THE UNIVERSITY OF CHICAGO

Performance Naps:

Exploring the Role of Naps in Auditory Generalized Learning

By

Alexander P Przybycin

August 2023

A paper submitted in partial fulfillment of the requirements for the Master

of Arts degree in the Master of Arts in Computational Social Science

Faculty Advisor: Jean Clipperton, Ph.D.

Preceptor: Sanja Miklin, Ph.D.

Abstract

The ability to learn and consolidate information is a fundamental cognitive process that underlies human decision making and problem-solving skills. Generalized learning, the ability to transfer knowledge and skills to novel situations, is an essential part of adaptive learning. This study aimed to investigate the impact of short sleep (napping) on generalized auditory learning using a computer-synthesized speech learning paradigm. Results indicated our findings were statistical not significant, though this study should be expanded with greater statistical power.

Introduction

1.1   Learning and Learning Consolidation

The ability to learn is an essential skill for humans to accumulate experience from interacting with the world in order to guide their future decisions in the actions they make (Wilhelm et al., 2011). Learning involves the acquisition, processing, and retention of information that enables individuals to adapt to their environment, solve problems, and improve cognitive abilities. The process of learning involves attention to relevant information, encoding the information into memory, consolidation, and reinforcement to integrate prior experiences for applications in novel situations (Huber, 2007).

1.2   Rote vs generalized learning

The acquisition of complex skills depends on the ability to generalize beyond exact situations experienced during learning (Lau et al., 2011). It has been argued that the ability to generalize is the defining feature of adaptive learning, and the quality that distinguishes it from simple associative memory (Poggio & Bizzi, 2004). Many models of memory suggest that generalized learning relies on the same underlying associative mechanisms as learning of specific experiences; generalization depends on abstraction from associations acquired through learning (McClelland and Rumelhart, 1985). In contrast, other theories suggest that memory involves both specific representations and abstract representations (Anderson et al., 2004). Evidence suggesting that there may be different mechanisms underlying rote and generalized learning would present a challenge for models that posit only specific representations and would provide support for models that allow for both specific and abstract representations.

Rote learning refers to a learning method that involves the memorization of information through repetition and without necessarily understanding the underlying meaning or the relationships between pieces of information (Lau et al., 2011). Instead, it relies on memorizing information as isolated units without context or broader understanding. Such as memorizing facts, procedures, or specific details without necessarily comprehending or making meaningful connections between them. Rote learning tends to have limited transferability to new situations or contexts as the learned information is often tied to specific cues or conditions present during the learning process and may not be easily applied or adapted to different settings. Rote learning can be effective for memorizing certain types of information, such as basic facts, vocabulary, or formulas, where recall and repetition are crucial. However, it is often criticized for its limited capacity to promote deeper understanding and the application of knowledge in meaningful contexts (Heald et al., 2022).

Generalized learning grants the ability to transfer knowledge, skills, or strategies learned in one context to another context or task that may be different but shares some similarities. Generalization involves applying what has been learned in a specific situation to novel situations. It involves using previously acquired knowledge or experiences to solve novel problems (Batterink et al., 2014). Transfer of learning being the application of knowledge or skills learned in one situation to a different but related situation. Generalized learning involves abstracting underlying principles or concepts from specific instances and applying them to new situations. It requires identifying common features or patterns across different contexts and generalizing the acquired knowledge or skills to similar situations (Francis et al., 2007). In the context of auditory learning, the ability to generalize and apply learned auditory information to novel situations,

such as applying underlying linguistic rules in a situation which it has not been used before (Heald et al., 2022). Requiring a deeper level of understanding and application of underlying rules rather than mere repetition or memorization.

1.3   Generalized Auditory Learning and Synthesized Speech

In this study we utilize a computer synthesized speech learning paradigm, mimicking a difficult to understand speaker, to investigate generalized auditory learning (Francis et al., 2007). A primary concern is inducing cognitive load when making sense of what a difficult to understand speaker is communicating. An unfamiliar or difficult to understand foreign accent can induce additional cognitive load on an individual by requiring them to remap familiar acoustic representations of words to novel representations produced by the speaker (Bradlow & Bent, 2008). Prior research suggests that individuals can overcome these difficulties through generalized learning, a form of perceptual learning in which learning is facilitated through repeated exposure to novel stimuli (Francis et al., 2000). Repeatedly exposing an individual to foreign accented speakers will lead them to remap their acoustic representations of words in context of the speaker's voice, making the speaker more intelligible to the student (Francis et al., 2000).

Performance on the synthetic speech learning task is the result of individuals ability to shift their attention to phonetic ques following exposure and feedback, updating perceptual models of phonetic sound mappings allowing for intelligible comprehension. (Heald et al., 2022) Individuals without prior training on computer synthesized speech rely on applying experience of human generated speech, allowing for greater error in comprehension due to mismatch in mapping of phonetic and auditory categories. This comprehension error may be minimized by

training participants to shift their attention to auditory phonetic cues, a process involving

feedback provided as on-screen text of the word which had just been heard (Francis et al., 2000).

As individuals are exposed to these pairs which represent a range of phonetic information, their

perceptual model is tuned allowing for application of this information to comprehend unheard

synthesized words.

The training allows them to differentiate between similar sounds and recognize the subtle

differences that contribute to word identification. This enhanced discrimination helps

participants better understand and distinguish individual words in the synthesized speech

recognition tests (Francis et al., 2007). Generalized auditory learning facilitates the transfer of

learning from trained words to untrained words, by developing the ability to apply their

knowledge of phonetic patterns and discrimination skills to new words that were not explicitly

trained during the learning task (Heald et al., 2022). This transfer of learning is essential for

generalized auditory learning and enables participants to demonstrate improved performance on

untrained words.

1.4 Sleep and Learning

Adequate sleep improves various cognitive functions that are essential for learning, such

as attention, concentration, and problem-solving (Ruch et al., 2021). Sleep deprivation, on the

other hand, impairs these cognitive processes and negatively affects learning and memory

performance (Alger et al., 2012). Memory consolidation research suggests that sleep consolidates

procedural and perceptual skills but the vast majority of this research has emphasized tasks

wherein learning is restricted to the exact information encountered during training. (Fenn et al.,

2003) Tasks used to study procedural consolidation typically focus on learning one motor pattern

or discrimination of one visual pattern which may be considered rote procedural learning (Hoedlmoser et al., 2022). The process of generalized auditory learning relies on recognition of phonological categories across various acoustic patterns. Prior studies have identified that this recognition performance increases post training but degrades with subsequent testing over the span of a day. Sleep has been found to restore recognition performance to the level of the prior's days initial test and protects against further degradation (Fenn et al., 2003).

Although some of the sleep research in rote procedural learning has been questioned, there is strong evidence that sleep consolidates generalized learning and promotes abstraction of information (Lau et al., 2010). In generalized procedural learning, performance degrades across waking retention and is restored by sleep. Sleep also inoculates memory against subsequent degradation (Brawn et al., 2008, Fenn et al., 2003). Consistent with this, studies have reported that after controlling for reactive inhibition, rote motor learning follows the same general pattern of waking degradation and restoration after sleep (Brawn et al., 2008). Other studies that have investigated generalized learning and sleep have shown that sleep can restructure information acquired during waking (Wagner et al., 2007). Of note, a study by Wagner et al., trained participants on a complex algorithm that contained a hidden rule that allowed the problem to be solved in fewer steps. Participants were more likely to become aware of the hidden rule if tested after sleep than after a waking interval. Similarly, infants who were exposed to an artificial language showed evidence of generalization and abstraction of the rules of the language after a nap (Wagner et al., 2004). In contrast, after a waking interval, infants showed patterns of preference for familiar over unfamiliar words, but did not show any evidence of abstraction or generalization (Gómez et al., 2006). Thus, there is strong evidence that sleep consolidates generalized learning and promotes abstraction or restructuring of information.

In learning, sleep is reported to protect against interference and degradation of what was learned; performance degrades to a lesser degree after sleep than after an equal interval of wakefulness (Huber, 2007). Although several studies have reported this effect, recent work has argued that apparent memory enhancements may be explained by reactive inhibition (Rickard, Cai, Rieth, Jones, & Ard, 2008) or circadian differences at test (Cai & Rickard, 2009). During sleep, especially during the rapid eye movement (REM) and slow-wave sleep (SWS) stages, the brain consolidates and strengthens newly acquired memories (M. A. Tucker & Fishbein, 2008). This process involves transferring information from short-term memory to long-term memory storage, making it easier to retrieve and apply the learned information in different contexts (Kemény & Lukács, 2016). Sleep allows the brain to engage in the reactivation and reorganization of memories, integrating newly acquired information with existing knowledge, leading to more effective and generalized learning outcomes (Walker & Stickgold, 2004). This integration process helps extract underlying principles, identify patterns, and identify connections between varying units of information (Censor et al., 2006). By integrating new and old knowledge, sleep facilitates the extraction of relevant information and reduces interference from irrelevant or competing stimuli that can interfere with learning (Alger et al., 2012). Interference, in the context of learning, occurs as a disruption or impairment in the acquisition, retention, or retrieval of information through the presence of competing or conflicting information (Lahl et al., 2008). It occurs when new information interferes with the ability to remember or recall previously learned information, or when previously learned information interferes with the learning or recall of new information (Batterink et al., 2014). While in a sleep state, the brain filters and prioritizes important information, discarding irrelevant or less

significant information (Alger et al., 2012). By consolidating memories during sleep, the brain creates more stable and resistant memory traces that are less susceptible to interference (Lau et al., 2010). This selective processing helps consolidate and retain essential knowledge, facilitating the application of generalized learning.

1.5   Naps vs Sleep

The length of sleep for cognitive benefits is widely debated, with little agreement as to the ideal length of sleep (S. Mednick et al., 2003). Prior research suggests that a nap, or a short amount of sleep, may provide similar benefits to those seen from a full night of sleep (S. Mednick et al., 2003). The length of a nap for cognitive benefits has been investigated previously, with prior research suggesting that a 90-minute nap, the length of one full sleep cycle including REM and SWS phases, provides greater benefit than a shorter nap with a fragmented sleep cycle (eg. 10 minutes with no REM). A previous study investigated whether sleep specifically promotes learning or if restful waking can provide similar benefits (S. Mednick et al., 2003). The researchers examined the effects of sleep, busy waking (watching a film), and restful waking (lying in the dark) on auditory tone sequence learning. The results indicated that both sleep and restful waking lead to greater performance improvements in auditory tone sequence learning compared to busy waking. Suggesting that reducing interference from ongoing sensory input and cognitive activities during waking, can facilitate learning (Wilhelm et al., 2011). Napping provides an opportunity for memory consolidation, similarly to overnight sleep. During a nap, the brain processes and consolidates newly acquired information, enhancing memory retention, and strengthening the neural connections associated with auditory learning. This consolidation process helps to solidify the learned auditory information and facilitate its integration into long-term memory. Napping also allows for a period of reduced sensory input

and cognitive activity (M. Tucker et al., 2006). This reduction in external stimuli and cognitive load can minimize interference from ongoing sensory input and other cognitive processes that may interfere with auditory learning (Alger et al., 2012). Napping can help restore attention and alertness, which are essential for effective auditory learning. Fatigue and decreased alertness can impair learning performance and increase susceptibility to interference. By taking a nap, individuals can restore their cognitive resources, improving their ability to sustain attention and concentrate on the auditory stimuli, leading to better learning outcomes (Huber, 2007). These cognitive improvements can positively impact auditory learning by facilitating the encoding, storage, and retrieval of auditory information (Kurdziel et al., 2017). By enhancing these cognitive processes, a nap can optimize the capacity to perceive and comprehend auditory stimuli, leading to more effective learning and retention (Gottselig et al., 2004) .

1.6   Naps for Enhanced Generalized Auditory Learning

Incorporating naps into the comprehension training of synthesized speech may protect against diminished performance due to wakefulness and facilitate consolidation of generalized learning (Gottselig et al., 2004). Napping can help restore cognitive resources, reduce fatigue, and enhance alertness. If participants were fatigued or experienced a decline in cognitive performance during the earlier post-tests, a nap could provide an opportunity for recovery and restoration of cognitive abilities (Kurdziel et al., 2017). This restoration could contribute to better long-term performance on the later post-tests. During wakefulness, there is a higher likelihood of interference from new stimuli or information, which can affect memory retrieval and performance. Taking a nap between the second post-test in block4 and third post-test in block5 might provide a period of reduced sensory input and cognitive processing, reducing the potential interference that could impact performance.

The ability to hold onto bits of information while making a decision plays a significant role in cognitive abilities and allows humans to develop complex abilities (Shelton et al., 2010). For example, when an individual is faced with a novel word mid-sentence, they can infer the meaning of the word by rehearsing it in their memory while waiting to receive the remainder of the sentence to gain context, which will inform their decision as to the meaning of the novel word. With the identification of working memory being an important factor in developing higher level cognitive abilities, there has been a great interest in enhancing this memory system in order to boost human performance (Shelton et al., 2010). Research in this line of work focuses on the top-down cognitive processes of attention in use of working memory. This approach has been supported by research suggesting that working memory can be used more efficiently by using attention to guide individuals in selecting the most relevant information to making a decision (Francis, 2002).

Hypothesis: Participants who take a nap will exhibit greater retention of learning of computer synthesized speech following the nap than those who remained awake.

Based on the existing research, we hypothesize that participants who engage in a period of sleep after the learning task will demonstrate better retention and improved performance on the recognition and comprehension of computer synthesized speech compared to participants who remain awake during the same period (Fenn et al., 2003; Gottselig et al., 2004). We expect the waking group to experience some decay or interference in their learning, while the sleep group will exhibit better consolidation of learning (M. Tucker et al., 2006). The group that remains awake without napping might experience some degree of cognitive fatigue or

diminishing attentional resources over time. Given this we can anticipate potential differences in performance between the two groups (one taking a nap and the other remaining awake) from the first post-test to last post-test. Without the opportunity for rest and consolidation provided by a nap, their performance may plateau or show a slight decline on subsequent tests (Kurdziel et al., 2017). Factors related to cognitive fatigue could potentially impact their ability to sustain attention and retain information. Taking a nap between testing sessions could enhance memory consolidation processes, leading to better retention of the learned material (Lahl et al., 2008). Additionally, the restorative effects of the nap could mitigate fatigue and cognitive decline, resulting in improved performance on subsequent tests. If the effects of napping manifest predominantly after the nap itself, we might not observe substantial differences between the two groups until post-test four (Gottselig et al., 2004). In this case, performance in both groups may be similar up until the test immediately preceding a nap, but the nap group may demonstrate an improvement or a smaller decline on subsequent tests compared to the awake group.

2   Methods

This study aimed to investigate the effect of napping on generalized auditory learning using a computer synthesized speech learning task. Participants were pre-screened for conditions which may impact auditory processing or sleep mechanisms. The study followed a 12-hour laboratory experiment with six task blocks from 9:00 AM to 9:00 PM, consisting of pre-test, training, and post-tests at different intervals. During which the experimental group was instructed to take a ninety-minute nap, while the control group remained awake. To measure learning and retention, the researchers calculated scores based on the number of correctly interpreted words at various stages of the synthetic speech learning tasks.

2.1   Participants

Participants (n = 23) were pre-screened to participate in this study. All reported English as their native language, with no history of speech difficulty, hearing problems, ringing in ears, dyslexia, cochlear implants, poor or uncorrected vision, or current ear infection. Twelve participants were randomly assigned to the sleeping condition, and the remaining eleven participants were randomly assigned to the awake control group.

2.2   Synthetic Speech Learning Task

A synthetic speech learning task was adopted from earlier studies in our lab in which participants listened to computer generated monosyllabic consonant-vowel-consonant words taken from a phonetically balanced list and responded by typing the word (Fenn et al. 2003). Following a standard lab paradigm for assessing perceptual learning of synthesized speech was used, participants completed a pre-test (80 words), training (300 words), and post-test (80 words). Presentation of words was randomized such that no word was repeated, resulting in participants hearing each word only once throughout the task. During training participants listened to the word, typed out their answer, and were provided with the correct word as feedback. Pre- and post-test were administered before and after the training session, in which participants listened to words, typed their response, but did not receive feedback.

2.3   Procedure

Participants were initially screened to be native English speakers without current pathological conditions which may affect listening abilities. The study consisted of 6 task blocks over the course of twelve hours from 9:00AM to 9:00PM. Participants entered the lab at 9am for

study preparation. Participants began the study at 10am, starting with block1 for pre-test, block2

for training, and block3 for the first post-test (See Table 1). An auditory N-back task and

questionnaires were administered after block3. At 2:30PM, after completion of the working

memory task, both groups completed block4 for the second post-test. The experimental

intervention occurred from 3:00PM-4:30PM, during which the experimental group was

instructed to take a nap and the control group received a break. During the break period for the

control group, participants were not allowed to leave the lab or sleep, but they were allowed to

engage in other tasks (such as homework or video games). At 5PM, after the experimental

intervention, both groups completed block5 for the fourth post-test. Final post-test was

administered at 9:00PM in block6. Participants completed both listening tasks using Sennheiser

headphones with a pre-amp and were allowed to self-adjust volume to a comfortable level.

Block(s)	Time	Task
1-3	10:00 AM	Pre-Test, Training, Post-test
4	2:30 PM (right before sleep)	Post-test
Sleep/Wake	3:00-4:30 PM	
5	5:00 PM (right after sleep)	Post-test
6	9:00 PM (after break)	Post-test

Table 1. Temporal Layout of study tasks

3   Results

A laboratory experiment was carried out with the use of working memory and synthetic

speech learning tasks. Participants were randomly assigned to sleep and wake conditions.

Performance was assessed in terms of a learning rate on synthetic speech learning. These results were considered in respect to outcomes post sleep session.

Learning and retention were calculated from performance on the synthetic speech learning task. A pre- and post-test score was calculated as ratio of correctly interpreted words to total number of words tested. Represented as n(correct)/n(total), where n is the number of responses. Learning was calculated by subtracting the pre-test from post-test1 score, such that $learning = block3 - block1$. Retained learning was calculated by subtracting the pre-test from fourth post-test, $Retained\ Learning = block6 - block1$. Retention then was calculated by subtracting learning from retained learning, $Retention = Retained\ Learning - Learning$.

Measure	**Calculation**
Learning	$posttest1[block3] - pretest[block1]$
Retained Learning	$posttest4[block6] - pretest[block1]$
Retention	$Retained\ Learning - Learning$

Table 2. *Formulae for calculation of retention based on task performance. Tasks listed with corresponding block*

3.1   Statistical Analysis

The findings revealed no statistically significant distinctions in learning and retention between the nap group and the awake control group. An ANOVA was conducted to investigate if the retention of learning significantly differed between the two groups due to the intervention of taking a nap. The mean and standard deviation values for each group indicate that, on average, the nap group (mean = -0.071, SD = 0.062) had slightly less loss of learning than the awake control group (mean = -0.083, SD = 0.061). However, the lack of statistical significance (F-stat =

0.358, p > 0.05) suggests that this difference in retention scores could have occurred by chance and is not a meaningful effect of the nap intervention. (See Fig.1) Since the p-value is greater than the alpha level of 0.05, we fail to reject the null hypothesis, which means that there is not enough evidence to claim that there is a significant difference in learning retention between the two groups. We conducted post-hoc test on the difference in retention between the two groups by measuring effect size using Cohen's d. The resulting Cohen's d of 0.46 still represents a moderate effect size, indicating that there may be a practical difference in learning retention between the groups.

	Sleep			Wake			*ANOVA*	
	M	SD	Var	*M*	SD	Var	F-statistic	P-value
Retention	-0.071	0.062	0.004	-0.083	0.061	0.004	0.358	0.556
Learning Retention	0.092	0.087	0.008	0.055	0.080	0.006	1.120	0.302
Learning	0.175	0.086	0.007	0.126	0.068	0.005		

Figure 1. Mean values for variables by group. ANOVA results for differences in retention and learning retention
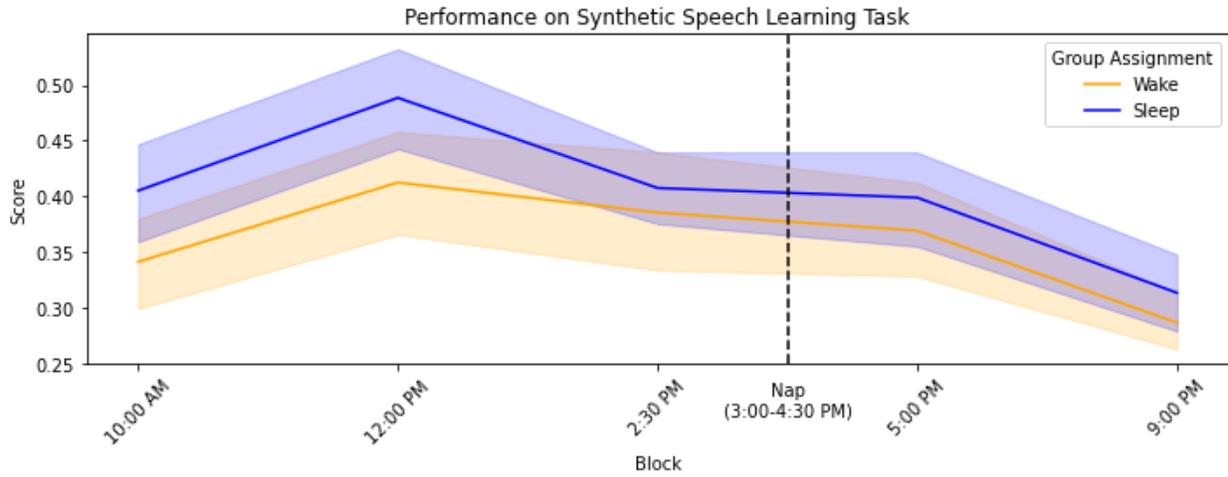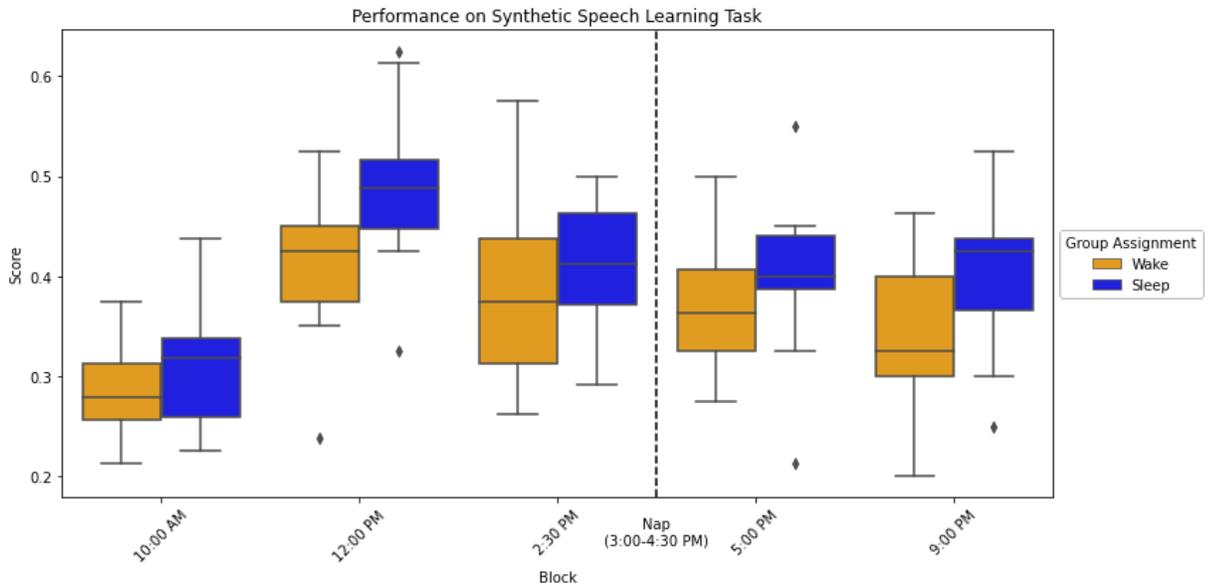
Fig 2. Performance on comprehension tests over time

Fig 3. Performance on comprehension tests over time with variance
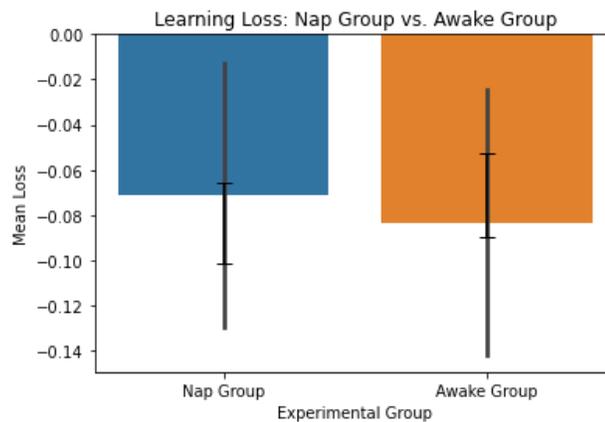

Fig 4. Average Retention of Learning as loss from initial test

4   Discussion

The study sought to explore the impact of napping on generalized auditory learning using a synthetic speech learning task. Participants engaged in the process of generalized auditory learning, allowing them to improve their ability to detect subtle acoustic differences, recognize phonetic patterns, and apply their knowledge to unfamiliar words (Heald et al., 2022). As a result, they became more skilled in comprehending and interpreting computer synthesized speech, leading to enhanced performance in the learning task. Generalized auditory learning boosted their perceptual abilities and pattern recognition skills, which in turn enabled them to successfully complete the learning task and demonstrate improved recognition and understanding of computer synthesized speech (Brawn et al., 2008; Francis et al., 2000).

The aim was to explore whether taking a nap after the learning task will lead to better retention and improved performance on recognizing and comprehending computer synthesized speech compared to participants who remain awake. The study involved two groups, one assigned to take a nap between post-tests and the other remaining awake throughout the experiment. The hypothesis suggested that the nap group will demonstrate better retention and improved performance due to limitation of interference from competing information sources in memory and better consolidation of learning during sleep. However, the statistical analysis did not find significant differences between the experimental groups.

Conducting post-hoc test on the difference in retention between the two groups by measuring effect size using Cohen's d. Effect size measures the magnitude of the difference between two groups or conditions in a study. It is a standardized measure that allows researchers to understand the practical significance or meaningfulness of the observed difference. The Cohen's d of 0.46 indicates that the nap intervention has a moderate effect on learning and

retention compared to the control group. This finding could still be valuable and relevant, particularly when considering the potential benefits of napping for memory consolidation and learning enhancement. However, because the ANOVA did not reach statistical significance, it suggests that the sample size may not have been large enough to detect the effect reliably. running the experiment with a larger sample size can increase the statistical power, making it more likely to detect the true effect if it exists. Additionally, considering the moderate effect size (Cohen's d = 0.46), a larger sample size may help to confirm whether the observed effect is reliable and practically meaningful.

The study's results do not support the initial hypothesis that taking a nap would lead to significantly better retention and learning outcomes compared to remaining awake. The findings suggest that the nap intervention did not have a significant impact on generalized auditory learning in this particular experimental setting. It is essential to acknowledge that not all experiments yield statistically significant results, and in this case, the observed differences were not strong enough to be considered statistically meaningful. Further research and a larger sample size might be needed to draw more definitive conclusions about the effects of napping on learning retention in the context of synthetic speech learning.

Given the findings of prior research, we expected learning to occur from pre-test to the first post-test. Then performance on subsequent post-tests was expected to decrease but the degree of decrease is expected to be less on post-tests once the participant has slept (Fenn et al., 2003). Though the nap group did show a higher retention on average, our statistical analysis of learning between post-tests did not show significant effects of intervention, indicating that performance on the specific learning tasks did not differ between post-tests whether the participant had slept or not.

4.1   Further Research

Expanding the sample size would increase the statistical power of the study, making it more likely to detect small but meaningful effects and strengthen the generalizability of the findings. With a larger sample, we can better assess whether the observed trends in learning and retention are consistent across a broader population, providing more reliable conclusions.

Additional analysis may help gain further insights regarding the encoding of information in the synthetic speech learning task. The observed learning in these auditory learning tasks was based on a binary coding of correct/incorrect responses. Though learning may have still occurred as greater intelligibility of synthetic speech, so an additional analysis of distance between response and answer could show change in overall similarity scores between expected and actual results. Which could indicate increased performance by a shifting of attentional cues mediated by working memory, though not enough to correctly comprehend a given word.

In addition to the benefits of a larger sample, the integration of brain activity using electroencephalography (EEG) into the study would provide unique insights into the neural processes underlying auditory learning. EEG offers a real-time assessment of brain activity during the learning task, revealing moment-to-moment changes in neural responses to auditory stimuli (Heald et al., 2022). This neurophysiological data would complement the behavioral measures, providing a more comprehensive understanding of how the brain processes and encodes auditory information during learning. By analyzing EEG data, we could scrutinize neural markers of successful learning and memory consolidation. This would unveil specific brain regions and networks engaged in the generalized auditory learning process, unveiling the neural architecture supporting the adept comprehension of computer synthesized speech.

Moreover, EEG can detect shifts in cognitive load and attentional capacity, enabling us to evaluate the impact of napping on cognitive fatigue and learning performance. The combination of EEG and behavioral data would allow for more sophisticated analyses, such as event-related potentials (ERPs) and frequency domain analyses (Alger et al., 2012). ERPs would reveal specific patterns of brain activity in response to stimuli, providing insights into the timing and processing of auditory information during learning. Frequency domain analyses would explore changes in brain oscillations related to learning and memory consolidation, offering a more comprehensive picture of the neural dynamics during the task.

Combining a larger sample size with EEG measurements would significantly strengthen the current study's scientific rigor and enrich our understanding of auditory learning and memory consolidation. A larger sample would improve statistical power and generalizability, while EEG would offer real-time insights into neural processes during the learning task. This integration of approaches would provide a more comprehensive and nuanced understanding of the cognitive and neural underpinnings of auditory learning, with potential ramifications for personalized learning interventions and educational practices (Heald et al., 2022). This open's a particularly fruitful avenue for deploying generalized learning interventions such as naps that optimize participant performance.

In conclusion, this study contributes to our understanding of generalized auditory learning and its interaction with sleep in the context of computer-synthesized speech. Despite the lack of significant differences in learning outcomes between the nap and awake groups, both groups exhibited evidence of generalized learning, highlighting the robustness of this cognitive process. The study provides valuable insights into the complex relationship between sleep,

learning, and memory consolidation and paves the way for future investigations into optimizing

learning interventions for improved cognitive performance.

Data and Code Availability Statement

The data collected in this study is available on GitHub via the DOI link in the citation below:

Alex Przybycin. (2023). Performance Naps: Exploring the Role of Naps in Auditory

Generalized Learning. Zenodo. https://doi.org/10.5281/zenodo.8173289

Acknowledgment

I would like to acknowledge and express gratitude to Howard Nusbaum and the

Attention, Perception, and EXperience (APEX) Lab for providing the data for this research.

Without their mentorship and gracious support during the COVID-19 pandemic, this thesis on

sleep and perceptual learning would not have been possible.

References

Alger, S. E., Lau, H., & Fishbein, W. (2012). Slow wave sleep during a daytime nap is necessary for protection from subsequent interference and long-term retention. *Neurobiology of Learning and Memory*, *98*(2), 188–196. https://doi.org/10.1016/j.nlm.2012.06.003

Anderson, J. R., Bothell, D., Byrne, M. D., Douglass, S., Lebiere, C., & Qin, Y. (2004). An Integrated Theory of the Mind. *Psychological Review*, *111*(4), 1036–1060. https://doi.org/10.1037/0033-295X.111.4.1036

Batterink, L. J., Oudiette, D., Reber, P. J., & Paller, K. A. (2014). Sleep facilitates learning a new linguistic rule. *Neuropsychologia*, *65*, 169–179. https://doi.org/10.1016/j.neuropsychologia.2014.10.024

Bradlow, A. R., & Bent, T. (2008). Perceptual adaptation to non-native speech. *Cognition*, *106*(2), 707–729. https://doi.org/10.1016/j.cognition.2007.04.005

Brawn, T. P., Fenn, K. M., Nusbaum, H. C., & Margoliash, D. (2008). Consolidation of sensorimotor learning during sleep. *Learning & Memory*, *15*(11), 815–819. https://doi.org/10.1101/lm.1180908

Cedernaes, J., Sand, F., Liethof, L., Lampola, L., Hassanzadeh, S., Axelsson, E. K., Yeganeh, A., Ros, O., Broman, J.-E., Schiöth, H. B., & Benedict, C. (2016). Learning and sleep-dependent consolidation of spatial and procedural memories are unaltered in young men under a fixed short sleep schedule. *Neurobiology of Learning and Memory*, *131*, 87–94. https://doi.org/10.1016/j.nlm.2016.03.012

Censor, N., Karni, A., & Sagi, D. (2006). A link between perceptual learning, adaptation and sleep. *Vision Research*, *46*(23), 4071–4074. https://doi.org/10.1016/j.visres.2006.07.022

Fenn, K. M., Nusbaum, H. C., & Margoliash, D. (2003). Consolidation during sleep of

   perceptual learning of spoken language. *Nature*, *425*(6958), 614–616.

   https://doi.org/10.1038/nature01951

Francis, A. L., Nusbaum, H. C., & Fenn, K. (2007). Effects of Training on the Acoustic–Phonetic

   Representation of Synthetic Speech. *Journal of Speech, Language, and Hearing*

   Research, *50*(6), 1445–1465. https://doi.org/10.1044/1092-4388(2007/100)

Gómez, R. L., Bootzin, R. R., & Nadel, L. (2006). Naps Promote Abstraction in Language-

   Learning Infants. *Psychological Science*, *17*(8), 670–674. https://doi.org/10.1111/j.1467-

   9280.2006.01764.x

Gottselig, J. M., Hofer-Tinguely, G., Borbély, A. A., Regel, S. J., Landolt, H.-P., Rétey, J. V., &

   Achermann, P. (2004). Sleep and rest facilitate auditory learning. *Neuroscience*, *127*(3),

   557–561. https://doi.org/10.1016/j.neuroscience.2004.05.053

Heald, S. L. M., Van Hedger, S. C., Veillette, J., Reis, K., Snyder, J. S., & Nusbaum, H. C.

   (2022). Going Beyond Rote Auditory Learning: Neural Patterns of Generalized Auditory

   Learning. *Journal of Cognitive Neuroscience*, *34*(3), 425–444.

   https://doi.org/10.1162/jocn_a_01805

Hoedlmoser, K., Peigneux, P., & Rauchs, G. (2022). Recent advances in memory consolidation

   and information processing during sleep. *Journal of Sleep Research*, *31*(4).

   https://doi.org/10.1111/jsr.13607

Huber, R. (2007). Memory Formation: Sleep Enough before Learning. *Current Biology*, *17*(10),

   R367–R368. https://doi.org/10.1016/j.cub.2007.03.029

Journal of Sleep Research—2008—LAHL - An ultra short episode of sleep is sufficient to

   promote declarative memory.pdf. (n.d.).

Kemény, F., & Lukács, Á. (2016). Sleep-independent off-line enhancement and time of the day

    effects in three forms of skill learning. *Cognitive Processing*, *17*(2), 163–174.

    https://doi.org/10.1007/s10339-016-0750-0

Kurdziel, L. B. F., Mantua, J., & Spencer, R. M. C. (2017). Novel word learning in older adults:

    A role for sleep? *Brain and Language*, *167*, 106–113.

    https://doi.org/10.1016/j.bandl.2016.05.010

Lahl, O., Wispel, C., Willigens, B., & Pietrowsky, R. (2008). An ultra short episode of sleep is

    sufficient to promote declarative memory performance. *Journal of Sleep Research*, *17*(1),

    3–10. https://doi.org/10.1111/j.1365-2869.2008.00622.x

Lau, H., Alger, S. E., & Fishbein, W. (2011). Relational Memory: A Daytime Nap Facilitates the

    Abstraction of General Concepts. *PLoS ONE*, *6*(11), e27139.

    https://doi.org/10.1371/journal.pone.0027139

Lau, H., Tucker, M. A., & Fishbein, W. (2010). Daytime napping: Effects on human direct

    associative and relational memory. *Neurobiology of Learning and Memory*, *93*(4), 554–

    560. https://doi.org/10.1016/j.nlm.2010.02.003

Mednick, S. C., Cai, D. J., Kanady, J., & Drummond, S. P. A. (2008). Comparing the benefits of

    caffeine, naps and placebo on verbal, motor and perceptual memory. *Behavioural Brain*

    Research, *193*(1), 79–86. https://doi.org/10.1016/j.bbr.2008.04.028

Mednick, S., Nakayama, K., & Stickgold, R. (2003). Sleep-dependent learning: A nap is as good

    as a night. *Nature Neuroscience*, *6*(7), 697–698. https://doi.org/10.1038/nn1078

Ong, J. L., Lau, T. Y., Lee, X. K., Van Rijn, E., & Chee, M. W. L. (2020). A daytime nap restores

    hippocampal function and improves declarative learning. *Sleep*, *43*(9), zsaa058.

    https://doi.org/10.1093/sleep/zsaa058

Poggio, T., & Bizzi, E. (2004). Generalization in vision and motor control. *Nature*, *431*(7010), 768–774. https://doi.org/10.1038/nature03014

Ruch, S., Valiadis, M., & Gharabaghi, A. (2021). Sleep to learn. *Sleep*, *44*(8), zsab160. https://doi.org/10.1093/sleep/zsab160

Shelton, J. T., Elliott, E. M., Matthews, R. A., Hill, B. D., & Gouvier, Wm. D. (2010). The relationships of working memory, secondary memory, and general fluid intelligence: Working memory is special. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(3), 813–820. https://doi.org/10.1037/a0019046

Stickgold, R. (2004). Dissecting Sleep-Dependent Learning and Memory Consolidation. *Sleep*, *27*(8), 1443–1445. https://doi.org/10.1093/sleep/27.8.1443

Tucker, M. A., & Fishbein, W. (2008). *Enhancement of Declarative Memory Performance Following a Daytime Nap Is Contingent on Strength of Initial Task Acquisition*. *31*(2).

Tucker, M., Hirota, Y., Wamsley, E., Lau, H., Chaklader, A., & Fishbein, W. (2006). A daytime nap containing solely non-REM sleep enhances declarative but not procedural memory. *Neurobiology of Learning and Memory*, *86*(2), 241–247. https://doi.org/10.1016/j.nlm.2006.03.005

Wagner, U., Gais, S., Haider, H., Verleger, R., & Born, J. (2004). Sleep inspires insight. *Nature*, *427*(6972), 352–355. https://doi.org/10.1038/nature02223

Wagner, U., Kashyap, N., Diekelmann, S., & Born, J. (2007). The impact of post-learning sleep vs. Wakefulness on recognition memory for faces with different facial expressions. *Neurobiology of Learning and Memory*, *87*(4), 679–687. https://doi.org/10.1016/j.nlm.2007.01.004

Walker, M. P., & Stickgold, R. (2004). Sleep-Dependent Learning and Memory Consolidation. *Neuron*, *44*(1), 121–133. https://doi.org/10.1016/j.neuron.2004.08.031

Werchan, D. M., & Gómez, R. L. (2013). Generalizing memories over time: Sleep and reinforcement facilitate transitive inference. *Neurobiology of Learning and Memory*, *100*, 70–76. https://doi.org/10.1016/j.nlm.2012.12.006

Wilhelm, I., Diekelmann, S., Molzow, I., Ayoub, A., Mölle, M., & Born, J. (2011). Sleep Selectively Enhances Memory Expected to Be of Future Relevance. *The Journal of Neuroscience*, *31*(5), 1563–1569. https://doi.org/10.1523/JNEUROSCI.3575-10.2011

Wislowska, M., Heib, D. P. J., Griessenberger, H., Hoedlmoser, K., & Schabus, M. (2017). Individual baseline memory performance and its significance for sleep-dependent memory consolidation. *Sleep Spindles & Cortical Up States*, *1*(1), 2–13. https://doi.org/10.1556/2053.1.2016.001

Appendix

Participant ID Code (for experimenter use only)

THE UNIVERSITY OF CHICAGO

CENTER FOR COGNITIVE AND SOCIAL NEUROSCIENCE

Date: _____   ID#: _____

Evening of:_____

1.   Time you went to bed:_____
2.   Approximately how long did it take you to fall asleep? _____
3.   Time that you got out of bed in the morning: _____
4.   Did you feel well-rested when you awoke?   Yes   No
5.   Approximately how many times did you awake last night? _____
      a)   What was the total amount of time that you were awake (approximately)? _____
6.   What is the total amount of time that you slept? _____

Evening of:_____

1.   Time you went to bed:_____
2.   Approximately how long did it take you to fall asleep? _____
3.   Time that you got out of bed in the morning: _____
4.   Did you feel well-rested when you awoke?   Yes   No
5.   Approximately how many times did you awake last night? _____
      a)   What was the total amount of time that you were awake (approximately)? _____
6.   What is the total amount of time that you slept? _____

Evening of:_____

1.   Time you went to bed:_____
2.   Approximately how long did it take you to fall asleep? _____
3.   Time that you got out of bed in the morning: _____
4.   Did you feel well-rested when you awoke?   Yes   No
5.   Approximately how many times did you awake last night? _____
      a)   What was the total amount of time that you were awake (approximately)? _____
6.   What is the total amount of time that you slept? _____

SL

THE UNIVERSITY OF CHICAGO

CENTER FOR COGNITIVE AND SOCIAL NEUROSCIENCE

Date: _____   ID#: _____

Participant Questionnaire

REMINDERS:

☐ No Alcohol or Drug use starting night before
☐ No caffeinated beverages for 48 hours prior to the experiment
☐ No previous exposure to this task

1. What time do you usually go to sleep?

2. Do you fall asleep easily?

3. How deeply do you sleep (Light, Medium, Deep)?

4. What time do you usually wake up?

5. Do you usually feel well rested?

6. Have you ever sought medical attention for a sleep disorder?

7. Do you have any disabilities that disrupt your sleep?

8. Are you currently taking any medications to help you sleep?

9. Are you taking any other medications?
   (excluding oral contraceptives)

10. Do you have a history of substance abuse or diagnosed major mental illness?

11. How many caffeinated beverages do you drink each day?

SQ

Language Experience Questionnaire

Age: _____

Gender: _____

Primary Language: _____

1. Do you speak any secondary languages?   YES   NO

If so, please list them below, along with your level of proficiency for each:

_____   Basic   Proficient   Semi-Fluent   Fluent

_____   Basic   Proficient   Semi-Fluent   Fluent

_____   Basic   Proficient   Semi-Fluent   Fluent

_____   Basic   Proficient   Semi-Fluent   Fluent

2. In what country were you born?   _____

3. Please list the different areas in which you have lived, including the country, region/state, and number of years. Please write your answers chronologically (earliest to most recent).

_____   _____

_____   _____

_____   _____

_____   _____

_____   _____

_____   _____

(City, State/Province/Region, Country)   (Number of Years)

THE UNIVERSITY OF
CHICAGO
CENTER FOR COGNITIVE AND SOCIAL NEUROSCIENCE

Demographic Information

How old are you?_____years

Are you: ☐ Male   ☐ Female   ☐ Other _____

Are you: ☐ Left-handed   ☐ Right-handed

Are you a student? ☐ Yes   ☐ No

     If yes, what year?

     What is your major / what department are you in?