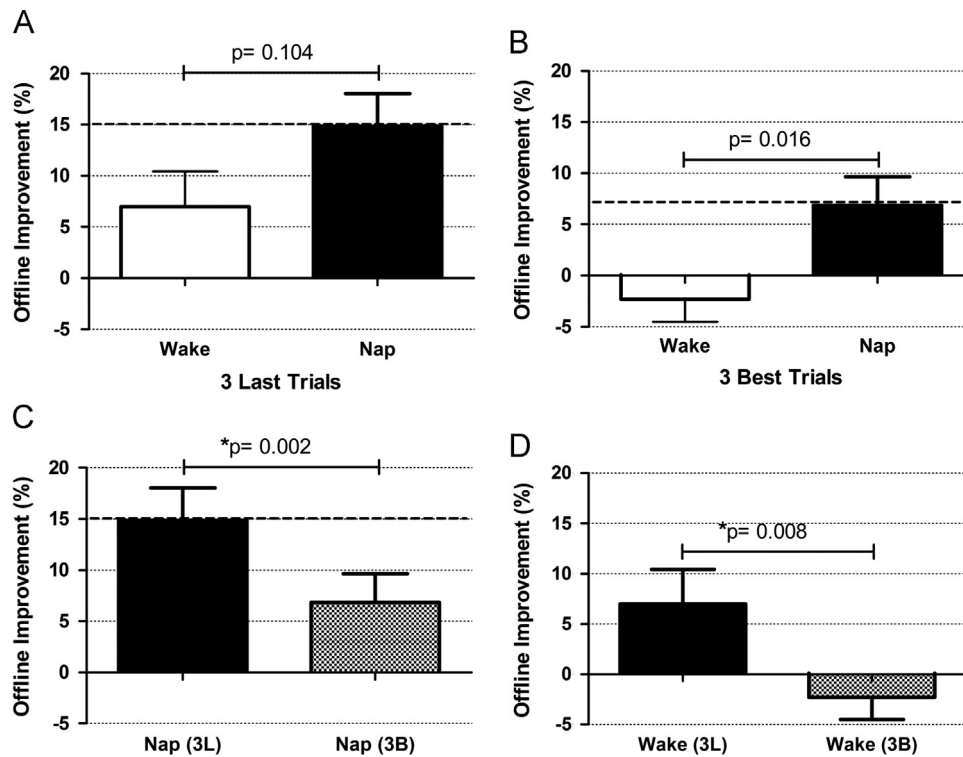
**Table 1 – Sample characteristics and actigraphy data.**

	Wake	Nap	<i>p</i>
<i>n</i>	15 (12F)	15 (12F)	–
Age	21.5 (1.0)	23.4 (1.0)	0.181
MEQ	48.2 (2.5)	44.9 (3.2)	0.424
ESS	10 (0.7)	10.5 (1.0)	0.653
KSS 1	4.0 (0.4)	4.5 (0.4)	0.351
KSS 2	4.2 (0.4)	4.5 (0.3)	0.509
Nocturnal TST (min)	387 (15)	385 (11)	0.904
Sleep efficiency (%)	84 (2)	88 (1)	0.109

MEQ: Morningness–Eveningness Questionnaire; ESS: Epworth Sleepiness Scale; KSS: Karolinska Sleepiness Scale; TST: Total Sleep Time; Unpaired t-tests.



**Fig. 1 – Individual performance on the training and test sessions of the FTT of the nap group (A and B) and the wake group (C and D). Results on the left-hand side represent data from the 3 last trials (A and C) and on the right-hand side the 3 best trials (B and D). Reported *p*-values refer to paired t-test.**



**Fig. 2 – Offline improvement on the FFT of the nap and wake groups, calculated with the conventional formula (A) and with our proposed modified formula (B) (reported *p*-values refer to unpaired *t* test); comparison of the OI (%) within the nap group (C) and the wake control (D) (reported *p*-values refer to paired *t*-tests).**

**Table 2 – Nap architecture and FFT performance correlations.**

		OI % (3L)		OI % (3B)	
		<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
Sleep Latency (min)	9.37 (1.97)	–	–	–	–
WASO (min)	13.20 (3.04)	–	–	–	–
NREM 1 (%)	22.57 (3.56)	0.439	0.101	0.129	0.648
NREM 2 (%)	43.33 (3.98)	–0.161	0.567	–0.290	0.295
SWS (%)	13.74 (4.71)	0.326	0.235	0.455	0.088
REM (%)	4.33 (2.08)	–0.085	0.764	–0.089	0.753
Nap TST (min)	69.40 (3.27)	0.578	0.024*	0.398	0.141

WASO: Wake After Sleep Onset; NREM: Non-Rapid Eye Movement; SWS: Slow Wave Sleep; REM: Rapid Eye Movement; TST: Total Sleep Time; Spearman's correlation.

Here, we have shown that when unrelated sources of variance are attenuated, the performance enhancing effect of sleep on a motor skill is significantly diminished, from 14.9 (3.2)% (3 last trials) to 6.9 (2.8)% (3 best trials), but it still represents an increase in speed. On the other hand, the wake control exhibits a worsening of performance associated with a decrease in speed. Therefore, our results are in line with others previously published [4–7] supporting a role for sleep in motor skill consolidation but they also highlight the possibility that the magnitude of this effect may have been overestimated, as suggested by a different set of studies [9–11].

If an opportunity to rest alone could explain the offline gains, one would expect the wake group to present similar results. However, this was not the case, since subjects who remained in quiet wakefulness actually performed worse after the retention interval. Given that both groups were

matched for the control variables (age, MEQ, ESS and KSS scores, nocturnal sleep and end-training typing speed) it is reasonable to assume that the differences encountered were due to the intervention experienced during the retention interval.

Our modified formula enabled us to decrease the influence unrelated sources of variance and thereby increase the accuracy of the estimate of the benefit accrued from sleep, without the need to alter any of the existing and well-established protocols for conducting this task [4]. These results do not speak against an important role of sleep on the consolidation of motor skills, since the difference in the behavioral output of the nap and wake groups was conserved. Another important point raised by this study is the correlation between sleep architecture variables and the subsequent offline gains. While performance seemed to

benefit more from longer naps when the conventional formula was used, no relationships were found if our proposed formula was used instead. For this reason, results of this sort should always be interpreted with caution. Further evidence is provided by the literature, where some studies have found such correlations [4,5] and others have not [19].

In conclusion, if unrelated sources of variation are taken into account during the analysis of finger tapping task data it appears that sleep's effect on motor skills has been overestimated, from an apparent gain of ~15% to an actual enhancement of ~7% only. Hence, our results might help to explain some of the discrepancies found in the literature on procedural learning and shed light on an easy and effective solution to this problem. The authors of this study would like to invite other researchers to apply the same methodology to their own data and report their findings. Perhaps it is time to consider an update in the formula used to access performance on the finger tapping task.

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