Does Napping Boost Benefits of Brain-Training for Working Memory?

Rainita Narender[1], Dakota Salazar[2],
Elizabeth A. McDevitt[1], Aaron R. Seitz[1]

1 Department of Psychology

2 Department of Molecular, Cell and Systems Biology

ABSTRACT

Working memory (WM) is engaged in most cognitive tasks deployed in the human brain. Brain-training regimens that target WM may promote plasticity, leading to improved WM skills. Additionally, sleep is known to facilitate consolidation of newly learned information and skills. Here, we asked if napping could boost benefits of brain-training for WM. Participants completed ten days of WM training on an N-back task; on each training day, a subset of participants were given a 30-minute nap opportunity (with EEG recording) immediately following their training session (training+nap). In Study 1 (n=10), we equated the amount of training (20-min training/day) in all participants and compared training only to training+nap. In Study 2 (n=8), we asked if napping can effectively replace additional time spent training; we compared training+nap (20-min training/day) to double training (40-min training/day). On average, the nap group slept 16.0±5.77 minutes/nap in Study 1 and 15.98±7.44 minutes/nap in Study 2. Our dependent measure of performance was the highest N-level achieved on each day of training. In both studies, we found that performance improved across the ten days of the study. However, there was no day x group interaction in either study, suggesting that the degree of improvement did not differ between training only vs. training+nap groups. In Study 2, there was a trend towards more improvement with double training compared to single training+nap. For people looking to dedicate time each day to improving their WM, it may be more beneficial to spend the entire time training rather than training+napping.

Keywords: brain-training, video-games, working memory, neuroplasticity, sleep, N-back

FACULTY MENTOR

Dr. Aaron Seitz

Professor in the Department of Psychology

Professor Aaron Seitz is an internationally recognized expert on the mechanisms of learning and memory using behavioral, computational and neuroscientific methodologies. His research over the last 15 years has focused on mechanisms of plasticity and learning in the sensory/perceptual systems. A key aspect of his recent research is applying knowledge of plasticity mechanisms in the brain to create brain-training video games that are effective in improving performance in real-world tasks. A notable example is his vision training game ULTIMEYES that leads to vision improvement that positively transfers to on-field performance in baseball. He is now the Director of the newly founded UCR Brain Game Center for Mental Fitness and Well-being that has the mission to research, test, and disseminate game software instrumented with expert knowledge to optimize human brain processes with an aim to make scientifically principled brain games that translate to performance in real-life activities.

Rainita Narender

Department of Psychology

Rainita Narender is a fourth year majoring in Psychology and Economics. Her research focuses on the effect of sleep on memory processes. Recently, she collaborated with UCR's Brain Game Center to examine if sleep facilitates working memory brain-training. After being awarded Best Poster at the 11th Undergraduate Research Symposium, she was encouraged to apply and receive a travel grant. These opportunities have supported her future pursuits to research ways to improve cognitions as a PhD student.

Dakota Salazar

Department of Molecular, Cell and Systems Biology

Dakota Salazar is a fourth year Neuroscience major in the department of Cell Biology and Neuroscience. As a Research Assistant in Dr. Mednick's Sleep and Cognition Lab, Dakota teamed up with UCR's Brain Game Center to explore whether or not sleep was able to facilitate working memory brain-training. Dakota is the President of Highlander Chefs, a Senior Team Member with UC Neuro and an Academic Mentor with the Medical Scholars Program (MSP). He hopes to pursue his medical degree. (M.D.)

INTRODUCTION

Methods for improving memory have been a primary focus in cognitive psychology and neuroscience for many decades. Though research has made great strides in understanding memory domains and mechanisms, developing a reliable way to improve memory has proved challenging. Recently, working memory (WM) has been targeted as a promising domain for improvement. WM is a cognitive system concerned with temporarily holding information for immediate use. WM underlies, and interacts with, many other cognitive systems, including long-term memory and our ability to reason, comprehend and learn. Therefore, improving WM capacity (i.e., the amount of information that is temporarily stored for immediate use) and accuracy (i.e., ability to correctly remember such information) could yield benefits across many cognitive domains (Deveau et al., 2015). Since WM plays an interactive role in other cognitive domains, improving this facet could therefore improve cognition and help combat cognitive deficits faced with age. Research has indicated that WM is a plastic domain that can be strengthened with more practice (Klingberg, 2010).

Brain plasticity (i.e., neuroplasticity) is the brain's ability to change and/or strengthen connections based on use of specific brain regions or populations of neurons. Though WM was initially considered to be a "non-plastic" domain, unable to improve or weaken, recent studies have found the opposite is true (Klingberg, 2010). WM can be strengthened; improvements in WM are associated with the frontal and parietal regions of the brain (Thompson & Waskom, 2016). Specific regions associated with WM improvement are the executive function region of the brain (pre-frontal cortex) and the attentional network (dorsal parietal cortex) (Thompson & Waskom, 2016).

Previous studies have primarily utilized N-back tasks in order to train WM (Jaeggi et al., 2008; Smith et al., 2009; Buschkuehl and Jaeggi, 2010; Thompson & Waskom, 2016). The term "N-back" refers to how many objects back the test-taker is required to match their response with. The most common utilization of N-back training constitutes recalling shapes of different colors a certain number of screens (N) back (Figure 1B). Conversely, Thompson & Waskom (2016) implemented a different N-back task consisting of auditory and visual cues of consonant letters spaced in peripheral regions of a computer screen. Regardless of discrepancy in N-back task arrangement, this task has proven to be a useful tool in increasing working memory abilities on the specific task.

More research is required to extend these WM improvements to a more accessible and generalized platform. Research into creating an accessible tool for everyday use has led to development of applications aimed at exercising cognition, so-called brain-training games. Brain-training games are intended to improve cognitive functions and hopefully generalize to be to domains not specifically trained (Green & Seitz, 2009). Based on previous findings focused to improve WM, increased cognitive training in the WM domain not only yields improvement in task but has also led to altered neural networks causing an expansion in WM capacity (Thompson & Waskom, 2016).

Post-learning sleep has been shown to facilitate plasticity and improve behavioral performance in a wide-range of memory domains (Diekelmann & Born, 2010). However, the impact of sleep on WM has mostly been studied in the context of WM deficits due to sleep deprivation or sleep disorders (Mednick et al., 2002). One domain that has shown a benefit of sleep, and might share general learning mechanisms with WM, is perceptual learning (Deveau et al., 2015; Mednick et al., 2003). Perceptual learning is improved performance on a sensory task, typically following training or practice. Visual perceptual learning is vulnerable to deterioration from over-training within a session or day (Mednick et al., 2002, 2005); however, sleep, including short periods of sleep (i.e., napping), can recover performance and lead to performance gains without additional training (Mednick et al., 2003). This suggests that sleep works to promote experience-dependent changes in brain plasticity induced by training.

Here, we aim to test if this benefit of napping extends to plasticity induced by WM training. In the current study, we examined two main questions: Does training+napping facilitate the rate of WM improvement across ten days of training (when time spent training is held constant)? And can napping replace additional time spent training (in other words, is 20min of training plus 20min of napping just as effective as 40min of training)? We hypothesized that greater WM improvements would be elicited by training+napping than by training alone, and that napping would impart the same amount of WM benefit as additional time spent training.

METHODS

Participants

A total of 19 participants (8 female) between ages 18-30 (19.94±1.68 years old) were recruited through an email invitation sent to students at the University of California, Riverside (UCR). Interested individuals responded to the email with their availability; Those who were available every weekday for at least 90-minutes between the hours of 11am-4pm were then invited to meet with the researchers to learn more about the study. Eligibility requirements included refraining from caffeine and alcohol consumption the morning of each study day. Each participant signed a written consent form to participate in the experiment, which was approved by the Human Research Review Board at UCR.

Protocol

The WM training regimen involved performing an N-back WM task each day for a total of 10 days (excluding weekends). Time-of-day of training was not strictly controlled, but all training sessions were completed between the hours of 11am-4pm. Participants were assigned to either a training-only or a training+nap group. In Study 1, all participants completed one, 20-minute WM training session per day (single training). Following the training session, participants in the training-only group were allowed to leave the lab. Participants in the training+nap group had EEG electrodes attached (~15 min), followed by a 30-minute opportunity to nap. In Study 2, the nap+training group followed the same procedure; however, the training only group completed two 20-minute training sessions per day (double training), with a 5 minute break between sessions.

Working Memory N-Back Task

In this study, participants completed a common WM task called the N-back task (Jaeggi et al., 2008; Smith et al., 2009; Buschkuehl and Jaeggi, 2010). The task was performed on an iPad using an application developed for this study.

An experimental *trial* consisted of three separate stages: the response, feedback and inter-stimulus stages (Figure 1A). In the response stage, a colored object was displayed on screen and participants were given 2500 milliseconds (ms) to determine whether or not it matched the object shown "n" trials back. If there was a match, participants responded by tapping the screen. After the response stage, participants saw a 300 ms feedback window where the shape was circled in green for a correct response or in red for an incorrect response (Figure 1B). Following the feedback stage, a grey object appeared on screen for 200 ms during the inter-stimulus stage. This was meant to reset the trial before presenting a new colored object. The overall trial was 3000 ms in length.

An experimental *block* consisted of 40 trials with the same "n" level. The difficulty of sequential blocks was adaptively adjusted during the session based off a participant's performance. This is a common method used in the N-Back Task; however, different studies have differing thresholds for level changes (Harbison et al., 2011). In our study, if a participant achieved 80% correct or above on a given block, the task became harder with a +1 increase in "n" level. If a participant achieved 50% correct or below on a given block, the task became easier with a -1 decrease in "n" level. If a participant achieved between 50% and 80% correct, the task difficulty and "n" level remained the same. The highest "n" level achieved for each participant on each day of training was our measure of WM performance.

Polysomnography (PSG)

PSG data was acquired using with Ag/AgCI electrodes placed according to the international 10-20 System (Jasper, 1958). We recorded electroencephalogram (EEG) from scalp electrode sites C3, C4, O1 and O2, as well as an online common reference channel (FCz location). Additional channels included two mastoids for offline re-referencing (A1 and A2), two electrooculogram (EOG), and one ground. Recordings were sampled at 500Hz.

Offline, EEG and EOG data were re-referenced to contralateral mastoids and filtered between 0.3 Hz and 35 Hz. A 60 Hz notch filter was also used to eliminate potential background noise. Data was visually scored in 30-s epochs according to the sleep staging criteria of Rechtschaffen and Kales (1968). Sleep architecture variables included minutes and percentage of Stage 1, Stage 2, slow wave sleep (SWS), and rapid eye movement (REM) sleep, as well as total sleep time (TST), sleep latency (SL), and sleep efficiency (SE).

Statistical Analyses/Data Reduction

Mixed-model analysis of variance (ANOVA) was utilized to examine performance across the ten days of the study in our experimental groups. In these analyses, Day (1-10) was our within factor, and group (training-only vs. training+nap) was our between factor. Independent-sample t-tests were used to examine group differences at individual timepoints of interest. Repeated-measures ANOVA tested for changes in nap total sleep time across the 10 naps.

One participant (Study 1) was removed from data analyses due to receiving double training instead of single training on half of the study days. Of the total 100 naps recorded across studies 1 and 2, 4 nap records were missing due to technical error. Behavioral data from these days are included in the analyses; however, sleep stage variables were unavailable and were treated as missing. Sleeping throughout the entire 30-minute nap opportunity was not required and not all nap group participants slept duringe every nap opportunity; days where participants were unable to sleep were still included in the analyses. Our final sample size for each study is as follows:

Study 1 (single training: *n* = 4, training+nap: *n* = 6) and Study 2 (double training: *n* = 4, training+nap: *n* = 4). For participants assigned to double training in Study 2, we calculated their highest N-level per day by averaging the highest N-level achieved in each of their 2 sessions/day.

RESULTS

Nap Results

People were able to nap given a 30-minute opportunity. Sleep descriptives, including minutes spent in each sleep stage, can be found in ***Tables 1 and 2.*** In Study 1, TST did not significantly vary across the 10 naps [F(9,27)=0.704, p=0.7] ***(Figure 2A).*** Conversely, Study 2 showed a significant increase in TST across naps [F(9,18)=3.59, p=0.01] ***(Figure 2B)***.

Behavioral Results

In Study 1, participants were assigned to either a single training or training+nap group. Over the course of ten days of training, the single training group completed

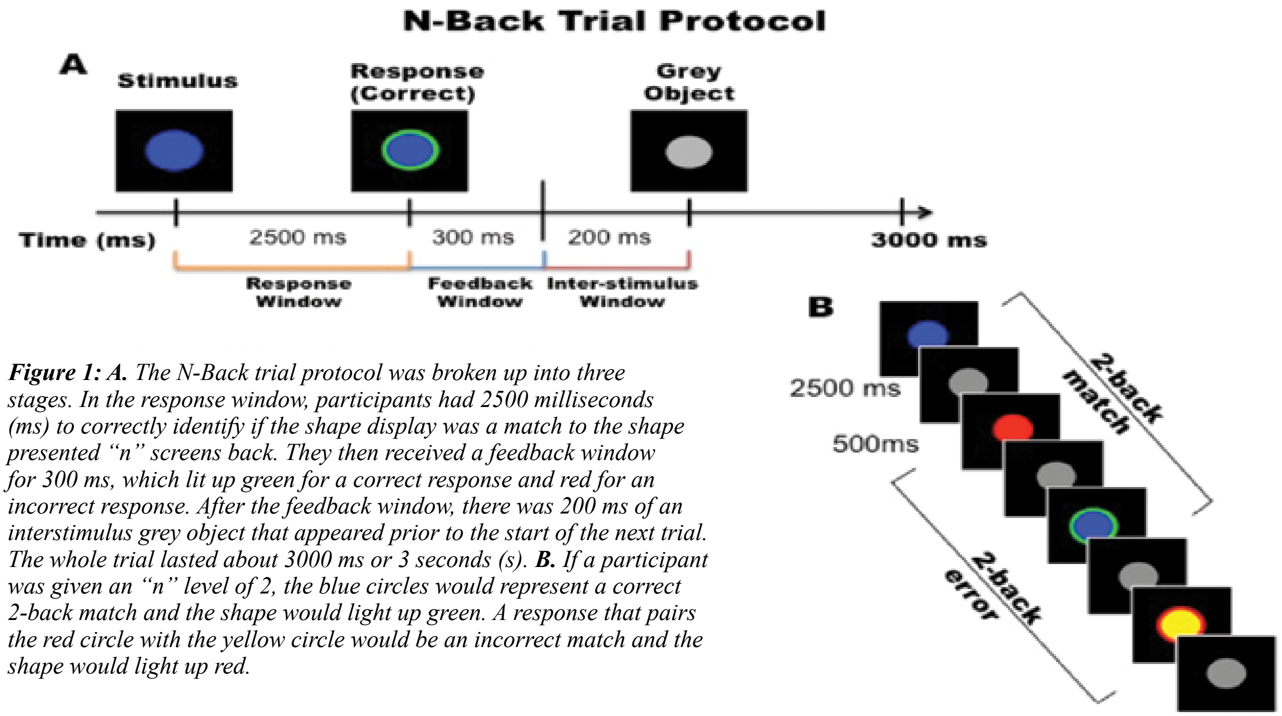
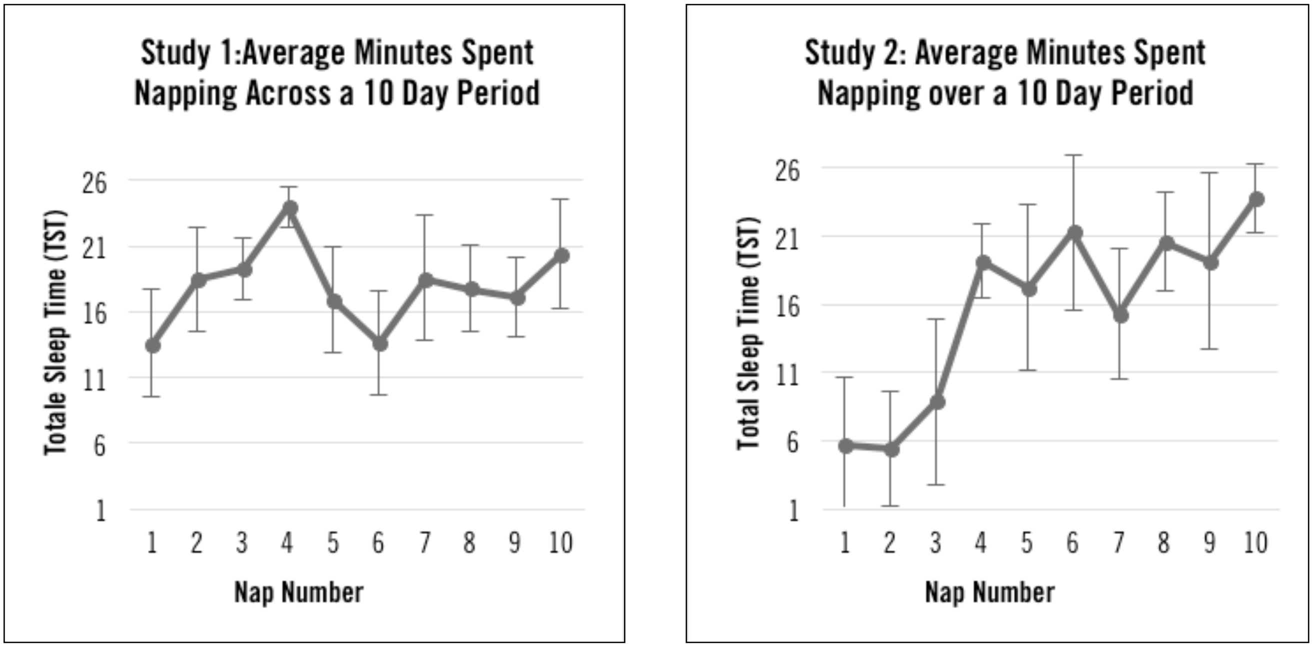


Figure 1: A. *The N-Back trial protocol was broken up into three stages. In the response window, participants had 2500 milliseconds (ms) to correctly identify if the shape display was a match to the shape presented "n" screens back. They then received a feedback window for 300 ms, which lit up green for a correct response and red for an incorrect response. After the feedback window, there was 200 ms of an interstimulus grey object that appeared prior to the start of the next trial. The whole trial lasted about 3000 ms or 3 seconds (s).* ***B.*** *If a participant was given an "n" level of 2, the blue circles would represent a correct 2-back match and the shape would light up green. A response that pairs the red circle with the yellow circle would be an incorrect match and the shape would light up red.*



Study 1:Average Minutes Spent Napping Across a 10 Day Period

Study 2: Average Minutes Spent Napping over a 10 Day Period

***Figure 2**- Average Total Sleep Time Per Nap*

***(A)** In Study 1, there was no overall change in total sleep time across ten naps. **(B)** In Study 2, total sleep time increased across ten naps. Error bars represent +/- 1 standard error of the mean.*

	TST	Stage 1	Stage 2	SWS	REM	Sleep Efficiency
Mean	16.34	4.91	9.66	1.77	0	54.39
Std. Deviation	5.77	1.83	4.33	2.33	0	19.60
Minimum	6.56	2.83	3.72	0	0	20.98
Maximum	21.00	8.00	15.90	4.95	0	70.35

Note: TST = total sleep time; SWS = slow wave sleep; REM = rapid eye movement; Sleep efficiency was calculated as TST/time in bed. Besides sleep efficiency (which is a percentage), the units of all other variables are minutes.

***Table 1**- Sleep Descriptives for Study 1*

	TST	Stage 1	Stage 2	SWS	REM	Sleep Efficiency
Mean	15.98	4.76	8.59	1.95	0.69	52.92
Std. Deviation	7.44	3.05	4.14	3.36	0.85	23.75
Minimum	4.95	1.70	3.25	0	0	17.95
Maximum	20.72	8.50	13.00	6.95	1.75	69.12

Note: TST = total sleep time; SWS = slow wave sleep; REM = rapid eye movement; Sleep efficiency was calculated as TST/time in bed. Besides sleep efficiency (which is a percentage), the units of all other variables are minutes.

***Table 2**- Sleep Descriptives for Study 2*

a total of 88.8 ± 6.4 (mean±SD) blocks of training, and the training+nap group completed 90.7 ± 5.8 blocks of training. A Group x Day mixed-model ANOVA showed a significant main effect of Day (F(9,72)=10.66, p<0.001), indicating that overall, participants showed improvement in highest N-back level reached over the 10-day training period ***(Figure 3A).*** There was no main effect of Group (F(1,8)=1.05, p=0.34), and the Group x Day interaction was also non-significant (F(9,72)=1.48, p=0.17). The lack of a significant interaction suggests that both groups improved along a similar trajectory. Thus, we did not find evidence that 30-minutes of napping facilitates training-induced WM improvements.

In Study 2, participants were assigned to either a double training or training+nap group. Over the course of ten days of training, the double training group completed 292.8 ± 13.0 (mean±SD) blocks of training, and the training+nap group completed 151.5 ± 11.8 blocks of training. Similar to Study 1, participants showed overall improvement in highest N-back level achieved over the 10-day period (F(9,54)=4.24, p<0.001, ***(Figure 3B)***. There was no main effect of Group (F(1,6)=2.11, p=0.20), and the Group x Day interaction was trending, but did not reach traditional levels of significance (F(9,54)=1.87, p=0.08). The general pattern of results show that following training day 4, the double training group was numerically better than the training+nap group. By Day 10, the double training group was significantly better than the training+nap group (t(6)=3.61, p = 0.01, Cohen's d = 2.55). From this result, we can conclude that 30 minutes of napping does not replace a second training session. If anything, double training appears to be on a trajectory towards showing significantly greater WM improvements than training+napping.

DISCUSSION/CONCLUSION

The common goal of study 1 and study 2 was to determine if napping can facilitate training-induced improvements in WM. Study 1 compared 20-minutes of training plus a short nap to training alone; Study 2 compared 20-minutes of training plus a short nap to 40-minutes of training alone. We did not find a benefit of napping in either study. Additionally, the results of Study 2 suggest that the most effective training regimen might be double training. In other words, if you spend 40-minutes a day trying to improve your WM, that time might be best spent training

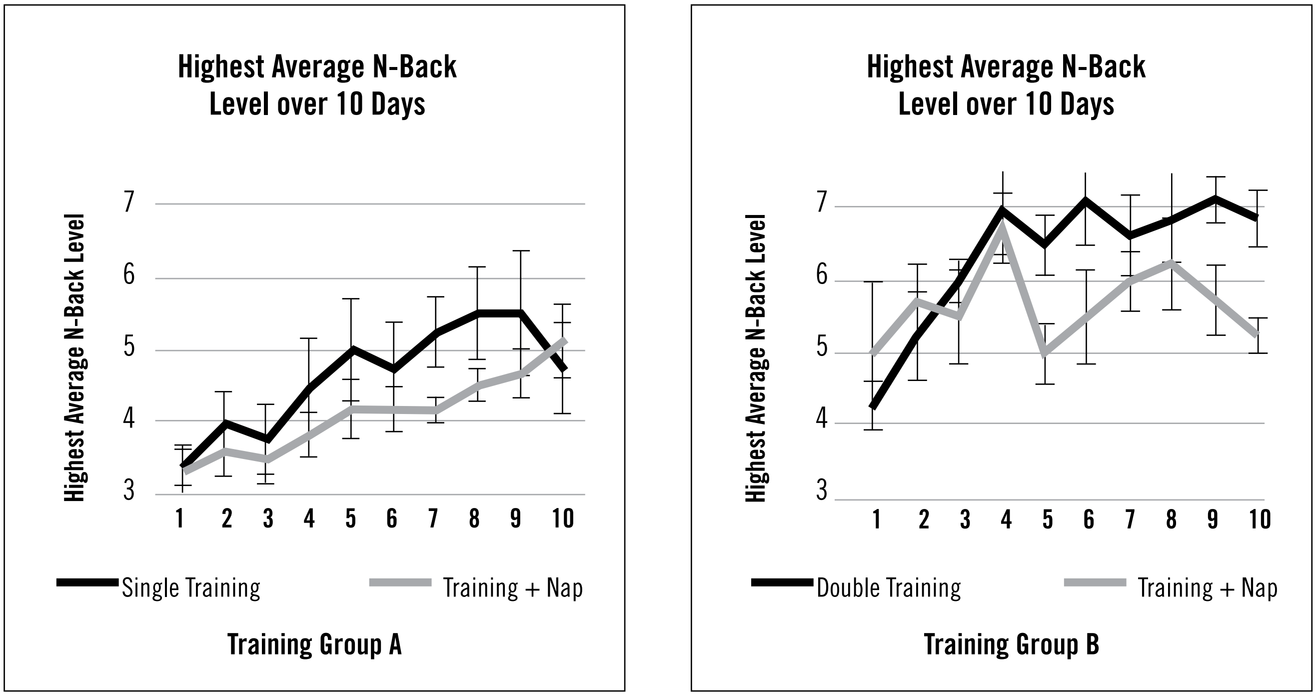


Figure 3 - Highest N-level Across 10 Days of Training for Study 1 and Study 2
(A) *In Study 1, the single training and training+nap groups show similar trajectories of improvement across ten days of training.*
(B) *In Study 2, the double training group shows a trends toward more improvement than the training+nap group.*

the entire time rather than training and taking a quick nap.

Both studies found an improvement in N-back task performance over the ten days of training. This supports previous findings that WM can be improved with practice (Klingberg, 2010). However, the current study only examined performance on one specific task. An important extension of this work will be to test if N-back training can lead to generalized improvements on other working memory tasks and other cognitive domains.

Neither Study 1 nor Study 2 found evidence that napping boosted training-induced WM gains. It is possible that WM is not a cognitive domain consolidated or strengthened by sleep. However, it is important to acknowledge that all participants did have sleep between days – at night – and these results do not conclusively eliminate sleep as a factor in the improvement we saw across days. Rather, we can only conclude that a short nap (~15 min) did not facilitate WM improvements. Another possibility is that the nap was too short to elicit sleep-related benefits. In general, research on napping and memory typically utilizes longer napping periods (60-90 minutes) in order to capitalize on potential benefits from all sleep stages in a sleep cycle (Mednick et al., 2003). For example, perceptual learning gains are typically seen in conditions where the naps include both slow wave sleep (SWS) and rapid eye movement (REM) sleep (Mednick et al., 2003). In the current study, our naps were predominantly composed of lighter Stage 1 and Stage 2 sleep, and had very little or no SWS or REM. Another caveat is that WM performance was not assessed immediately following the nap. Therefore, it is still possible that napping could boost same-day WM performance, perhaps by reducing fatigue. We can only conclude that napping did not benefit across-day WM performance. Future studies should investigate the impact of longer naps on training-induced WM performance and the relation between specific sleep stages/features and WM performance.

Another limitation of this study was the small sample size. This was due to space and time limitations - we could only have so many participants nap in the lab during designated napping hours each day. A larger sample size would give us the ability to examine factors related to individual differences that may be critical to understanding interactions between napping and WM training.

Overall, WM training may not be facilitated by a 30-minute nap opportunity. Rather, people who are looking to improve their WM might be better off investing the extra time doing additional training, not napping. Future work still needs to establish if training-induced WM improvements generalize to other tasks and cognitive functions. If WM brain-training does generalize to overall WM improvements, a viable outlet to improve cognition and battle degenerative deficits could be accomplished. In all, the study at hand showcases the potential benefits of WM training and demonstrates that this is a promising area of research for developing tools and strategies to counteract cognitive deficits associated with reduced WM abilities.

ACKNOWLEDGEMENTS

We greatly acknowledge NSF GRFP (E.M.) for funding the project at hand. Specifically, this study would not have been possible or successful without the mentorship of post-doctorate Elizabeth McDevittt and Dr. Aaron Seitz. Also, we thank the undergraduate and graduate students in the Brain Game Center and Sleep and Cognition lab for their diligence and efforts.

REFERENCES

Buschkuehl, M., and Jaeggi, S. M. (2010). Improving intelligence: a literature review. *Swiss Med. Wkly* 140, 266–272. doi: smw-12852

Deveau, J., Jaeggi, S. M., Zordan, V., Phung, C., & Seitz, A. R. (2015). How to build better memorytraininggames. *FrontiersinSystemsNeuroscience,8* doi:10.3389/fnsys.2014.00243

Diekelmann, S., Wilhelm, I., & Born, J. (2009). The whats and whens of sleep-dependent memory consolidation. *Sleep Medicine Reviews,* 13(5), 309-321. doi:http://dx.doi.org/10.1016/j.smrv.2008.08.002

Green, C. S., & Seitz, A. R. (2015). The Impacts of video games on cognition (and how the government can guide the industry). *Policy Insights from the Behavioral and Brain Sciences,2*(1), 101-110. doi:10.1177/2372732215601121

Harbison, I., Atkins, S., & Dougherty, M. (2011). N-back Training Task Performance: Analysis and Model. *Cogsci.*

Jaeggi, S., Sheehan, E., Tsai, N., Duncan, G. J., Buschkuehl, M., & Au, J. (2008). Improving fluid intelligence with training on working memory: A meta-analysis. *PsycEXTRA Dataset.* doi:10.1037/e524912015-029

Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences, 14*(7),317-324.http://dx.doi.org/10.1016/j.tics.2010.05.002

Mednick, S. C., Nakayama, K., Cantero, J. L., Atienza, M., Levin, A. A., Pathak, N., & Stickgold, R.(2002)The restorative effect of naps on perceptual deterioration. *Nature Neuroscience,5*(7), 677-681. doi:10.1038/nn864

Mednick, S., Nakayama, K., & Stickgold, R. (2003). Sleep-dependent learning: A nap is as good as a night. *Nature Neuroscience, 6*(7), 697-698. doi:10.1038/nn1078

Mednick, S., Grethe, A., Dinges, D., Ayalon, L., & Drummond, S. (2005). The neural basis of the psychomotor vigilance task. *Sleep.* doi:10.1093/sleep/28.9.1059

Smith, G. E., Housen, P., Yaffe, K., Ruff, R., Kennison, R. F., Mahncke, H. W., et al. (2009). A cognitive training program based on principles of brain plasticity: results from the improvement in memory with plasticity-based adaptive cognitive training (IMPACT) study.J.Am.Geriatr.Soc.57,594–603.

Thompson, T. W., Waskom, M. L., & Gabrieli, J. D. (2016). Intensive working memory training produces functional changes in large-scale frontoparietal networks. *Journal of Cognitive Neuroscience, 28*(4), 575-588. doi:10.1162/jocn_a_00916