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Formation of Implicit Memories from a Narrative Played During Sleep

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Abstract

Though, it was previously thought that the sleeping brain was dormant, research suggests that participants can process salient stimuli and form implicit memories of simple stimuli (e.g. words) during sleep. Thus, the current study aimed to determine whether participants could form implicit memories of a narrative played during sleep, and what role different sleep stages played in this memory formation. Participants were played a story while taking a nap, and EEG was used to track time spent in different sleep stages. Later, participants completed an implicit memory task where they were asked to differentiate between animal and non-animal words through a button press. It was found that participants responded faster to words stated directly in the story played to them during sleep. However, the same response was not seen for words related to the story. Additionally, no relationship was found between time spent in stage 2 or 3 sleep and implicit memory formation. Altogether, this study suggests implicit memory formation of a narrative is possible for directly-stated words, but more research is needed to see whether memories of story theme can be formed. Finally, it seems that time spent in certain stages is not the mechanism behind implicit memory formation.

Formation of Implicit Memories from a Narrative Played During Sleep

The layperson often assumes that the sleeping brain is inactive and as such they also often believe no processing is occurring by the brain during sleep. However, most people have had the experience of awakening to a loud clatter wanting to make sure they are safe. The fact people are awoken by startling sounds suggests that even during sleep the brain continues to monitor its environment and process information, and this is exactly what research has shown. Specifically, some studies have provided evidence that during sleep the brain can differentiate between important and unimportant information, as well as track relevant stimuli, such as stories, over time (Kouider, Andrillon, Barbosa, Goupil & Bekinschtein, 2014; Legendre, Andrillon, Koroma, & Kouider, 2019; Perrin, García-Larrea, Mauguière & Bastuji, 1999). Although these previous studies support the idea that the processing of external stimuli can occur during sleep, much less research has been performed examining the possibility of memory formation during sleep. For example, if a person is played a conversation during sleep, would they have any memory traces of what they heard once they wake up? To address this possibility of memory formation while sleeping, the current study investigates implicit memory formation of external stimuli heard during sleep.

Before getting into the literature I will define some terms essential in understanding sleep and memory research. Then I will examine some studies that addressed processing during sleep, followed by a review of studies providing evidence for implicit memory formation during sleep. Finally, the current study will be discussed.

Memory

Different types of memory exist. Explicit memory is what commonly comes to mind when discussing memory – it is described as a “conscious, intentional recollection of past events", as well as recollections of facts and information (Mulligan & Dew, 2009, p. 1522). Implicit memory on the other hand is an "unintentional, unconscious retrieval" of memories (Mulligan & Dew, 2009, p. 1522). Implicit memories are harder to measure than explicit memories, as by definition a person cannot verbally recall an implicit memory. Therefore, certain tasks have been developed to probe and measure implicit processing and memories.

One of these tasks is the Lexical Decision Task (LDT) (Meyer & Schvaneveldt, 1971). This task was initially used to look at implicit processing. A common way to look at implicit processing is through priming effects. During a LDT, participants are shown a word list, one word at a time, and asked to indicate through a button press whether the word is a real word (e.g. *bread*) or a pseudoword (e.g. *glater*). For example, participants could be primed with the word *butter* for less than a second, then they would be shown the word *bread* and asked to indicate whether it is a word or a pseudoword. It would be expected that participants would be faster to respond indicating *bread* is a word when it is primed by the word *butter*, in comparison to when it is primed by an unrelated word such as *nurse* (Marcel, 1983). The idea with implicit memory and implicit processing is that although people can not explicitly state that they processed this information, it is still stored in the brain and can be measured indirectly when they respond more quickly to related stimuli. As the Lexical Decision task has commonly been used to measure implicit processing in the past, the present study will be adapting a similar task to measure the formation of implicit memories of stimuli heard during sleep (Bentin, Moscovitch, & Heth, 1992; Marcel, 1983; Verfaellie, Cermak, Letourneau, & Zuffante, 1991).

Sleep Architecture

Typically in sleep research, electroencephalography (EEG) is used to monitor the sleeping brain; in particular what stage of sleep a person is in. Sleep can be separated into two categories: non-rapid eye movement (non-REM) sleep and rapid eye movement (REM) sleep (BaHammam et al., 2016). Non-REM sleep can further be differentiated into stage 1, stage 2 and stage 3 sleep (see Figure 1; BaHammam et al., 2016). When a person is awake, their EEG signal will show predominantly alpha activity (see Figure 1; BaHammam et al., 2016). As a person falls asleep, they typically transition from the wake phase to stage 1 sleep, which is the lightest sleep stage and it is characterized by theta activity and vertex sharp waves (BaHammam et al., 2016). During stage 1, people may not be aware of whether they are asleep or awake and can still somewhat keep track of their surroundings explicitly. Following stage 1 comes stage 2, an intermediate stage of sleep, which is identified through K complexes (sharp negative waves followed by slower positive waves) and sleep spindles (bursts of high frequency waves) (BaHammam et al., 2016). Stage 3 sleep is often called deep sleep as this is the stage of sleep where it is the hardest to awaken a person; it can also be referred to as slow-wave sleep as the EEG waves get larger and less frequent (BaHammam et al., 2016). Stage 3 is usually followed by REM sleep which has EEG characteristics similar to stage 1, but it can be differentiated from stage 1 by sharp peaked eye movements (BaHammam et al., 2016). Although stages of sleep are considered to follow this typical pattern, sleepers are variable. There is variability within and between sleepers in the amount of time spent in each stage and how often they switch between stages.

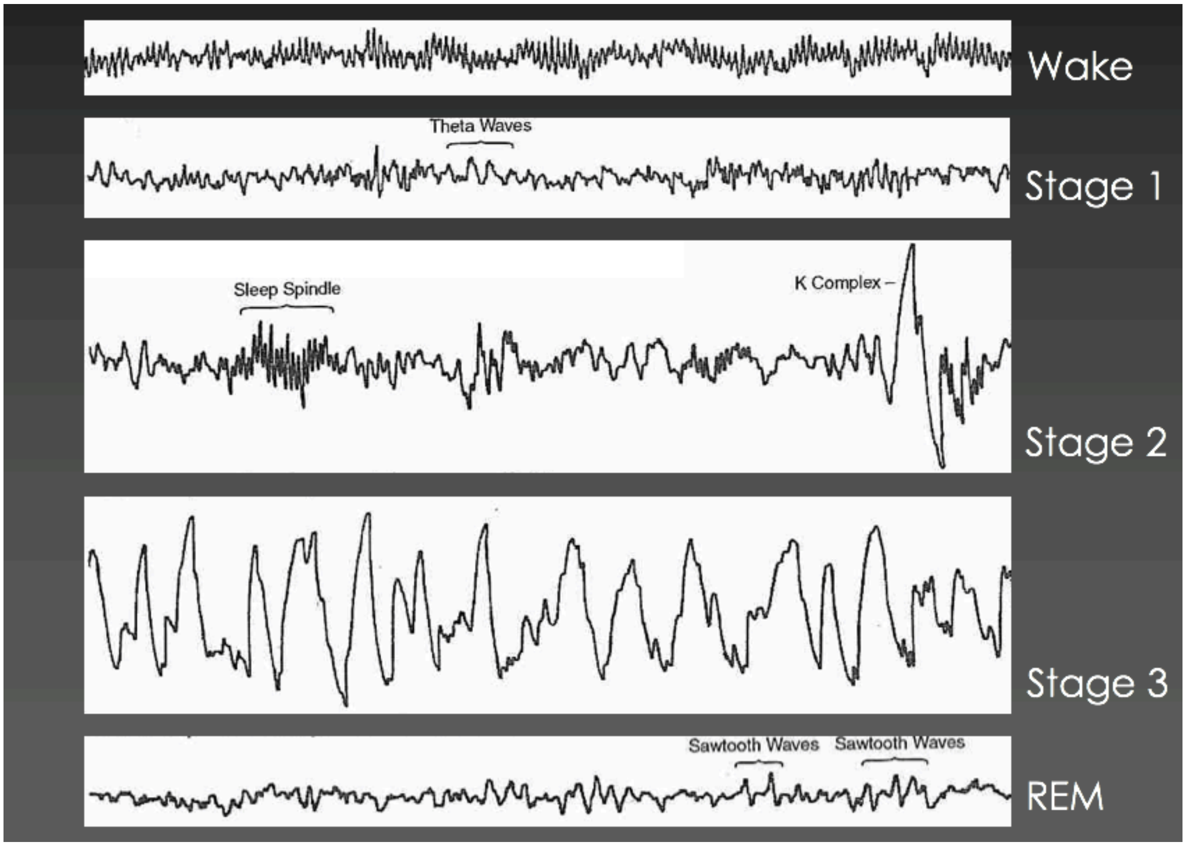

Figure 1. EEG characteristics of the wake stage and each sleep stage (Rechtschaffen, 1968).

Studies Showing Processing of External Stimuli During Sleep

Many studies have demonstrated that the brain can process stimuli from the external environment during sleep. Specifically, one study found that participants in stage 2 and REM sleep were capable of processing their own names as more salient and important than other first names (Perrin et al., 1999). A similar study investigated participants' processing of auditory emotional stimuli during stage 2 sleep (Blume et al., 2017). It was discovered that an angry voice in comparison to a neutral voice lead to increased delta event-related synchronization (ERS); this is EEG activity that has been found to indicate processing of salient stimuli. Researchers interpreted these findings to mean that the sleeping brain can detect angry voices as being more salient. These studies provide evidence that even during sleep the brain continues to process external information not just at a sensory level, but to the point where it is detecting salient or important stimuli.

A recent study extended these previous findings by showing that during stage 2 sleep, participants were more likely to track a one minute relevant speech stream in comparison to a jabberwocky speech stream that was played to them simultaneously (Legendre et al., 2019). This finding supports the idea that the brain can not only differentiate, but also track important information over time. To even further display the sleeping brain's abilities, there is also some evidence that the brain can produce task relevant responses during sleep (Kouider et al., 2014). Researchers had participants perform a LDT while listening to a word list, they used a button in their right hand to indicate a word and a button in their left hand to indicate a pseudoword. While awake the participants' EEG activity indicated what button they were preparing to press, before they actually performed the motor action. The study found even during stage 1 and 2 of sleep the brain continued to show similar EEG responses to the auditory words being played. This supports the idea that the sleeping brain was differentiating between words and pseudowords on a semantic level and preparing responses. Together, all these studies show although sleep is an altered state of consciousness, contrary to previous beliefs, deeper level processing can still occur in the sleeping brain.

Formation of Implicit Memories during Sleep Studies

Previous studies clearly displayed evidence of tracking and processing important stimuli during sleep, as well as the sleeping brain preparing task-relevant responses. However, they did not test to see if any memory traces were formed through this processing. There is some evidence that participants can form memories of words played during sleep. In a study by Andrillon and Kouider (2016), participants were played a list of words while they were awake, and they simultaneously performed the LDT with these words to ensure they were paying attention to this word list. Then participants were allowed to sleep and once they were in stage 2 or 3 sleep they were played a second list of words. When participants woke up these first two lists were combined with a third new list and presented to them. For each word, participants had to give a first order response indicating whether the word was an old word (a word they had previously heard during the study) or a new word (a word they had not heard before in this study). Then they also gave a second-order response indicating on scale from 1-7 how confident they were in their old or new categorization. The study found participants had no significant differences in the first order responses to words played during sleep and new words, indicating no explicit memory of words played during sleep. However, when participants rated sleep words and new words as old they were significantly more confident that the sleep words were old in comparison to the new words. They also found EEG evidence indicating even when sleep words and new words were both rated as new they were not processed in the same way. The researchers concluded that participants had formed implicit memories of the sleep words, using the different second-order responses and different EEG activity seen in response to sleep versus new words as evidence.

A similar study by Züst, Ruch, Wiest, and Henke (2019), looked at the formation of implicit memories of slightly more complex stimuli. The researchers played participants word-pairs, where one word was a pseudoword (e.g. *tofer*) and the other word was a real word indicating an object bigger or smaller than a shoebox (e.g. *house*). These word-pairs were played to participants during stage 3 sleep. When participants woke up they were presented with only the pseudowords and asked whether these pseudowords indicate an object bigger or smaller than a shoebox. These researchers found above chance performance on this task and this result was interpreted as an indication that participants had formed implicit memories of these word-pairs. Through additional analyses, these researchers also found that the word-pairs that frequently coincided with a slow-wave peak led to better performance in the implicit memory task. Thus, the authors concluded that slow-wave peaks assist implicit memory formation. Together these studies demonstrate that implicit memory formation is possible for individual words and word-pair associations during stage 2 or stage 3 sleep.

Current Study

Since the previous literature suggests that the sleeping brain is capable of processing important information and even forming new memories, it is important to determine the extent to which this processing and memory formation can occur. Can the sleeping brain only process simple words and word pairs, or can this function be pushed a step further? To help answer these questions on the upper limit of sleep processing, the current study will examine whether implicit memories of a narrative can be formed during sleep. Additionally, the study will examine whether time spent in different sleep stages impacts implicit memory formation.

To investigate implicit memory formation during sleep, a narrative was played to sleeping participants. Using a narrative as a stimulus furthered research in this area, as word-pairs were the most complicated stimulus used for previous sleep studies examining the formation of implicit memories. While Legendre et al. (2019) had used narratives as a stimulus they only examined processing of these narratives and did not test to see whether implicit memories were formed. A narrative is a more complex stimulus, but also a more natural stimulus in comparison to word lists, as participants are not exposed to word lists as often as they are to stories. Another shortcoming of previous literature was the lack of agreement for which sleep stage(s) are the best for processing or memory formation. Findings on which sleep stage(s) are optimal for processing or for memory formation have been mixed, as different studies play stimuli during different stages or found processing in different stages. Even when Züst et al. (2019) examined the role of sleep stages they focused only on stage 3 sleep. Therefore, this study also examined the role of different sleep stages in the formation of implicit memories.

In the current study, participants came into the lab and were fitted with an EEG cap. They then proceeded to the sleep lab to take a nap. EEG was used to track what sleep stage the participants were in, and when they entered stable stage 2 sleep the stimulus was played. The stimulus is an auditory recording of an abridged version of a short story by J.D. Salinger titled "*Pretty Mouth and Green my Eyes*" (GME). This story was chosen as it includes angry voices and the plot is ambiguous and suspenseful which leads to it being an emotionally salient story. Thus, we expect based on previous studies that participants will process and track this story during sleep (Blume et al., 2017).

When participants woke up, they completed an Animacy Decision Task which is similar to the Lexical Decision Task in that both can be adapted to measure the formation of implicit memories. During the Animacy Decision Task, words appear on a computer screen one at a time and the participant must indicate whether each word is an animal word or a non-animal word through a button press. Within the non-animal word list there are words directly-stated in the stimulus story (e.g. *gray*), words related to the story but not directly-stated (e.g. *suspicious*), and control words from the story Pie Man (e.g. *newspaper*) and control words unrelated to either story (e.g. *peaceful*). If the participants have formed implicit memories of this story, then they should be able to process words directly from the story and related to the story faster, and therefore they should respond more quickly to these words in comparison to control words. For example, we would expect a faster response to the word *gray* than to the word *peaceful*, as the participants heard the word *gray* in the story while asleep. Thus, it was predicted that participants would respond faster to directly-stated words in comparison to control story words from Pie Man. It was also predicted participants would respond faster to words related to the story in comparison to the control unrelated words. In addition to the Experimental group described above, two control groups were also run. One group (Story Control group) heard GME while awake and this group was run to ensure the Animacy Decision Task is sensitive to implicit memories formed of the story. The second group (No-Story Control group) completed the Animacy Decision Task without listening to GME and this group was run to ensure that there were no biases within the task that will lead to faster reaction times to certain word types (e.g. directly-stated words or related words).

An exploratory analysis will also be performed to examine the role of sleep stages in the formation of implicit memories. Particularly, the amount of time spent in each stage during the nap and how it is associated with the strength of the implicit memories will be examined. Although previous findings have been mixed, both studies that examined implicit memory formation of words and word-pairs, found that memory formation seemed to be linked to deeper non-REM sleep (Andrillon & Kouider, 2016; Züst et al., 2019). So, it is predicted that perhaps more time in stage 2 or 3 sleep will be related to stronger implicit memory formation.

Methods

Participants

Experimental group. There were 21 participants in this group. One participant was excluded from the analysis because there were issues in EEG data collection, thus 20 participants (16 females) were used for analysis. The participants ranged in age from 17 to 30 years old (M = 21.59, SD = 4. 51). Participants were either recruited from SONA (the Western University psychology research participant pool) and compensated 3 research credits (n = *10*), or participants were recruited via posters placed around Western Interdisciplinary Research Building and compensated $14 an hour (n = *10*). Inclusion criteria for the study required participants to have normal hearing, normal or corrected-to-normal vision, be habitual nappers and be in the age range of 17 to 35 years old. Also, participants confirmed they had no personal history of speech, hearing, learning, neurological, sleep or psychiatric disorders and they were not taking any medication that may affect brain functioning. Further, participants were requested to wake up an hour or two earlier than their usual waking time, this was done to increase sleep pressure and increase the likelihood that participants would be able to sleep in the afternoon. Participants were also asked to not consume any caffeinated drinks on the day of the experiment. Ethics approval for this study was provided by the Western University's Research Ethics Board REB#112576 (see Appendix A).

Story control group. This group included 16 participants (9 females). Participants age ranged from 18 to 34 years old (*M* = 23.19, *SD* = 5.47). These participants were recruited through SONA and compensated with 3 research credits (n = *7*), or recruited through posters and compensated with $14 an hour (n = *9*). Additionally, the inclusion criteria for this group was similar to the Experimental group, except participants did not have to be habitual nappers.

No-story control group. There were 11 participants in this group (5 females). The participants ranged in age from 18 to 22 years old (*M* = 20.73, *SD* = 1.62). These participants were recruited through SONA and were compensated through 0.5 research credits (n = *4*), or participants were recruited through word of mouth and volunteered their time (n = *11*). The inclusion criteria for the control participants included normal hearing, normal or corrected-to-normal vision and being aged 17 to 35 years old.

Materials

Auditory stimuli. Participants first listened to the audio from a relaxing YouTube video called “Unintentional ASMR | Most relaxing voice ever. Fall asleep in seconds... | John Butler ASMR” (Pure Unintentional ASMR, 2018). The clip’s volume was set by consulting the participants to ascertain it was loud enough that the participants could comprehend the words, but not so loud that they could not fall asleep. The relaxing audio was played as background noise as participants were falling asleep. This is because during the piloting stage of this study, participants would rouse awake when the stimulus was played after falling asleep in a quiet environment. In order to ease this transition, a non-relevant interview was played as participants fell asleep, so they would not be startled and awakened when the audio was switched to the main stimulus during sleep. The main stimulus used for this study was an excerpt from the short story “*Pretty Mouth and Green My Eyes*” by J.D. Salinger. A 7 minute recording of this excerpt was played once for the participants during their nap (see Appendix B). This story was chosen because of its emotional salience, as it includes angry voices and a suspenseful plot. Additionally, the story was not too salient where it would lead to participants awakening during sleep.

EEG and sleep stage measure. The Brain Products actiCAP 64-channel standard EEG system was used to record participants EEG activity for the duration of their nap. The participants had four external electrodes in addition to the 64-channel cap – two were used to measure eye movements, and two were used to measure facial muscle movement. The EEG activity was used to monitor what sleep stage the participants were in as they napped and in order to identify stage 2 sleep to begin playing the narrative. The narrative was played during stage 2 sleep as it is deep enough sleep that participant could not explicitly process the story. The

EEG data that was collected for each participants nap was also sleep scored to analyze the role of sleep stages in implicit memory formation. The sleep scoring was done in 30-second epochs, where each epoch was categorized as Wake, Stage 1, Stage 2, Stage 3 or REM.

Implicit memory task. The implicit memory task used for this study was the Animacy Decision Task. This task was created at the Brain and Mind Institute at Western University by Dr. Laura Batterink and Sarah Hollywood (M.Sc. student), and was programmed in PsychoPy. The task requires participants to indicate through a keyboard button press whether each word appearing on the screen is an animal word or a non-animal word. There were two versions of the task: version one where participants press A for animal word and L for non-animal word and version two where participants press A for non-animal word and L for animal word. These two versions were counterbalanced across participants. The animal word list consisted of 100 words (see Appendix C). The non-animal word list contained 30 words directly from GME (directly-stated), 20 words related to GME (related), 30 words from a story called Pie Man (control story), and 20 words completely unrelated to either story (unrelated) (see Appendix D). The words in these lists were chosen and then they were analyzed using MATLAB toolboxes. The WordtoVec toolbox was used to transform each word into a vector. Then the Fast Text Word Embedding toolbox was used to compare the 100 word vectors on 300 dimensions. It was established that the 100 words were similar enough that they were matched on these 300 dimensions (e.g. word length, phonology, etc.), but different enough from each other that each word would be considered novel. The directly-stated words were included to see if participants formed memories of words that were played to them during sleep. The related words were semantically related to the themes and ideas of the story GME, and so these words were included to examine whether sleeping participants could process the plot of the story. The unrelated words and the control story words were included to serve as a control for directly-stated and related words. As all the words in the directly-stated category are taken from the story GME there may be a common theme to the words which could potentially lead to faster reaction times to these words. To account for this thematic relatedness in the directly-stated words, control words were taken directly from the story Pie Man and so they would also have a theme. Thus, potential faster reaction times to directly-stated words in comparison to control story words could be assumed to be due to the implicit memories participants formed, and not due to effects of thematically related words in the task.

Explicit memory task. This task was developed by the Owen Lab at Western University (see Appendix E). During the task participants are asked questions about GME where they could type out a response to each question or click the option “I don’t know”. After selecting “I don’t know” they would be led to a forced choice version of the same question. This task was administered after the implicit memory task to prevent the explicit memory task questions from confounding performance on the implicit task. This task will not be analyzed for the purposes of this thesis, but was used for the bigger project.

Pre-nap and post-nap questionnaires. Participants’ demographic information was collected by the Adult Participant Information Sheet (see Appendix F). Participants were also given additional questionnaires which will be used for a bigger project, but will not be analyzed for the purposes of this thesis. Particularly, participants were given the Sleepiness Fatigue Questionnaire which combines the Epworth Sleepiness Scale and Stanford Sleepiness Scale (Hoddes, Dement, & Zarcone, 1972; John, 1991). The Karolinska Sleep Log and Karolinska Nap Log (Karolinska Sleep Log Modified for Afternoon Nap) were also given to participants (Kecklund & Åkerstedt, 1992; see Appendix G).

Procedure

The procedure for all three groups is summarized in Figure 2 below. Then a detailed procedure is provided for each group.

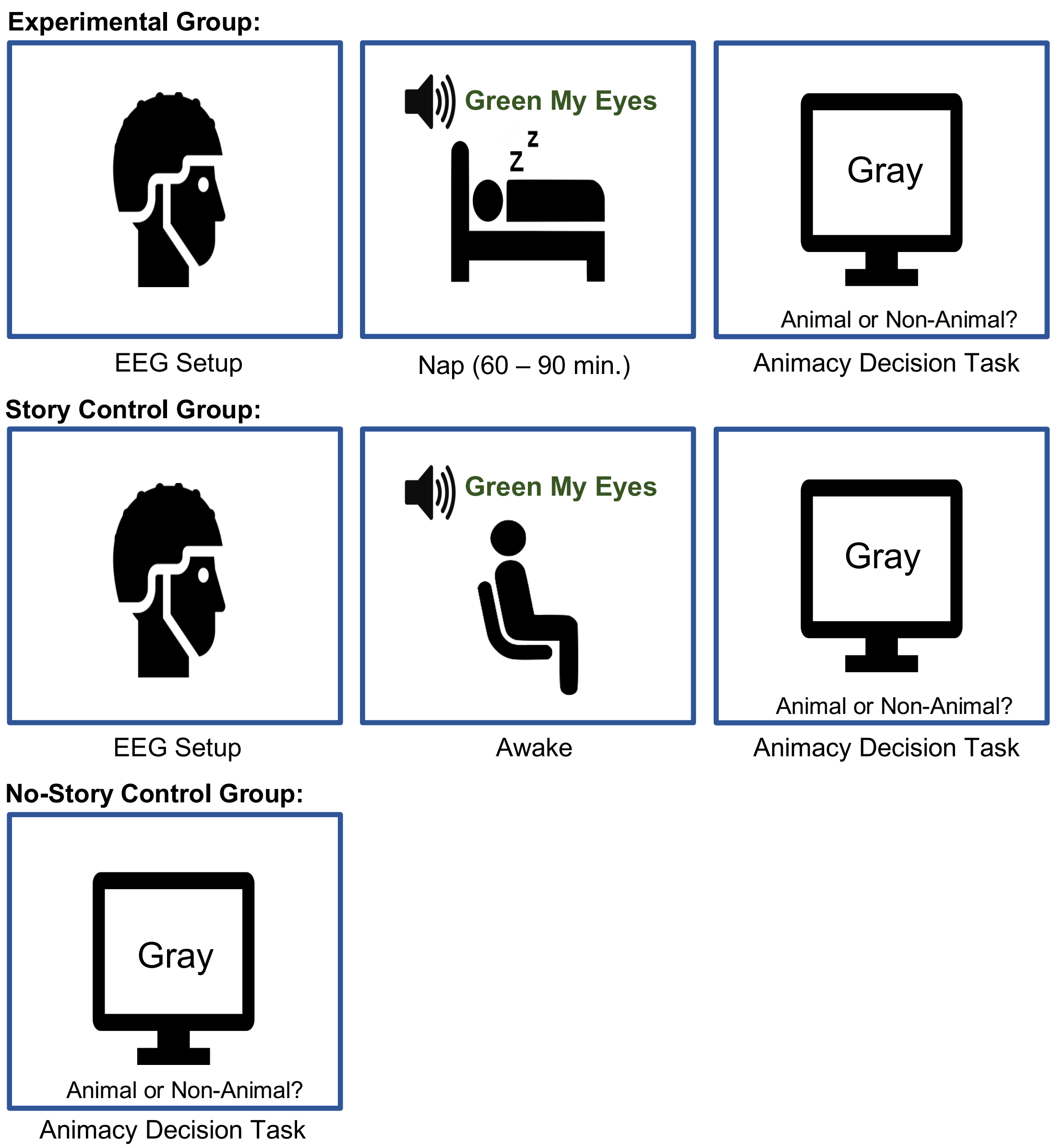

Figure 2. Summary of the procedure for the Experimental group, Story Control group, and No-Story Control group.

Experimental group. After participants arrived, they were given the Letter of Information and signed consent was obtained (see Appendices H and I). Then, participants completed the pre-nap questionnaires. Next, participants were fitted with an EEG cap and had the external electrodes placed onto their face. Participants then went to the sleep lab and were connected to the Brain Products EEG system. The relaxing audio clip was played from two computer speakers at the bedside table and the sound was adjusted to a comfortable volume. Then participants were left alone to fall asleep. Once participants had reached stable stage 2 sleep, indicated by the EEG activity showing stage 2 characteristics for three minutes, the audio was switched over to GME. After the 7 minute audio clip finished playing, participants were allowed to sleep in silence. Participants were permitted to nap up to 1.5 hours.

After the nap, participants were woken up by knocking on the door or the researcher entering the room if necessary. Participants were told to take their time waking up and that they will do a task in the room when they are ready. Participants usually took about 5 minutes to get up and then completed the Animacy Decision task using the Psychopy program on a laptop. Participants ERPs were recorded during this task for the bigger project, but they were not analyzed for the purposes of this study. Participants were given written instructions on the screen and as well as being verbally told, “Press A for an animal word and L for a non-animal word. Also, try not to blink when each word appears”. The instructions given changed slightly depending on what version of the task they are given. Sticky notes were also placed on the keyboard with the words “animal” and “non-animal” above the appropriate keys in case participants forgot the instructions. Each participant would see all 200 words in a randomized order and thus complete 200 trials. For each trial the participant would first see a fixation cross lasting 1 second, then a word would appear on the screen for 500ms, this would be followed by a black screen until the participant responded. After the participant responded the screen would be black for another second and then the next trial would begin.

Upon completing the Animacy Decision Task, participants went back to the EEG prep room and were able to take off the EEG cap. They were given time to use the washroom to wash their hair. Next, participants were briefly interviewed to see if they noticed any patterns in the stimuli played. Then participants completed the explicit memory task on Qualtrics. For this task participants were told they will be answering questions about one of the stimuli that were played for them during sleep. Finally, participants completed the post-nap questionnaire. Before leaving participants were given a debriefing form and were given the opportunity to ask any questions they may have about the study (see Appendix J). Overall, the study took approximately 3 hours to complete.

Story control group. Participants in this group went through the same procedure as the Experimental group; however, they were not given the opportunity to nap. Thus, these participants did not complete any sleep-related questionnaires. The participants in this group listened to GME while awake and connected to the Brain Products EEG system. These participant spent about 1.5 hours in the lab to complete the study. This control group was run in order ensure that the Animacy Decision Task was able to detect implicit memories formed of words directly-stated in and related to GME. Controls who were awake should be able to process and form memories of the narrative played to them, including memories of words directly said in the story and also memories of the story's theme. Thus, these participants who were primed with the story should display faster responses to directly-stated words and related words.

No-story control group. After arrival these participants read the Letter of Information and provided consent. Participants then completed the Adult Participant Information Sheet. Next, participants completed the Animacy Decision Task, the procedure for which was exactly the same as described for the Experimental group above. Participants were debriefed in the same manner as the other groups. These participants were in the lab for approximately 30 minutes each. This control group was run to check whether there were any biases within the Animacy Decision Task that would lead participants to respond faster to directly-stated words in comparison to control story words and respond faster to related words in comparison to unrelated words. If there are no inherent biases it would be expected these participants would respond equally fast to all four different word types as they have not heard GME.

Statistical Analyses

First, mean reaction times needed to be calculated for each participant for each word type condition (directly-stated, control story, related and unrelated). In order to do this any reaction times over 5 seconds were removed, and then mean and standard deviation were calculated for each word type condition. Next, any reaction times more than 2.5 standard deviations from the condition mean were excluded as outliers. Finally, mean reaction times were again calculated without the outliers for each condition and these mean reaction times were used in the statistical analyses.

Repeated measures ANOVAs were used for each group to examine whether there was a significant difference in mean reaction times to any of the word types. Then t-tests were used as follow ups for ANOVAs. Additionally, Pearson r correlations were run for the Experimental group to see the relationship between time spent in each sleep stage and memory strength.

Results

Implicit Memory Formation

Accuracy. The Experimental group, Story Control group, and No-Story Control group performed well on the animacy decision task, with mean accuracy for the task being 91.53% (SD = 4.97), 93.66% (SD = 4.38), and 90.68% (SD = 2.65), respectively.

Experimental group. For the implicit memory task, the differences in reaction times (ms) for directly-stated (M = 664.39, SD = 148.74), control story (M = 692.84, SD = 166.10), related (M = 666.53, SD = 152.28) and unrelated (M = 672.59, SD = 171.72) words were compared. The Mauchly's test of sphericity was non-significant; thus, there was little reason to believe the assumption of circularity of the covariance matrix has been violated, W = 0.81, $\chi^2(5) = 3.79$, p = .581. The repeated measures ANOVA revealed a statistically significant effect when comparing these reaction times, $F(3,57) = 3.49$, p = .021, η^2 = .155, power = 0.751 (see Figure 3). To figure out which particular word types differed, additional paired sample t-tests were run, comparing the directly-stated words to the control story words, and the related words to unrelated words. It was found that participants responded significantly faster to directly-stated words in comparison to control story words, $t(19) = -2.60$, p = .018. Also, there was no significant differences in response times to related words in comparison to unrelated words, $t(19) = -0.66$, p = .519.

Story control group. Again differences in reaction times (ms) to directly-stated (M = 617.69, SD = 74.69), control story (M = 633.45, SD = 63.84), related (M = 614.49, SD = 57.76) and unrelated (M = 611.92, SD = 68.33) words were compared. The Mauchly's test of sphericity was non-significant and so the assumption of circularity of the covariance could be assumed, W = 0.55, $\chi^2(5) = 8.22$, p = .146.The repeated measures ANOVA showed no effect, $F(3,45) = 1.50$, p = .226, η^2 = .091, power = 0.370 (see figure 3). Nonetheless, as a way to better compare results from the Story Control group with those from the Experimental group, an additional paired t-test between directly-stated word and control story word conditions was run. As well as a paired t-test comparing the related and unrelated word conditions. These additional analyses revealed a marginally significant difference when comparing reaction times to directly-stated words v.

control story words, $t(15) = -1.99$, $p = .065$, showing a similar pattern to the Experimental Group. Related and unrelated words did not show significantly different reaction times, $t(15) = 0.26$, $p = .801$.

No-story control group. As with the other groups, the differences in reaction times (ms) to directly-stated ($M = 621.00$, $SD = 106.91$), control story ($M = 625.05$, $SD = 104.56$), related ($M = 610.94$, $SD = 84.23$) and unrelated ($M = 612.77$, $SD = 113.36$) words were examined. Again, the Mauchly's test of sphericity established that there was little reason to believe the assumption of circularity of the covariance matrix has been violated, $W = 0.36$, $\chi^2(5) = 8.85$, $p = .117$. The repeated measures ANOVA was not found to be statistically significant, meaning there were no significant differences in reaction times to the different word types in this control group, $F(3,30) = 0.48$, $p = .699$, $\eta^2 = .046$, power = 0.135 (see Figure 3). Again t-tests comparing the directly-stated condition to control story condition and related condition to the unrelated condition were run to ensure there were no marginally significant effects. A comparison between reaction times to directly-stated words and control story words revealed no effect, $t(10) = -0.37$, $p = .720$. When comparing reaction times to related words and unrelated words, no significant differences were seen, $t(10) = -0.98$, $p = .924$.

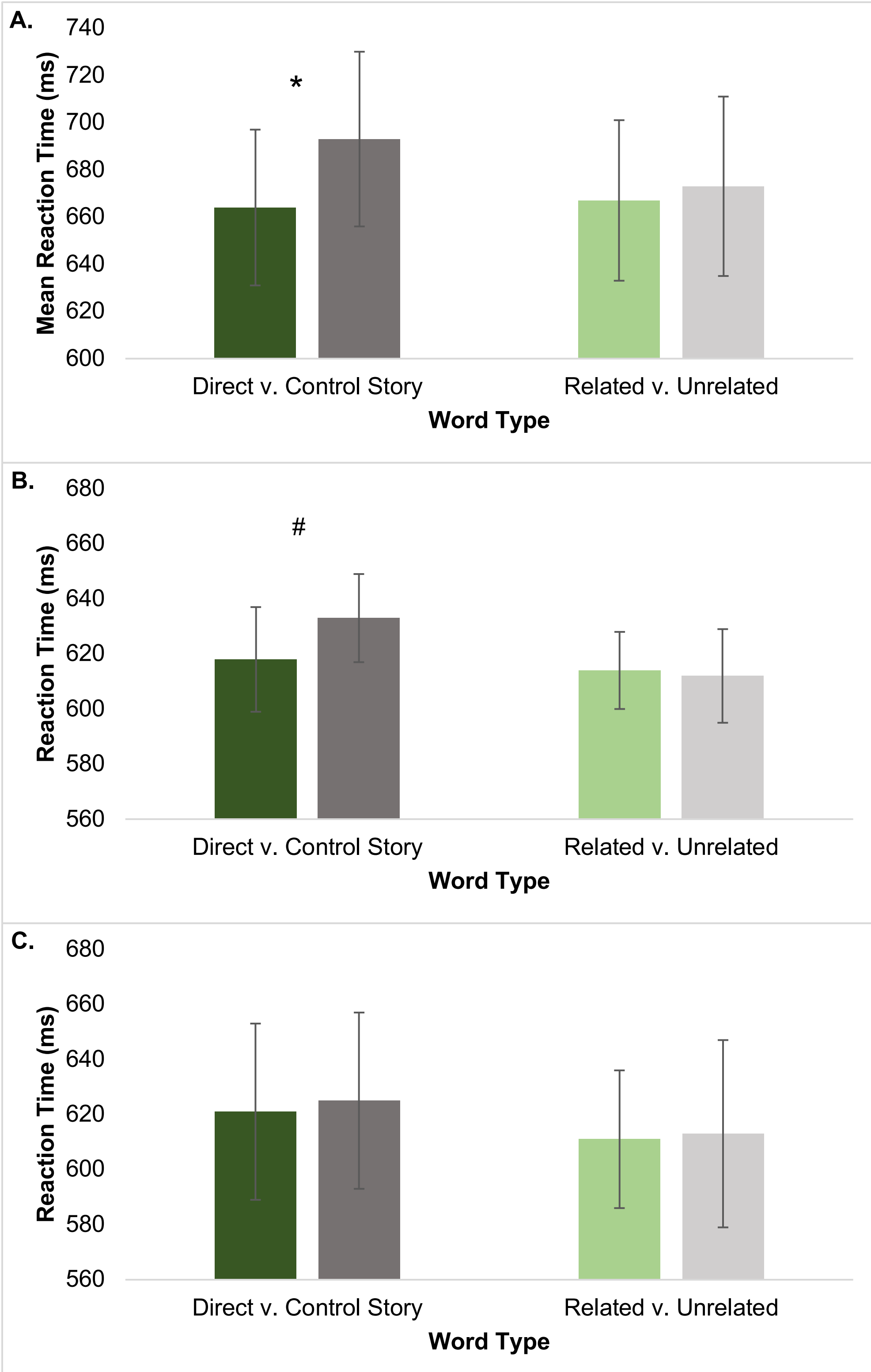

Figure 3. The Experimental (A.), Story Control (B.), and No-Story Control (C.) groups' mean reaction times mean reaction times to directly-stated words in comparison to control story words

and related words in comparison to unrelated words. Error bars represent standard error, *indicates a significant difference at $p < .05$ and #indicates a marginally significant difference at $p = .065$.

Role of Sleep Stages in Implicit Memory Formation

In order to examine the role of sleep stages in implicit memory formation the amount of time (min) spent in stage 2 sleep by the Experimental participants was correlated with the strength of the implicit memories formed. Implicit memory strength was defined as the mean difference in reaction time between directly-stated and control story words. Specifically, the mean reaction time to directly-stated words for each participant was subtracted from their mean reaction to control story words, and so a positive difference indicated a faster mean reaction time to directly-stated words. Thus, the larger the positive mean difference gets, the stronger the implicit memories for directly-stated words. It was found that time spent in stage 2 sleep did not relate to the strength of implicit memories formed for directly-stated words, $r(18) = .17$, $p = .487$ (see figure 4).

A correlation was also run between the amount of time (min) spent in stage 3 sleep and the strength of implicit memories. Implicit memory strength was defined as described above. No significant correlation was found between time spent in stage 3 sleep and the strength of implicit memories for directly-stated words, $r(18) = -.05$, $p = .844$ (see figure 4).

Finally, although time spent in stage REM and its effect on implicit memory formation should also be explored, it was not possible in this study as none of the participants reached REM sleep.

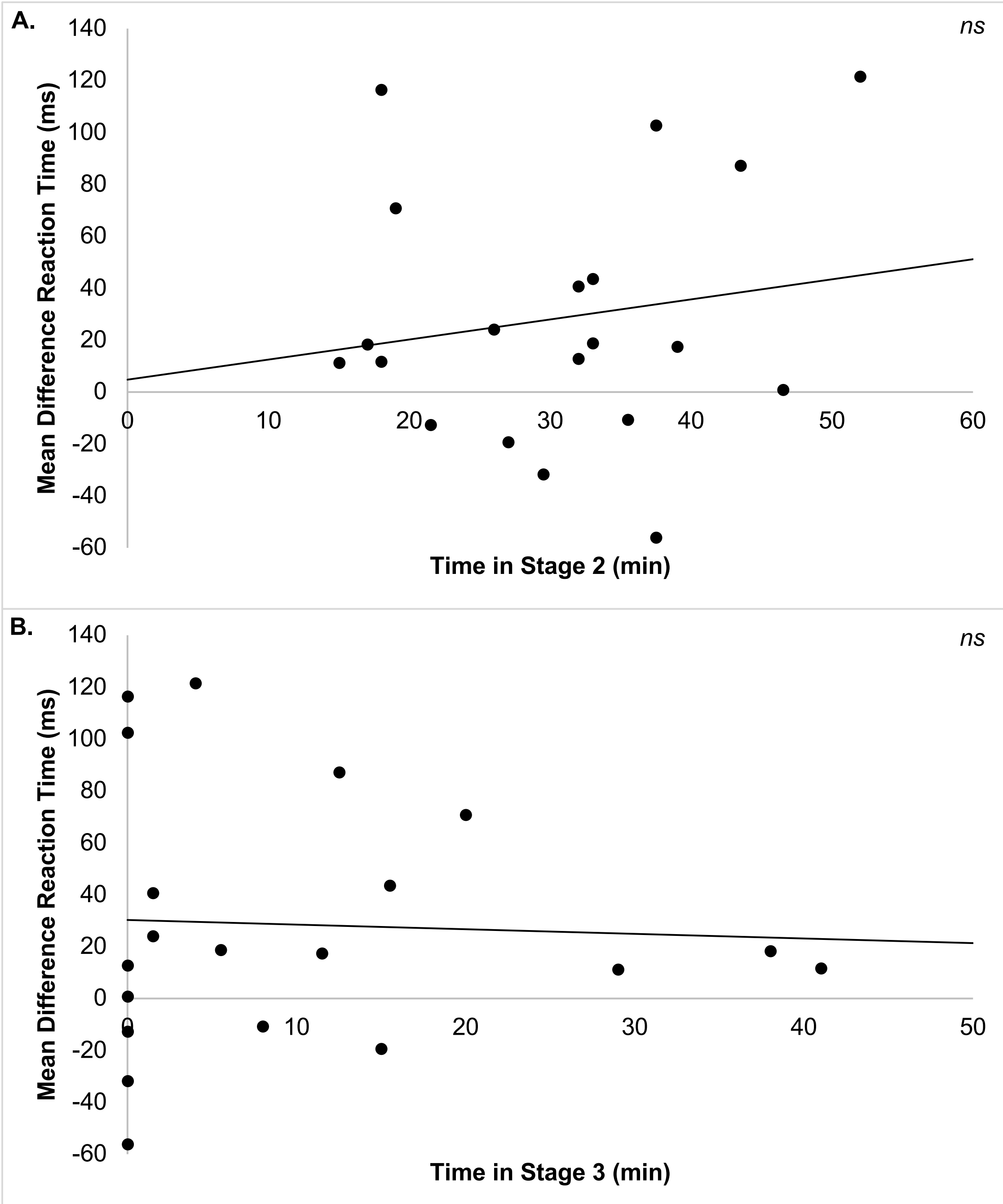

Figure 4. The correlation of time spent in stage 2 (A.) and stage 3 (B.) sleep with implicit memory strength of directly-stated words. *ns* indicates non-significance.

Discussion

Past research revealed processing external stimuli and forming implicit memories of external stimuli was possible during sleep (Andrillon & Kouider, 2016; Blume et al., 2017;

Legendre et al., 2019; Perrin et al., 1999; Züst et al., 2019). Thus, considering these findings, the current study aimed to examine whether sleeping participants could form implicit memories of a narrative played during sleep. Specifically, the story *Pretty Mouth and Green My Eyes* was played to participants while they napped, and it was predicted that participants would respond faster to words directly from this story or related to this story when completing an implicit memory task after their nap. Additionally, the role of sleep stages in implicit memory formation was analyzed, in order to examine whether particular stages of sleep contribute differentially to this memory formation process. Specifically, based on prior research, it was hypothesized that more time spent in stage 2 or 3 sleep would be associated with stronger implicit memories (Andrillon & Kouider, 2016; Züst et al., 2019).

Implicit Memory Formation

As predicted, participants responded faster to words directly from GME in comparison to control story words during the implicit memory task, indicating that implicit memories of these directly-stated words had been formed. This finding is in line with previous research, which has also found evidence for the formation of implicit memories during sleep (Andrillon & Kouider, 2016; Züst et al., 2019). A study by Andrillon and Kouider (2016) played participants a list of words during a nap, they found EEG and behavioural evidence of implicit memory formation of the words played. These authors used second order responses, specifically, confidence ratings as a behavioural measure of implicit memory formation. The current study extends this research by providing strong behavioural evidence of implicit memory formation of words heard during sleep. Particularly, this study used reaction times to look at implicit memory traces, which is a more direct behavioural measure than confidence ratings. Furthermore, the current study also reveals that sleeping participants can process and form memories of words from a continuous speech stream such as a story and not just from a word list. Züst et al. (2019) also found behavioural evidence of implicit memory formation during sleep. These authors played participants word pairs during sleep. Each word pair had a real word (e.g. *house*) and a pseudoword (e.g. *tofer*). Later, when participants woke up they were asked whether the pseudoword from each word pair was bigger or smaller than a shoebox and better than chance performance on this task was found. Overall, their study provided behavioural evidence that participants can also form implicit memories of word associations during sleep. Thus, the current study's finding in combination with the recent findings of Züst et al. (2019), support the idea that memories formed during sleep can have effect at the behavioural level.

Contrary to what was predicted, faster response times were not seen for words related to GME when compared to unrelated control words. The finding that participants do not show evidence of implicit memories for related words, but only for directly-stated words, could potentially suggest that only direct word-level processing is occurring during sleep, but not semantic or thematic level processing. This is supported by the fact that participants were primed for words directly said in the story (direct priming), but did not show priming or spreading activation of semantic associates (semantic priming), which would be expected had participants formed memories of story theme. Alternatively, the lack of an effect seen for related words could be due to limitations in the sensitivity of the Animacy Decision Task, and not that of the sleeping brain. This idea is supported by the Story Control participants, who showed effects similar to those of sleeping participants even though they were exposed to the story while fully awake. Notably, these control participants also showed implicit memory traces for directly-stated words, but not related words. This suggests perhaps the Animacy Decision Task is not sensitive to semantic priming of thematically related words, as awake participants should have been able to fully process the meaning and theme of the story. This lack of sensitivity could also be due to the fact that there were fewer words in the related and unrelated word categories (20 words each) in comparison to the directly-stated and control story word categories (30 words each). Thus, perhaps semantic level processing and memory formation of the theme of the story is possible during sleep, but just not seen in the context of this study or task.

It was also important to establish that participants were responding faster to directly-stated words in comparison to the control story words due to the formation of implicit memories from the story played during sleep and not because of any systematic stimulus differences between the word lists that could influence reaction times. As such, another control group was run who performed the implicit memory task without listening to GME. It was found these No-Story Control participants showed no differences in response times to the four different word types. This suggests that there were no underlying biases in the task or word lists that would lead our sleeping participants to respond faster to directly-stated words. Hence the faster response times to directly-stated words in the Experimental group were due to implicit memory traces of the story heard during the nap.

Outside of the scope of this study, the current research on implicit memory formation during sleep opens the door to researching whether sleep encoding could help wake learning. Specifically, it may be possible that implicit encoding of information during sleep could help one process and learn the same information faster when going back to it while awake. However, much more research is needed to know whether this is a possibility.

Role of Sleep Stages in Implicit Memory Formation

Although it was predicted that stage 2 or 3 sleep would be associated with implicit memory formation, results did not support this prediction. No relationship was discovered between time spent in stage 2 or 3 sleep and strength of implicit memories in the context of this study. This suggests that perhaps time spent in certain sleep stages is not the mechanism behind implicit memory formation. Prior studies provide evidence that specific sleep EEG signatures might play a role in processing and memory formation during sleep. Particularly, participants have shown stronger memories of words heard during sleep if the word presentation coincided with a slow-wave peak (Züst et al., 2019). Thus, slow waves could be playing a role in implicit memory formation. Furthermore, the role of K-complexes could be important as well. Although, K-complexes have not previously been implicated in memory formation, K-complexes have been implicated in allowing the brain to integrate salient information such as parts of a story for a brief period of time after their occurrence (Legendre et al., 2019). Thus, there are other sleep stage mechanisms that could underlie implicit memory formation.

Limitations and Future Directions

A limitation of this study was the small sample size for the No-Story Control group, as this group only had 11 participants. Due to Covid-19, we were unable to increase the sample size of this control group, as originally planned. It would be beneficial to run more No-Story Controls to provide more support for the idea that there are no underlying biases in the Animacy Decision Task that would lead to faster reaction times to directly-stated words. Another limitation is that participants were only played GME once during their nap. A natural future direction would be playing participants a narrative multiple times during sleep and examining whether this leads to semantic priming and not just direct priming.

Another future direction for this research is examining the role of sleep stages in implicit memory formation in more depth. It would be important to examine the role of sleep stage at the item level by looking at which stage words were played during and whether words being played in certain stage lead to more robust memories. Additionally, it would be interesting to look at the role of certain EEG signatures of sleep such as slow waves or K-complexes and see whether they play a role in implicit memory formation of a narrative.

Conclusion

This study found evidence of direct priming, which suggests implicit memory formation of a narrative played during sleep is possible at least at the direct-word level. However, semantic priming was not found; hence, more research is needed to see whether memories capturing the theme and meaning of narratives can be formed by the sleeping brain. Additionally, it was found that time spent in stage 2 or 3 sleep was not associated with the formation of stronger memories, suggesting that perhaps time is not the mechanism behind any impact sleep stages' may have on implicit memory formation.

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Appendix A

Western University's Research Ethics Board Approval Letter

Western Research

Date: 17 August 2019

To: Dr Laura Batterink

Project ID: 112576

Study Title: Studies of sleep and language learning

Application Type: Continuing Ethics Review (CER) Form

Review Type: Delegated

Meeting Date: 06/Sep/2019

Date Approval Issued: 17/Aug/2019

REB Approval Expiry Date: 31/Aug/2020

Dear Dr Laura Batterink,

The Western University Non-Medical Research Ethics Board has reviewed this application. This study, including all currently approved documents, has been re-approved until the expiry date noted above.

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Daniel Wyzynski, Research Ethics Coordinator, on behalf of Prof. Randal Graham, NMREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix B

Pretty Mouth and Green My Eyes Excerpt Script

0:00 – 0:44: WHEN the phone rang, the gray-haired man asked the girl, if she would rather for any reason he didn't answer it. The girl heard him as if from a distance, and turned her face toward him. The gray-haired man asked her to hurry up, and she raised up on her right forearm just quickly enough so that the movement didn't quite look perfunctory. She cleared her hair back from her forehead with her left hand and said, "God. I don't know. I mean what do you think?" The gray-haired man said he didn't see that it made a helluva lot of difference one way or the other. He reached for the phone with his right hand. "Hello?" he said resonantly into the phone. The girl stayed propped up on her forearm and watched him.

0:44 – 0:53: A man's voice — stone dead, yet somehow rudely, almost obscenely quickened for the occasion — came through at the other end: "Lee? I wake you?"

0:53 – 0:59: The gray-haired man glanced briefly left, at the girl. "Who's that?" he asked. "Arthur?"

1:00 – 1:01: "Yeah — I wake you?"

1:01 – 1:03: "No, no. I'm in bed, reading. Anything wrong?"

1:04 – 1:12: "The reason I called, Lee, did you happen to notice when Joanie was leaving? Did you happen to notice if she left with the Ellenbogens, by any chance?"

1:12 – 1:16: "No, I didn't, Arthur," he said. "Didn't she leave with you?"

1:16 – 1:19: "No. Christ. You didn't see her leave at all, then?"

1:20 – 1:25: "Well, no, as a matter of fact, I didn't, Arthur. Why? What's up? Joanie lost?"

1:25 – 1:33: "Oh, Christ. Who knows? I don't know. You know her when she gets all tanked up and rarin' to go. I don't know. She may have just — "

1:33 – 1:36: "You call the Ellenbogens?" the gray-haired man asked.

1:37 – 1:50: "Yeah. They're not home yet. I don't know. Christ, I'm not even sure she left with them. I know one thing. I know one goddam thing. I'm through beating my brains out. I mean it. I really mean it this time. I'm through. Five years. Christ."

1:50 – 2:02: "All right, Arthur," the gray-haired man said. "In the first place, if I know the Ellenbogens, they probably all hopped in a cab and went down to the Village for a couple of hours. All three of 'em'll probably barge — "

2:02 – 2:14: "I have a feeling she went to work on some bastard in the kitchen. I just have a feeling. She always starts necking some bastard in the kitchen when she gets tanked up. I'm through. I swear to God I mean it this time. Five goddam-"

2:14 – 2:18: "Where are you now, Arthur?" the gray-haired man asked. "Home?"

2:19 – 2:20: "Yeah. Home."

2:20 – 2:28: "Look, Arthur. You want my advice?" he said. "Get in bed and relax. Is it going to do any good to sit around and stew?"

2:28 – 2:44: "Yeah, I know. I wouldn't even worry, for Chrissake, but you can't trust her! I swear to God. I swear to God you can't. You know what I do? I'm ashameda tell ya, very nearly goddam do every night? When I get home? You want to know?"

2:44 – 2:46: "Arthur, listen, this isn't — -"

2:47 – 2:59: "Wait a second — I'll tell ya, God damn it. I practically have to keep myself from opening every goddam closet door in the apartment — I swear to God. Every night I come home, I half expect to find a bunch of bastards hiding all over the place."

2:59 – 3:16: "All right. All right. Let's try to take it a little easy, Arthur," the gray-haired man said. He turned his head again toward the girl, perhaps to show her how forbearing, even stoic, his countenance was. But the girl missed seeing it. Her eyes looked up at him a second too late.

3:17 – 3:33: "In the first place," he said, into the phone, "You know what you do? You actually go out of your way to torture yourself. As a matter of fact, you actually inspire Joanie-" He broke off. "You're bloody lucky she's a wonderful kid. I mean it."

3:34 – 3:45: "You know who I'm married to? I'm married to the greatest living undeveloped, undiscovered actress, novelist, psychoanalyst, and all-around goddam unappreciated celebrity-genius in New York. You didn't know that, didja?"

3:46 – 3:51: "For a helluvan intelligent guy, you're about as tactless as it's humanly possible to be."

3:51 – 3:55: "She doesn't respect me. She doesn't even love me, for God's sake."

3:55 – 4:09: The gray-haired man listened another moment. "Now, Arthur. Listen. I say this in all sincerity. Willya get undressed and get in bed, like a good guy? And relax? Joanie'll probably be there in about two minutes."

4:09 – 4:18: "Yeah. I hear you. Listen. I've kept you awake all night anyway. Could I come over to your place for a drink? Wouldja mind?"

4:18 – 4:25: The gray-haired man straightened his back and placed the flat of his hand on the top of his head, and said, "Now, do you mean?"

4:25 – 4:34: "Yeah. I mean if it's all right with you. I'll only stay a minute. I'd just like to sit down somewhere and — I don't know. Would it be all right?"

4:34 – 4:50: "Yeah, but the point is I don't think you should, Arthur," the gray-haired man said, lowering his hand from his head. "I mean you're more than welcome to come, but I honestly think you should just sit tight and relax till Joanie waltzes in."

4:50 – 4:53: "I don't know. I swear to God, I don't know."

4:53 – 4:58: "Look. Why don't you hop in bed now, and relax, and then later, if you feel like it, give me a ring."

4:58 – 4:59: "All right."

4:59 – 5:06: The gray-haired man continued for a moment to hold the phone to his ear, then lowered it into its cradle.

5:06 – 5:09: "What did he say?" the girl immediately asked him.

5:09 – 5:11: "He wanted to come over here for a drink."

5:11 – 5:15: "God! What'd you say?" said the girl.

5:15 – 5:18: "You heard me," the gray-haired man said, and looked at her.

5:18 – 5:24: "You are wonderful. Absolutely marvellous," the girl said, watching him.

5:24 – 5:29: "Well, it's a tough situation. I don't know how marvellous I was."

5:29 – 5:31: "You were. You were wonderful."

5:31 – 5:39: The gray-haired man looked at her. "Well, it's a very, very tough situation. The guy's obviously going through absolute — "

5:39 – 5:47: The phone suddenly rang. The gray-haired man said "Christ!" but picked it up before the second ring. "Hello?" he said into it.

5:47 – 5:49: "Lee? Were you asleep?"

5:49 – 5:50: "No."

5:50 – 5:54: "Listen, I just thought you'd want to know. Joanie just barged in."

5:54 – 5:55: "What?" said the gray-haired man.

5:56 – 6:26: "Yeah. She just barged in. About ten seconds after I spoke to you. I just thought I'd give you a ring while she's in the john. Listen, thanks a million, Lee. I mean it. Apparently Leona got stinking and then had a goddam crying jag, and Bob wanted Joanie to go out and grab a drink with them somewhere. Anyway, so she's home. What a rat race. Honest to God, I think it's this goddam New York. I mean — except you — who do we know in New York except a bunch of neurotics?

6:26 – 6:40: "Listen, Arthur," the gray-haired man interrupted, taking his hand away from his face, "I have a helluva headache all of a sudden. You mind if we cut this short? I'll talk to you in the morning — all right?" He listened for another moment, then hung up.

6:40 – 6:57: Again, the girl immediately spoke to him, but he didn't answer her. He picked a burning cigarette out of the ashtray and started to bring it to his mouth, but it slipped out of his fingers. The girl tried to help him retrieve it before anything was burned, but he told her to just sit still, for Chrissake, and she pulled back her hand.

Appendix C

Animal Word List

Alligator	Eel	Lion	Rabbit
Ant	Emu	Llama	Rat
Ape	Fish	Lizard	Raven
Armadillo	Frog	Lobster	Reindeer
Antelope	Falcon	Lynx	Rhinoceros
Bear	Flamingo	Leopard	Salmon
Butterfly	Ferret	Moose	Skunk
Beaver	Goat	Minnow	Swan
Beetle	Goldfish	Mongoose	Snail
Buffalo	Gorilla	Moth	Squirrel
Badger	Grasshopper	Mule	Sheep
Crow	Gerbil	Mosquito	Turkey
Cow	Gazelle	Newt	Toad
Cat	Hawk	Nightingale	Turtle
Cheetah	Hippo	Ostrich	Tuna
Chicken	Hamster	Otter	Termite
Crab	Hedgehog	Owl	Vole
Dog	Hornet	Octopus	Vulture
Donkey	Horse	Opossum	Worm
Duck	Iguana	Pig	Weasel
Deer	Jaguar	Peacock	Wolf
Dolphin	Junebug	Penguin	Walrus
Dove	Jellyfish	Porcupine	Woodpecker
Eagle	Koala	Panda	Yak
Elk	Kangaroo	Quail	Zebra

Appendix D

Non-Animal Word Lists

Directly-Stated	Related	Pie Man	Unrelated
Phone	Affair	Journalism	Peaceful
Gray	Suspicious	Reporter	Silence
Hair	Frustrated	Campus	Relax
Night	Husband	Elusive	Closeness
Drink	Deception	Cream	Camaraderie
Advice	Conflict	Pie	Vacation
Call	Betray	Attack	Foreign
Relax	Vulnerable	Embellishment	Secure
Stew	Jealous	Pastry	Public
Home	Friend	Cape	Legitimate
Situation	Secret	Flannel	Innocent
Closet	Uncertain	Spirit	Pride
Stoic	Worry	Rumour	Stability
Cigarette	Domestic	Nuance	Engaging
Neurotic	Trust	Barbeque	Support
Headache	Guilt	Sensation	Extroverted
Late	Hesitant	Newspaper	Uplifted
Burn	Flirt	Dean	Contentment
Awake	Embarrass	Student	Satisfy
Bed	Honorable	Story	Wholesome
Read		Avenger	
Forearm		Prize	
Cab		Mask	
Tough		Latin	
Countenance		Library	
Lost		Letter	
Brain		Scene	
Hand		Question	
Slip		Costume	
Answer		Shoulder	

Appendix E

Explicit Memory Task Questions

Please summarize the story using as many details as you can remember.

How much did you like this story?

Did you feel engaged with this story?

Have you ever heard this story before?

Was the narrator a male or female?

What were the names of the two men in the story?

Why did Arthur call Lee?

What did Arthur worry Joanie was doing?

What did Lee say Joanie was probably doing?

What did Lee advise Arthur to do?

What did Lee think was Arthur's problem?

What did Arthur ask Lee towards the end of their FIRST conversation?

What did Lee tell Arthur to do?

What did the girl ask after Lee hung up?

What did Arthur tell Lee in the SECOND phone call?

What did Arthur say about why Joanie had come back home so late?

How does Arthur end the SECOND phone call with Lee?

What does Arthur do after he hangs the phone at the end of the story?

Appendix F

Adult Participant Information Sheet

Subject Code: _________________________ Birth date: _________________________
Sex:___

Do you consider yourself: ☐ right-handed ☐ left-handed ☐ ambidextrous

Language Background

Is English the first language that you learned? ☐ yes ☐ no

If *No*, what language did you first learn?____

If *No*, at what age did you first begin learning English?______________________________

In what context?____

If *No,* in which language (English or your native language) are you more comfortable?___

Are you fluent in any language other than English? ☐ yes (list language),______________ ☐ no

Are you regularly exposed to any language other than English? ☐ yes,________________ ☐ no

If *Yes*, in what context? ____

Are there are other languages not asked about above that you know? ☐ yes,____________ ☐ no

If *Yes*, please list and describe how you learned them. ____________________________________

____

____

What is your field of study/major?

____

Neurological History

Have you ever had brain surgery? ☐ yes ☐ no

Have you ever had, or do you currently have, any neurological disorders (e.g., seizures, schizophrenia)?

☐ yes ☐ no If *Yes*, please explain: ____

Are there any known neurological problems in your family? ☐ yes ☐ no

If *Yes*, please explain: ____

Are you currently taking any medication(s) that may affect brain functioning (including but not limited to anti-depressants, anti-psychotics, anti-seizure)? ☐ yes,_____________ ☐ no

Have you ever had, or do you currently have, any speech, hearing, learning, or psychiatric disorders?

☐ yes ☐ no If *Yes*, please explain: ____

Vision and Hearing

Do you have normal or corrected-to-normal vision? ☐ yes ☐ no

Do you have normal hearing? ☐ yes ☐ no

Current State

How many hours of sleep did you get last night? __________

How many hours of sleep do you typically get per night? __________

Do you feel like you got enough sleep last night to function normally both physically and mentally?

☐ yes ☐ no If no, please explain:

____

Is there any *other* circumstance (not asked about above) that makes you feel like you are not at your mental best right now? ☐ yes ☐ no If yes, please comment:

____

Please rate your level of current fatigue on a 1-10 scale, where 1 is "so tired I can barely function today" and 10 is "I feel super rested, I've never felt better." (Circle 1-10)

(very tired) 1 2 3 4 5 6 7 8 9 10 (feel great)

Appendix G

Karolinska Nap Log (Karolinska Sleep Log Modified for Afternoon Nap)

1. How long did you nap for? ___________hours and ___________minutes
2. How long did it take you to fall asleep? ___________hours and ___________minutes
3. How many awakenings did you have during your nap? ___________
4. How many total minutes were you awake after falling asleep? __________minutes

(Don't include time in bed before falling asleep)

Circle one per question only:

5. How did you sleep?

1	2	3	4	5
Very Poorly				Very Well

6. Did you feel refreshed after woke up?

1	2	3	4	5
Not at all				Completely

7. Did you sleep soundly?

1	2	3	4	5
Very Restless				Very Soundly

8. Did you sleep throughout the time allotted for your nap?

1	2	3	4	5
Woke up after a short time				Slept for 90 min or more

9. How easy was it for you to wake up?

1	2	3	4	5
Very Easy				Very Difficult

10. How easy was it for you to fall asleep?

1	2	3	4	5
Very Easy				Very Difficult

11. How much did you dream during your nap?

1	2	3	4	5
None				Much

Appendix H

Letter of Information

Project Title: Studies of Sleep and Language Learning

Principal Investigator:
Dr. Laura Batterink
Department of Psychology, The University of Western Ontario, London, ON
Telephone: 519-661-2111 x85409; Email: lbatter@uwo.ca

1. Invitation to Participate

You are being invited to participate in a research study about how the role of sleep in memory consolidation and language learning.

The purpose of this letter is to provide you with information required for you to make an informed decision regarding participation in this research. It is important for you to understand why the study is being conducted and what it will involve. Please take the time to read this carefully, and feel free to ask questions if anything is unclear or if there are words or phrases you do not understand.

2. Why is this study being done?

The purpose of the study is to investigate how sleep contributes to the learning, consolidation and retention of different aspects of language, such as vocabulary and grammar. The results from this research will help us understand how sleep contributes to language learning, including clarifying whether sleep plays a more central role in learning some aspects of language compared to others. Our results will also help to pinpoint the underlying physiological mechanisms during sleep that may contribute to language learning and consolidation. This research has important implications for adult second language learners and may eventually lead to novel methods of boosting second language learning and retention through sleep.

3. How long will you be in this study?

It is expected that this study will take approximately [# of hours 3 - 5] hours to complete.

4. What are the study procedures?

The experiments conducted as part of this study will test how humans process and learn about different types of linguistic stimuli, such as syllables, words, phrases and sentences. If you agree to participate, you will be asked to listen to language-related auditory stimuli and/or read words and sentences on a screen. You may be asked to perform different tasks associated with the stimuli, such as responding to targets by pressing a button, or making different judgments or ratings about your impressions of the stimuli. You may be asked to respond using your voice, and your voice may be recorded using an audio recorder. If you do not wish to be recorded, you can still participate in other parts of the study.

Your brain activity will be recorded using a technique called electroencephalography (EEG), where electrodes placed on the scalp measure electrical signals that brain cells use to communicate. An elastic cap will be placed on your head. The cap will be strapped down to fit snugly and comfortably. The sensors, which look like white pieces of plastic about 1 inch in diameter attached to the cap, will be filled with a small amount of conductive gel. To monitor blinking and eye movements, the experimenter will place similar sensors on the skin surface near your eyes. These sensors will be secured in place using tape. When the sensors are removed, the gel will be wiped off using tissue. Some gel may remain in your hair, but it can easily be removed by rinsing with water. You will be given the opportunity to wash your hair at the end of the study.

You will be given the opportunity to take a nap in the sleep lab in the Western Interdisciplinary Research Building (WIRB) while your brain activity is recorded using EEG. Each room in the sleep lab is equipped with a comfortable bed. You will be asked to lie down in the bed for a [1-2] hour period. While you nap you will be monitored using video and audio monitoring equipment by the experimenter in an adjacent room. The experimenter will be available throughout the nap if needed, and you can communicate with the experimenter at any time during this nap opportunity through use of the 2-way audio monitor.

The task(s) will be conducted in the Brain and Mind Institute in the Western Interdisciplinary Research Building (WIRB) on the University of Western Ontario campus.

5. What are the risks and harms of participating in this study?

There are no known or anticipated risks or discomforts associated with participating in this study. However, you may experience a minor inconvenience as some gel may remain in your hair at the end of the study. The gel can easily be removed by washing your hair. You will be given the opportunity to wash your hair at the end of the study.

6. What are the benefits?

You do not directly stand to benefit from this study. Although you may not directly benefit from your participation, the information gathered may provide benefits to society as a whole which include enhancing our scientific understanding of sleep, memory consolidation, language, learning, and the brain, and leading to advancements in second language training and treatment of language-related disorders (for example, specific language impairment and autism).

7. Can participants choose to leave the study?

You may refuse to participate, refuse to answer any questions or withdraw from the study at any time. If you decide to withdraw from the study, you have the right to request withdrawal of information collected about you. If you wish to have your information removed please let the researcher know. Withdrawing or refusing to answer questions will not result in loss of promised compensation.

8. How will participants' information be kept confidential?

Any personal or identifying information obtained from this study will be kept confidential and will be accessible only to the investigators of this study. Identifiable information that will be collected during the study includes your full name, telephone number, email address, partial date of birth (month and year) and, in some cases, audio voice recordings. In the event of publication, any data resulting from your participation will be identified only by case number, without any reference to your name or personal information. Only the research team will have access to information that identifies you to carry out this research study.

If files are shared with other researchers or the results are made public, any personal information that could identify you will be removed. Only anonymized data will be shared outside the research team (e.g., in an open access repository for publication purposes, or for other researchers to verify the findings or re-analyze).

Any documents identifying you by name will be kept separately from your data, and will be destroyed after 7 years. De-identified and anonymous study records will be maintained for a minimum of 7 years. A list linking your study number with your name will be kept by the researcher in a secure place, separate from your study file.

Representatives of the University of Western Ontario Non-Medical Research Ethics Board may require access to your study-related records to monitor the conduct of the research.

9. Are participants compensated to be in this study?

You will receive course credit (1 credit per hour) or monetary compensation ($14 per hour) for your participation in this study. If you do not complete the entire study you will still be compensated a pro-rated amount (based on the same rates specified above: 1 credit/h or $14/h). When calculating prorated compensation, your total participation time will be rounded up to the nearest half hour. For example, if you withdraw after 1 hour and 15 minutes, your participation time will be rounded to 1.5 h and you will receive 1.5 credits or $21. Therefore, even if you withdraw prior to completing study, you will still be compensated for the amount of time you spent participating.

10. What are the rights of participants?

Your participation in this study is voluntary. You may decide not to be in this study. Even if you consent to participate you have the right to not answer individual questions or to withdraw from the study at any time. If you are a student at Western and you choose not to participate or to leave the study at any time, it will have no effect on your academic standing.

We will give you new information that is learned during the study that might affect your decision to stay in the study.

You do not waive any legal right by signing this consent form

11. Whom do participants contact for questions?

If you have questions about this research study please contact Laura Batterink, Principal Investigator, Telephone: 519-661-2111 x85409; Email: lbatter@uwo.ca

If you have any questions about your rights as a research participant or the conduct of this study, you may contact The Office of Human Research Ethics (519) 661-3036, email: ethics@uwo.ca.

This letter is yours to keep for future reference.

Appendix I

Consent Form

Project Title: Behavioral and EEG studies of language learning
Study Investigator's Name: Dr. Laura Batterink

I agree to be audio-recorded in this research.
☐ **YES** ☐ **NO**

I agree to be contacted for future research studies.
☐ **YES** ☐ **NO**

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

Participant's Name (please print): ____

Participant's Signature: ____

Date: ____

My signature means that I have explained the study to the participant named above. I have answered all questions.

Person Obtaining Informed Consent (please print): ____________________________

Signature: ____________________________

Date: ____________________________

Appendix J

Debriefing Form

Project Title: Studies of sleep and language learning

Principal Investigator:
Dr. Laura Batterink
Department of Psychology, University of Western Ontario
Telephone: 519-661-2111 x85409
Email: lbatter@uwo.ca

Thank you for your participation in this study. The purpose of this study was to examine how sleep contributes to the consolidation and retention of new linguistic information. Sleep has been shown to play an important role in memory consolidation, and also in the generalization and abstraction of hidden patterns or overarching rules in the environment. Our main hypothesis is that sleep contributes to the consolidation and strengthening of many different aspects of language, such as learning of sound patterns and vocabulary acquisition. We hypothesize that sleep may play an especially important role in generalization aspects of language learning, such as grammatical rule generalization. We are also interested in testing which—if any—aspects of language processing can occur during sleep, by assessing how the brain responds to different types of linguistic stimuli presented at non-awakening thresholds during sleep.

By having you complete different tasks, we were able to assess what you learned, consolidated, and retained about the language-related stimuli that you were presented with. We also recorded your brain activity to monitor how your brain responds to different types of stimuli, and how these brain responses relate to overall learning success. By recording your brain activity while you were given the opportunity to nap, we were also able to see how long you slept, and what stages of sleep you were in. Your data will help us understand how different sleep mechanisms contributes to memory consolidation in a language-learning context. Your participation and responses are much appreciated.

As part of this experiment, you may have been in an experimental condition in which auditory stimuli were presented at low volumes while you were asleep. We did not inform you about this possibility prior to your nap, because expecting that auditory sounds may be presented can make it more difficult to fall asleep, and may also lead to differences in processing the stimuli during sleep, potentially leading to greater likelihood of arousal. If this makes you uncomfortable you are free to withdraw your data from our sample.
If you would like to learn more, here are some interesting references on the role of sleep in memory consolidation and language:

- Schreiner, T., & Rasch, B. (2017). The beneficial role of memory reactivation for language learning during sleep: A review. *Brain and Language*, *167*, 94–105.

- Diekelmann, S., & Born, J. (2010). The memory function of sleep. *Nature Reviews Neuroscience,* 11, 114–126.

- Walker, M. P., & Stickgold, R. (2010). Overnight alchemy: Sleep-dependent memory evolution. *Nature Reviews Neuroscience*, 11, 218–219.

- O'Neill, J., Pleydell-Bouverie, B., Dupret, D., & Csicsvari, J. (2010). Play it again: Reactivation of waking experience and memory. *Trends in Neurosciences*, 33, 220–229.

Your results are confidential to the experimenters and all results are published anonymously as group data. If you have any further questions about this study please contact Sarah Hollywood (shollywo@uwo.ca) or Dr. Laura Batterink (email: lbatter@uwo.ca, office: WIRB 5140, phone: 519-661-2111 ext. 85409).
If you have questions about your rights as a research participant, please contact the

Director of the Office of Research Ethics at ethics@uwo.ca or 519-661-3036.