THE EFFECT OF SLEEP-BASED CONSOLIDATION

ON MOTOR SPEECH LEARNING

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THE EFFECT OF SLEEP-BASED CONSOLIDATION

ON SPEECH MOTOR LEARNING

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Abstract:

This study investigated the effect of sleep on motor speech learning. Forty-five participants practiced a non-meaningful speech phrase and were tested later for retention. Testing occurred 12-24 hours after practice. Participants were split into three groups: a sleep group, a no-sleep group, and a sleep with an extra practice group. Results revealed that participants who slept between practice and delayed retention testing performed better than those who did not. Additionally, those who slept and received an extra practice session did not perform better than those who slept and didn't receive extra practice. These findings expand on the understanding of motor learning and may impact treatment in speech-language pathology.

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CHAPTER I

INTRODUCTION

What is motor learning?

Daily life requires constant movement, from simple gestures like giving a “thumbs up” to more complex actions like playing sports. Some movements seem to be automatic, like swallowing, while others are acquired, like kickboxing. The latter type can be referred to as a skill and is acquired through the process of motor learning. This process begins with practice and leads to a “relatively permanent change” in behavior (Schmidt & Lee, 2011).

Stages of Motor Learning

Motor learning is classified as either explicit or implicit. Implicit learning occurs predominantly without conscious effort and may also be called procedural learning. An example of implicit learning is learning to ride a bike. Alternatively, explicit learning requires conscious effort and direction. An example of this is learning to play tennis. Explicit motor learning can be subdivided into the stages of acquisition, consolidation, and retention (Schmidt & Lee, 2011).

Motor skill acquisition begins with determining how to approach a task (Fitts & Posner, 1979). An individual first processes the requirements and parameters of an action. This stage primarily focuses on sensory feedback and execution of the correct movements, which require deliberate thought and effort. Behavioral outcomes in this stage begin with unskilled andinconsistent movements. As the individual explores different strategies, they discover effective methods, which lead to a rapid and drastic improvement in performance (Luft & Buitrago, 2005).

The next stage is termed consolidation. By now, the individual has discovered an efficient way to enact the movement sequence and their performance accuracy and speed are slowly improved through experience. The individual may consciously control some parts, while others may be controlled below awareness. The motor memories are stabilized, and the focus is long-term storage. They are also now resistant to interference and so are less likely to be disrupted by other motor learning (Schmidt & Lee, 2011).

The transition from consolidation to retention is fluid and not easily identifiable. This late stage is also known as automatization because performance requires little cognitive effort and is mostly automatic (Fitts & Posner, 1979). It takes much practice to arrive at this stage, years for athletes. Movements are reliable and consistent, though small adjustments can still be made, mostly slight alterations for efficiency (Schmidt & Lee, 2011).

Models of motor learning

Though it is clear there are distinct stages of learning, the exact process of motor learning is still unclear. Several theories attempt to explain the exact mechanism at play, each approaching motor learning from a different angle. Some well-recognized theories include the Closed Loop Theory, Schema Theory, and Dynamic Systems Theory.

Closed Loop Theory

The Closed Loop Theory (Adams, 1971) frames motor learning as an interaction between the person performing the movement and the feedback they receive. Heavily rooted in behaviorist principles, movements are theorized to be reinforced through feedback called the known response (KR). The KR can be feedback in various forms, including tactile, visual, and proprioception. This is a closed-loop process where the individual always compares their perceptual trace, or memory of past movement, to KR. When the two do not match, the individual attempts to reconcile the difference by altering their movement in the act of learning.

During the early learning stage or the verbal-motor stage, the individual heavily relies on the KR. Their goal is not to match their perceptual trace but to avoid making the same mistake. As their error rate shrinks and they begin reliably producing the desired response, the individual moves into the second stage, subject reinforcement. The individual's growing experience has strengthened their perceptual trace. This means that by comparing their current movements to their perceptual trace, they can recognize when their actions are correct, and they no longer require outside feedback from KR to learn. As the perceptual trace strengthens, they graduate to the final phase, the motor stage. Now, KR is dropped completely, and the action which once required so much cognitive effort is now automatic.

Schema Theory

Schema Theory (Maas et al., 2008; Schmidt & Lee, 2011) describes movements as occurring through Generalized Motor Programs (GMP), which contain rules regarding muscle commands. Instead of having specific instructions for every slight variation of a movement, GMP's are generalized so that they can conform to many situations. Schemas contain information regarding GMPs in relation to other factors, such as information about sensory input, initial conditions, and possible outcomes. There are two main types of schemas: recall schema and recognition schema. The recall schema collects information regarding the features of the movement, such as speed, timing, etc. The recognition schema compares the sensory information to the expected outcome. Based on these relations, a GMP can be adapted for any situation.

Motor learning occurs when schemas are informed through feedback. After a GMP is executed, information is collected about the outcome. If there is a mismatch between the actual outcome and the expected outcome, the schema is updated. According to this model, learning best occurs when practice contains variability between trials, this way the learner has more information about what works and what does not.

Dynamic Systems Theory

Dynamic Systems Theory (DST) emphasizes the interaction between multiple internal systems and the environment in the production of movement (Thelen, 1989). The model asserts that movement should be studied at the level of system development, not at a discrete level. This is contrasted with the idea that movements occur in isolation, that is, mechanisms are designated for specific tasks. Complex movements are developed by combining previously learned actions and are functionally defined. They do not exist as planned sequences, but rather are a culmination of multiple subsystems wholly bound by the context.

The birth of a new movement occurs through small changes in subsystems. An important distinction here is that the motor plan is not the subject of change; changes in the subsystems themselves galvanize new movements. Additionally, sensation and motor action are perpetually entwined in a feedback loop that shapes movement. Over time, persistent characteristics rise from recurrent actions that are reinforced through feedback from both proprioception and external sensation, which results in the learning of new skills.

Principles of motor learning

Regardless of how the process of motor learning is conceptualized, there are some guiding principles that facilitate the acquisition of new motor skills, known as the principles of motor learning (Mass et al., 2008). They are divided further into factors which involve practice structure and factors that concern feedback type. Variables pertaining to practice include the amount, distribution, variability, schedule, attentional focus, and target complexity, while variables relating to feedback include feedback type, feedback frequency, and feedback timing,

Practice amount refers to how much time is spent on the movements during practice and is measured as small versus large (Maas et al., 2008). Practice distribution is measured as either massed or distributed. The massed practice has less time between trials, while the distributed practice has more time between trials. Practice variability refers to whether practice trials should target the exact same movement repeatedly (constant) or whether the trials should differ in some ways (variable). For example, should a baseball batter practice for the same type of pitch every time, or should they practice for other types of pitches as well? Practice schedule refers to when more than one movement is being practiced. The trials can either follow a specific sequence where the trials are grouped together (blocked), or the trial order can vary and be unpredictable (random). The attentional focus has to do with what the learner is focusing on during practice. They can be focused on internal states like proprioception (internal), or they can focus on external aspects such as the effect of the movement (external). Movement complexity deals with whether a complicated movement should be split into smaller parts (simple) or should be left whole (complex) (Kaipa, 2016).

Feedback can be tailored to the learner and may consist of the known response (KR) or known performance (KP). KR occurs when the learner is informed on how they responded, or whether they missed the target. KP occurs when the learner is informed about the quality of their performance. Feedback frequency refers to how often the learner is given feedback. More frequent feedback is “high,” while less frequent feedback is “low.” Feedback timing deals with when the learner is notified of their performance. Feedback can be provided immediately after they complete the movement (immediate), or it can be provided a few seconds later (delayed) (Maas et al., 2008). The different PMLs are depicted below in Table 1.

Sleep and motor learning

While there is no doubt that the above principles of motor learning shape the process of motor learning significantly, a variable that is often overlooked in research pertaining to motor learning is the effect of sleep. Interestingly, sleep is known to influence learning novel motor learning skills.

Sleep is a state of consciousness where an individual is less active and less responsive to stimuli; it is reversible, natural, and homeostatically regulated (Rasch & Born, 2013). Sleep consists of two main stages: rapid eye movement (REM) and non-rapid eye movement (NREM) sleep and it is structured into 90-minute cycles (Stickgold, 2005). NREM sleep is divided into light sleep (LS) and slow wave sleep (SWS). In much of sleep literature, the early stages of sleep are known as LS or stage 1 and stage 2 sleep, and the later stages of sleep are stages 3 and 4. LS and SWS differ from each other on a neurophysiological level (Genzel et al., 2013), and SWS has been shown to aid in memory consolidation.

Biochemical Processes Involved with Encoding and Consolidation

Sleep is implicated in the process of motor learning in numerous previous studies (Christova et al., 2018; Gudberg & Johansen-Berg, 2015; Rasch & Born, 2013; Sheth et al., 2008; Siengsukon & Boyd, 2009). Memory formation can be broken down into two main stages: encoding and consolidation. The brain first inputs information during a wakeful state through the encoding stage. This includes the acquisition phase of motor learning and manifests in the brain as a process known as Long Term Potentiation (LTP), or the formation of new synaptic connections in the brain (Rasch & Born, 2013). These new memories are primarily stored in the primary motor cortex of the frontal lobe (Galea et al., 2011).

Next comes the process of consolidation, which occurs while we are asleep. Memories are consolidated during sleep through re-activation (Marshall & Born, 2007). The connections between the frontal cortex and the hippocampus are repeatedly activated and strengthened during SWS. This process incorporates them into existing networks. It is also likely that new memories are stabilized during sleep through a process called Long Term Depression (LTD) (Rasch & Born, 2013). Synaptic connections made during the encoding process of learning include both correct responses (signal) and erroneous responses (noise). During LTD, the weaker connections made by error responses are erased, and the memory is enhanced by increasing the signal-to-noise ratio. Some studies emphasize the cyclical nature of sleep and propose a role for REM sleep in consolidation as well (Ficca & Salzarulo, 2004; Giuditta et al., 1995). Other studies point out that REM may play a larger role in implicit memory, while SWS is more important for explicit memory (Maquet, 2001).

The role of sleep in motor learning

Several studies have investigated the effect of sleep on motor learning. One such study (Walker et al., 2002), measured the learning of simple finger movements on a keyboard across four different groups. In this study, participants were trained on a finger movement task and then were tested at different times to measure retention. Sleep was manipulated by controlling the time that the training took place and the time that performance was measured. If the period between training and testing was overnight, it was assumed that the participants slept. Group 1 finished one training session and then was tested regularly for the rest of the day to assess performance over the passage of time. Group 2 completed a training session and then was tested both 12 hours (without sleep) and 24 hours (with sleep) later. Group 3 was the same as group 2, except they wore mittens between the training and the 12-hour (without sleep) test to account for fatigue from finger movements. Finally, group 4 was trained in the evening, tested 12 hours later (with sleep), and then again 24 hours later (no additional sleep). They found that performance was not significantly increased in any of the groups when the subjects were tested 12 hours later without sleep. However, their performance showed a 20% improvement when tested after a night of sleep. This suggests that sleep plays an integral role in the motor learning process.

One year later, the same authors (Walker et al., 2003) completed another study using a similar task. Participants were trained in a finger movement task and then tested later to measure performance. Sleep was again manipulated by the time of day, but the timing for each group varied from the previous study. Group 1 was given one training session and tested periodically over 36 hours. Group 2 completed one training session and then was tested 24 hours later. Group 3 was given two training sessions and then were tested 24 hours later. The results revealed four interesting findings. (1) The findings corroborated the results from the previous session. (2) Both speed and accuracy improved after a night of sleep, more than the predicted performance from practice alone. (3) The amount of practice did not influence the speed or accuracy of performance on the following day. This suggests that there are two separate processes occurring, a practice-dependent learning, and a sleep-dependent learning. (4) The bulk of improvement occurred after the first night of sleep, but improvement continued for at least three nights.

More recently, Malangré and Blischke (2016) investigated sleep and motor learning using an arm movement task. Participants maneuvered a handheld peg into holes in a pegboard, which required a specific arm movement sequence. The study began with a practice session and then participants were tested three times: (1) 15 minutes later, (2) 12 hours later, and (3) 24 hours later. To investigate the effect of sleep, all participants began the study at two different times of the day, thus the sleep interval was manipulated to occur either between test 1 and test 2 or between test 2 and test 3. Group 1 completed training during the morning, were tested 12 hours later in the evening, then were tested again in the morning, a total of 24 hours after the training session. Group 2 completed training in the evening, were tested 12 hours later in the morning, and then 24 hours later in the evening. In both groups, performance was significantly increased after a period of sleep, and was unchanged after a period of no sleep. This is consistent with previous findings that suggest sleep has a positive effect on memory consolidation.

Another study (Al-Sharman & Siengsukon, 2013) used a novel walking task to investigate the role of sleep in learning a functional motor task. Outcomes from both the amount of time taken to walk around the path and spatio-temporal gait were measured. Two groups underwent a practice procedure and then were tested 12 hours later. Group 1 practiced in the morning and then was tested at night, with no sleep in between, and group 2 completed practice at night and then were tested in the morning, after a night of sleep. An Actigraph wristwatch was used to ensure that participants in the sleep group slept and that participants in the no sleep group did not sleep. Results revealed that group 2, which slept in between practice and testing, took significantly less time to complete the walking task and showed an improvement in spatio-temporal gait measures, while the group that did not sleep had no significant difference in time or spatio-temporal gait measures. This suggests that sleep aids not only in small tasks, but also in more complicated and functional tasks as well.

The studies above illustrate that sleep undoubtedly enhances motor learning. However, a major shortcoming in the previously published literature is that the effect of sleep on speech motor speech has not been systematically examined. While it is logical to assume that the findings of sleep on limb-based motor learning experiments would be applicable to speech motor learning as well, it is important to understand that speech motor movements differ from limb movements regarding neurophysiology. To address this shortcoming, the current study aimed to investigate the effect of sleep on learning novel speech utterances. We also were interested in investigating if additional practice combined with sleep would yield additive learning benefits. To this end, three groups of participants were recruited to practice novel speech utterances. Practice amount and sleep was experimentally manipulated among the three groups of participants. Participants in Group A participated in a baseline session, followed by a practice session. They came back after an interval of 12 hours for a delayed retention session. Participants in Group B participated in a baseline session, followed by a practice session. They came back for a second practice session after an interval of 12 hours. Following this, they participated in a delayed retention test after an overnight sleep and was about 12 hours after the second practice session. Finally, participants in Group C participated in a baseline session and a practice session. They came back for a delayed retention session after an interval of 24 hours, which included an overnight sleep. Through this experimental design, we posed two research questions: (1) What is the role of sleep on learning novel speech utterances? (2) Will there be a role of practice amount in addition to sleep in learning novel speech utterances? Based on the previous literature, it is hypothesized that: (1) Groups B and C will perform better than Group A, and (2) Group C will not perform any better than Group

CHAPTER II

METHODS

Participants

A total of 45 healthy participants served as participants in the study. Among the 45 participants, 17 participants identified to be male and the remaining identified to be female. The age of the participants ranged from 18 to 50 years with the mean age being 26.65 years (SD = 8.58). To determine the sample size, a power analysis was conducted using G* Power 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009). For a mixed-effect model and a small-moderate effect size (partial eta squared – 0.3), the power analysis indicated a sample size of N = 39. It was decided to recruit a total of 45 participants to allow room for participant attrition, if any. The participants were recruited from the student body at Oklahoma State University and the local community through non-probability convenience sampling. The inclusion criteria were (1) completion of a high school diploma, (2) no history of speech, language, sensory, and/or cognitive disorders, (3) and no history of insomnia. Participants were instructed not to ingest any more caffeine than usual and no alcohol during the study period. All participants were required to wear sleep trackers throughout the duration of the experiment and record sleep duration and quality via a self-report questionnaire.

Procedures

The participants were randomly and equally assigned to three experimental groups (A, B & C). Regardless of the experimental differences among the three practice groups, all participants practiced producing a non-meaningful phrase, "Thak glers wur vasing veen arad moovly" (hereafter referred to as “the target speech phrase”). The non-meaningful phrase was chosen in accordance with the ‘Challenge Point Framework” which suggests that for motor learning to occur, the target stimulus should be sufficiently challenging (Guadagnoli & Lee, 2004). In addition, this phrase has been successfully used in previous experiments to examine speech motor learning outcomes (e.g., Kaipa, Robb, & Jones, 2017).

Prior to beginning the experiment, the participants were administered the Pittsburgh Sleep Quality Index (Buysse et al., 1989) to examine the participants’ sleep quality, the Stanford Sleepiness Scale (Hoddes et al., 1973) to assess their current sleepiness, and the Mental Health Inventory (MHI-5) (Berwick et al., 1991) to assess untreated mental illness. Participants were also asked about recent caffeine, nicotine, and alcohol consumption. Following this, the participants were debriefed on the nature of the experiment and motivated to learn the target phrase.

Participants in all three groups completed a baseline phase, an immediate retention phase, and a delayed retention phase. Participants in Group A attended two appointments. The first appointment was scheduled in the morning and contained a baseline session and a practice session, followed by an immediate retention session. They came back after an interval of 12 hours for the second appointment, where they participated in a delayed retention session. Similarly, participants in Group B attended an initial morning appointment including a baseline, practice, and an immediate retention session, then returned after 24 hours for a second appointment consisting of a delayed retention session. Finally, Group C participated in the initial morning appointment of baseline, practice, and immediate retention, then attended two additional appointments. The second appointment was scheduled 12 hours after the initial session, in the evening after a period of wakefulness. This appointment contained a delayed retention test, an additional practice session, and an immediate retention test. The third appointment was scheduled 24 hours after the initial appointment and contained a delayed retention test. The only difference between participants in Groups B and C is that the participants in Group C received an additional practice session. An illustration of the experimental design is shown in Figure 1.

To collect the baseline data, all participants viewed the speech phrase just once and then reproduced the speech phrase 10 times without visual or auditory feedback. The practice regime was carried out using a PowerPoint presentation. Each slide in the presentation included an orthographic rendition of the phrase along with its auditory representation. The auditory representation was recorded by a healthy adult female speaker. After the auditory presentation of the speech phrase in each slide, the participant verbally produced the target speech phrase. The complete production of the speech phrase following the orthographic and auditory accompaniments comprised one practice trial. The participants completed this step 50 times for a total of 50 practice trials. After every 10 practice trials, the researcher provided summary feedback to the participant, which included how the participant performed for each production. Immediate retention occurred directly after the practice session, where participants produced 10 trials of the phrase without auditory or visual cues. The same procedure took place after a delayed period for delayed retention.

Data analysis

The outcome measure for evaluating speech motor learning involved calculating the Percentage of Phoneme Correct (PPC) (Shriberg et al., 1997). This measure is not only known to be a sensitive indicator of non-word repetition but has also been used successfully to evaluate speech motor learning outcomes in previous studies (e.g., Kaipa, 2016). During each of the baseline, immediate as well as delayed retention phases, each of the 10 production trials were transcribed using the International Phonetic Alphabet (IPA). The PPC was calculated by dividing the number of correct phonemes by the total number of phonemes and multiplying by 100. Differences in production due to dialectal differences were not penalized. A mean PPC was obtained from the 10 production trials during each of the baseline, immediate retention, and delayed retention phases. Additionally, the sleep duration and sleep quality of each participant was tracked.

Statistical analysis

Statistical analysis was carried out using SPSS (version 26.0; IBM Corp., Armonk, NY). A mixed-model analysis of variance (ANOVA) was carried out to compare the differences between the three groups as a function of sleep and practice. The between-group variable was the three groups (groups A, B, and C) and the within-group variable was the data collection points (baseline, immediate retention, and delayed retention). This allowed the investigation of main effect of the groups, data collection points, and interaction effect (if any) between the groups and the data collection points.

In addition to the typical *F* and *p* values, the mixed model ANOVA test yielded partial eta squared value to determine the effect size. We made use of the guidelines suggested by Barnette (2006) to relate the partial eta-squared values to the effect size recommended by Cohen (Cohen,1992). About one percent of the variance that is accounted by the predictor variable relates to a small effect size (0.2), a variance of 6% accounted by the predictor variable relates to a medium effect size (0.5), and a variance of 14% accounted by the predictor variable relates to large effect size (0.8). Additionally, the assumptions of homogeneity of variance and sphericity were evaluated. Alpha (*p*) was set at 0.05.

Interrater reliability

Interrater reliability was conducted for PPC by randomly choosing 25% of the original data through intraclass correlation (ICC). Reliability ratings were conducted by a second rater, who was not involved in data collection and is an experienced researcher who has conducted a similar line of research. ICC estimates and their 95% confident intervals were calculated using SPSS statistical package version 26 (version 26.0; IBM Corp., Armonk, NY) based on a mean-rating ($k = 2$), absolute-agreement, 2-way mixed-effects model. Typically, ICC values less than 0.5 are indicative of poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values greater than 0.90 indicate excellent reliability (Koo & Li, 2016). The ICC estimate for the interrater reliability was 0.991 (0.968-0.998), suggesting excellent reliability.

CHAPTER III

RESULTS

Levene's test of equality of variance revealed that the statistical assumption of homogeneity of variance between the groups was met, $F(2, 42) = 1.604$, $p = .213$. Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $\chi2(2) = 4.965$, $p = .084$.

The results of the mixed-model ANOVA revealed that there was no main effect of the groups, $F(2, 42) = 1.262$, *ns*. There was a main effect of the data collection points, $F(2, 84) = 85.307$, $p < 0.001$. However, this main effect was qualified by an interaction effect between the groups and the data collection points, $F(2, 84) = 85.307$, $p < 0.001$; $\eta^2 = 0.1117$. Pair wise comparisons revealed the following findings: (1) in group A, participants had significantly higher PPC scores at immediate retention ($M = 75.76$) and delayed retention ($M = 55.61$) compared to baseline ($M = 28.72$), and PPC scores were higher at the immediate retention phase ($M = 75.76$) compared to delayed retention phase ($M = 55.61$). (2) In group B, participants had significantly higher PPC scores at immediate retention ($M = 82.73$) and delayed retention ($M = 78.30$) compared to baseline ($M = 29.76$). There was no significant difference regarding PPC scores between immediate and delayed retention phases. Finally, (3) in group C, participants had significantly higher PPC scores at immediate retention ($M = 81.34$) and delayed retention ($M = 74.00$) compared to baseline ($M = 24.87$). Like group B, there was no significant difference regarding PPC scores between immediate and delayed retention phases in group C. The PPC scores of the participants in the three groups and across the three data collection points are depicted in Figure 2.

Sleep quality

The participants' average sleep duration was 6.5 hours. The participant sleep ratings indicated that the participants were alert at the time of experiment. However, one participant indicated to be tired.

CHAPTER IV

DISCUSSION

The current study aimed to investigate the effect of sleep-based consolidation in a motor speech learning task. It was hypothesized that (1) groups which received sleep between practice and delayed retention (Groups B and C) will perform better than Group A, who did not receive sleep, and (2) Group C, which received an extra practice session, will not perform any better than Group B.

It should be noted that learning occurred for all three groups, as evidenced by performance on the immediate retention measure compared to the baseline measure. Additionally, all three groups performed similarly on the baseline and immediate retention measures, suggesting that there were no intergroup variables that obstructed learning. Groups B and C performed significantly better than group A. Both groups B and C experienced a night of sleep before being tested again, while C did not. If performance were based on time elapsed, Group A would be expected to perform better than the other groups, because only 12 hours passed between the training session and the testing session. This confirms the first hypothesis, that sleep provided some advantage to performance on the motor speech task.

Groups B and C did not perform differently from one another on the delayed retention measure. Both groups were tested 24 hours after the initial practice session, but Group C received an extra practice session 12 hours after the initial practice. Their similar performance suggests that individuals reach a point where additional practice is no longer helpful. In other words, sleep more accurately predicts performance than extra practice does. These results support the second hypothesis, that sleep will influence motor speech learning in a way that cannot be accounted for by practice aloneInterestingly, Group A performed much worse on the delayed retention session than on the immediate retention session. The individuals did not retain the information after a wake-state interval of 12 hours. In contrast, Groups B and C performed with the same accuracy level on the delayed retention session as on the immediate retention. Performance neither improved nor worsened after a period of sleep, indicating that participants who slept overnight were able to retain the novel information they learned.

While it would be appropriate to compare the findings to similar studies that have investigated the effect of sleep on speech motor learning, interestingly, there is no empirical body of research that investigates this line of inquiry to the best of our knowledge. Walker (2005) breaks consolidation down into two distinct processes, consolidation-based stabilization (CBS) and consolidation-based enhancement (CBE). Consolidation of memory is classically defined as a relatively stable state which is resistant to interference. Consolidation-based stabilization refers to the point at which a memory has reached this state. A memory is stable in the sense that performance after the delay is comparable to performance immediately after practicing the task. The memory has neither degraded nor improved from when it was originally learned. CBS includes an additional increase in learning, resulting in an improvement in performance after a delay. Walker (2005) posits that consolidation-based stabilization can be achieved after a period of wakefulness, whereas consolidation-based enhancement may only be achieved after a period of sleep.

Results from this current study do not support the process of consolidation-based stabilization or enhancement proposed by Walker (2005). Participants who were tested after a 12-hour delay demonstrated memory decay after a 12-hour wakeful period, indicating that memory stabilization did not occur during the delay. Additionally, participants who experienced a period of sleep performed at the same level as immediately after practice, revealing a state more consistent with CBS than CBE. This difference can be attributed to the nature of the learning task used in the current study. Walker (2005) was based on a review of several studies focusing on non-speech motor learning. It is possible that in the case of motor learning, at least one night of sleep is required for memory stabilization. It can be hypothesized that additional nights of sleep may result in memory enhancement. The reason for this difference is that motor speech learning involves not just implicit but also explicit learning.

This conclusion is further supported by Pan and Rickard (2015). Several studies were reviewed with the conclusion that sleep does not enhance motor learning. The role of sleep in the stabilization of memory cannot be conclusively determined based on the current literature. So, it is logical to conclude that sleep-based consolidation is influenced by the type of experimental design, the nature of the learning task, and the outcome measure used.

Limitations

There were some limitations of this study that may have influenced the results. First, a convenience sample was used, which consisted mainly of college students. Also, study design has been shown to be a possible variable. The sleep and non-sleep groups were tested over differing periods of time to control sleep, but it is possible that amount of elapsed time could affect performance. Additionally, it has been proposed that the window of sleep-based consolidation is 48 hours. Future research should focus on testing over a longer window of time and controlling for time delay between practice and retention sessions.

Conclusion

Despite a few limitations, the current study contributes significantly to our understanding of how sleep influences speech motor learning. Based on the current findings, it can be inferred that: (1) sleep facilitates speech motor learning more than additional practice, (2) sleep helps to maintain novel speech skills, but it remains to be investigated if it facilitates memory enhancement, especially on a long-term basis. Future research should investigate if these findings can be extrapolated to the clinical population with impaired speech motor skills.

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APPENDICES

Table 1. The Principles of Motor Learning

Principle	**Factors**
Practice Amount	small vs. large
Practice Distribution	massed vs. distributed
Practice Variability	constant vs. variable
Practice Schedule	blocked vs. random
Attentional Focus	internal vs. external
Target Complexity	simple vs. complex
Feedback Type	KP vs. KR
Feedback Frequency	high vs. low
Feedback Timing	immediate vs. delayed

Table 2. Table of Demographic and Sleep Data for Participants by Group

SSS represents sleepiness at the time of experiment. The SSS scores ranges from 1 to -7, where the lowest score of 1 represents "wide awake" and the highest scores of 7 represents "lost struggle to stay awake". The PSQI represents the median scores obtained on the Pittsburgh Sleep Quality Index. The PSQI scores ranges from 0 to 21, where lower scores represent better quality of sleep and the higher scores of represent poor sleep quality. A score of less than or equal to 5 is considered good sleep quality.

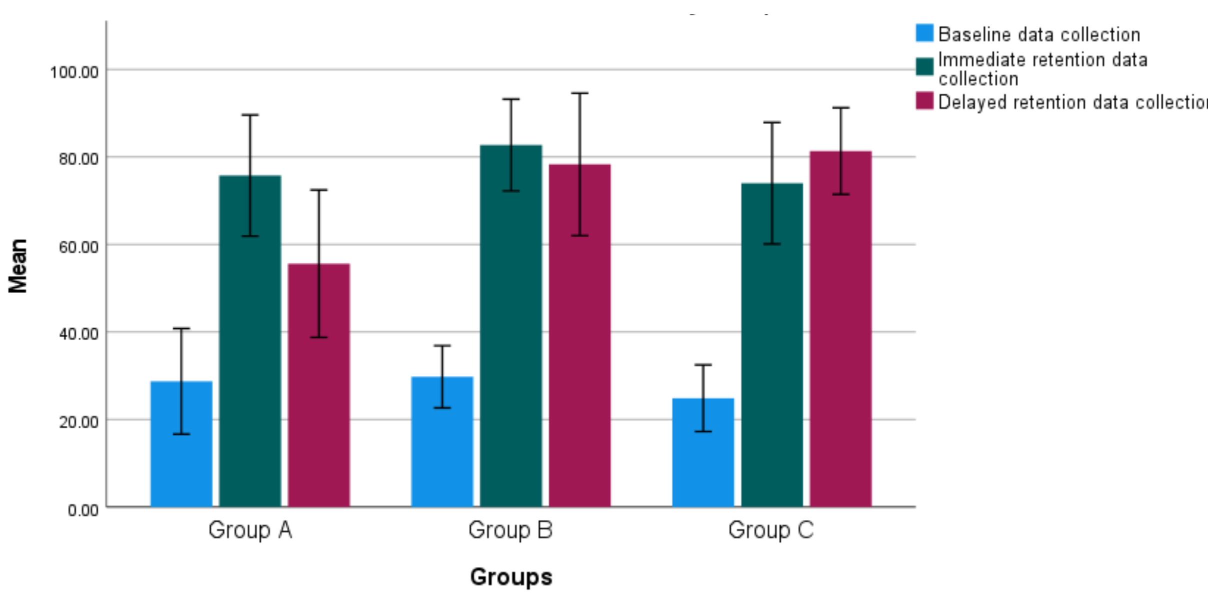
Group	**Age (years)** Mean (±SD)	**Gender**	**Education**	**Sleep Amount (hours)** Mean (±SD)	**SSS** Median (IQR)	**PSQI** Median (IQR)
A	28.01 (±11.57)	68.8% female 31.2% male	43.8% some college 50.0% bachelor's degree 6.3% master's Degree	6.47 (±0.74)	2 (IQR = 1-3)	5 (IQR = 3-8)
B	25.57 (±6.54)	63.4% female 36.6% male	28.6 % high school/GED 14.3% some college 7.1% associate degree 35.7% bachelor's degree 14.3% doctorate degree	6.75 (±0.85)	2 (IQR = 1-3)	5 (IQR = 2.75-7)
C	25.93 (±6.14)	46.7% female 53.3% male	13.3% high school/GED 20.0% some college 6.7% associate degree 33.3% bachelor's degree 26.7% master's degree	6.62 (±1.12)	3 (IQR = 1-3)	4 (IQR = 3-7)

Figure 1. Visual illustration of the experimental design

	Group 1		Group 2		Group 3	
	Acquisition (practice)	Retention	Acquisition (practice)	Retention	Acquisition (practice)	Retention
AM (day 1)	Ö		Ö		Ö	
PM (day 1)		Ö	Ö			
AM (day 2)				Ö		Ö

Figure 2. Visual Depiction of Performance Across Groups

The X-axis represents the groups, and the Y-axis represents the mean PPC scores collected during the baseline, immediate retention, and delayed retention phases. The error bars represent ±2 standard errors.



Oklahoma State University Institutional Review Board

Date:	01/20/2022
Application Number:	IRB-21-495
Proposal Title:	The Effect of Sleep on Motor Speech Learning
Principal Investigator:	Katie Redman
Co-Investigator(s):	
Faculty Adviser:	Ramesh Kaipa
Project Coordinator:	
Research Assistant(s):	
Processed as:	Expedited
Expedited Category:	

Status Recommended by Reviewer(s): Approved
Approval Date: 01/20/2022

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

This study meets criteria in the Revised Common Rule, as well as, one or more of the circumstances for which continuing review is not required. As Principal Investigator of this research, you will be required to submit a status report to the IRB triennially.

The final versions of any recruitment, consent, and assent documents bearing the IRB approval stamp are available for download from IRBManager. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be approved by the IRB. Protocol modifications requiring approval may include changes to the title, PI, adviser, other research personnel, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms.
2. Submit a status report to the IRB when requested
3. Promptly report to the IRB any harm experienced by a participant that is both unanticipated and related per IRB policy.
4. Maintain accurate and complete study records for evaluation by the OSU IRB and, if applicable, inspection by regulatory agencies and/or the study sponsor.
5. Notify the IRB office when your research project is complete or when you are no longer affiliated with Oklahoma State University.

If you have questions about the IRB procedures or need any assistance from the Board, please contact the IRB Office at 405-744-3377 or irb@okstate.edu.

Sincerely,
Oklahoma State University IRB

VITA

Katelyn Redman

Candidate for the Degree of

Master of Science

Thesis: THE EFFECT OF SLEEP-BASED CONSOLIDATION ON SPEECH MOTOR LEARNING

Major Field: Communication Sciences and Disorders

Biographical:

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Completed externship at Swallowing and Neurological Rehabilitation, Tulsa, Oklahoma in 2022

Professional Memberships:

Student Member of American Speech-Language-Hearing Association