The Effects of Sleep Deprivation on Memory

Kylie R. Gannon and Kacy E. Lloyd

Department of Psychology, Longwood University

Abstract

This is a proposal for a research project that will access the effects of sleep deprivation on memory. We predict that an increase in sleep deprivation will cause a decrease in memory. We will measure these effects on 50 college-aged participants using an item recognition test. The participants will take 3 different versions of an item recognition test at various times of the day. Participants will be divided into two groups, a not sleep-deprived group, and sleep-deprived group, by using a random numbers table. We will use three independent sample t-test to analyze the results of the experiment because we want to see if there is a significant difference between the number of words recognized by the two groups. Based on past studies, the results of this study would more than likely support our hypothesis. The suspected result would be significant because it would show the importance of sleep.

Keywords: sleep deprivation, memory, item recognition

The Effects of Sleep Deprivation on Memory

Sleep deprivation can affect one's brain and their memory. When someone is sleep-deprived, they are not getting the appropriate amount of sleep which leaves them feeling tired and may affect their performances of tasks (Van Heugten, 2020). Numerous researchers have tested theories on how memory can be affected by the lack of sleep.

In a study, half of the participants were sleep-deprived, and the other half were not, making it a between-group design. The participants were given a task where they were to complete steps in a specific order. After a couple of steps or trials, they would be interrupted for several seconds. The participants were then expected to continue with the proper trial. The completion of the task and the amount of errors were used to determine how sleep deprivation affected the participants' memory. The results suggest that participants who have been sleep-deprived were more likely to be unwilling or unable to perform the same procedural tasks that they had done previously. If the participants were able to complete the task, they made more errors than they had before (Stephan et al., 2019).

In another study, the researchers conducted two experiments: one where participants underwent 24 hours with no sleep (total sleep deprivation [TSD]), and another where the participants slept less than seven hours a night (partial sleep deprivation [PSD]). This was a within-subjects design, with the order of the experiments randomized for the participants. The Stanford Sleepiness Scale (SSS) was used to assess how tired the participants were (1 = *wide awake*, 7 = *no longer fighting sleep*). The results of the experiment showed a negative effect of TSD and PSD on cognitive abilities, as well as a reduced speed regarding response to tasks (Gosselin et al., 2017).

In a third study, researchers wanted to study the effect of multi-night sleep restriction on long-term memory retention. Participants were randomized into one of two groups. Participants in the sleep restricted group slept for five hours for 5 nights whereas the control group got to sleep for 9 hours. After the fourth night of sleep restriction, the participants learned facts about species of arthropods across a 6 hour time period. There were three tests that contained 120 questions that tested memory retention of the information on the arthropods. The researchers passed the tests out to the participants 30 minutes after learning the information, then 3 days later, and finally 42 days after the learning period. The results concluded that long term memory is compromised when students learn after being sleep restricted (Cousins et al., 2019).

In a fourth study, the effects of two types of sleep deprivation were studied on visual working memory: one night of total sleep deprivation and four nights of partial sleep deprivation with four hours in bed each night. Each participant was studied by researchers for six nights where they slept nine hours each. After the six nights, participants were randomly assigned into one of the two sleep-deprived groups. The participants could have ended up in four different groups due to the sleep-deprived condition and well-rested condition being counterbalanced across the participants. In this study, the researchers examined two different visual working memory components: capacity and filtering. The researchers measured capacity by showing a picture that contained four to eight colored squares and asked the participants to try and remember as many as they could. They then showed participants a new image and asked the participants to recall if the image was different from the first image. The researchers measured filtering by assessing the participants' capability to disregard irrelevant information and focus on the stimuli. The researchers found that neither partial or total sleep deprivation lessened visual working memory capacity and total sleep deprivation can indeed have an affect on the potential to ignore irrelevant stimuli (Drummond et al., 2012). The result of this study regarding visual working memory goes against the common assumption that memory would be negatively impacted by sleep deprivation. Contrary to these results, in other research it has been found that sleep deprivation does have a negative impact on memory.

In a randomized controlled crossover study, participants were randomly assigned to either have a full night of sleep, or they experienced one night of sleep deprivation. The participants completed the experiment from home by turning in online questionnaires every 45 minutes. Various cognitive and physical tests were performed. One cognitive test was the SIMON© game, which is when colors and sounds are recited in random order. As the test continued, more color-sound combinations were added. This test was completed three times. The other cognitive test was a standard stroop chart. First, the patients had to read in black text. Then they had to read words typed in a different or opposing color. Thirdly, the patients viewed color blocks, where they had to say the color of the blocks. Finally, the patients were required to read conflicting words, where they had to state the color of opposing or mismatched words. The physical tests involved spirometry for lung function, ruler drop testing for reaction time, heart rate, blood pressure during exercise, and rate of perceived exertion. The results of this study indicate there were no significant differences in the cognitive tests. In other words, one night without sleep did not have a significant effect on cognitive abilities (Patrick et al., 2017). The result of this study regarding cognitive tests does not support the common assumption that cognitive abilities would decline due to a lack of sleep. Despite these findings, in other studies researchers have found the opposite results.

Finally, a study by Ratcliff and Van Dogen measured the effects of sleep deprivation on two things: item recognition memory and associative recognition memory. The participants were in the laboratory for six nights and seven days. The researchers assigned them into either the control group or the sleep-deprived group. To measure item recognition, the participants are given a period of time to study the 16 words pairs and then are shown 64 words on a computer screen. They were then prompted to press the *?/* key on the keyboard if they had seen that word previously in the word pairs or the *Z* key if they had not. To measure associative recognition, the participants are given a period of time to study 16 word pairs and were then prompted to press the *?/* key on the keyboard if the two words on the screen were in the same pair when they were studying or the *Z* key if they were different. The researchers found that the effects of sleep deprivation were similar for both item and associative recognition memory. For both item and associative recognition, the response proportions were similar for the experimental and control groups in the baseline and recovery sessions. However, in the sleep-deprived session, the participants' accuracy was different from the participants in the control session (Ratcliff & Van Dongen, 2018).

Due to all of this research, we want to test the effects of sleep deprivation on memory. Through this study we are examining whether a full 24 hours of no sleep would have a negative impact on the memory of students. We predict that the students going 24 hours with no sleep will recognize fewer words compared to the control group that will get to sleep for 8 hours.

Method

Sample

We will obtain our convenience sample of 50 right-handed female college students between the ages of 18 and 22 from a public, liberal arts university in Virginia. The college students will take part in this study in order to obtain extra credit for a psychology class. The participants must have never been diagnosed with a memory or sleeping disorder. Examples of disorders may include insomnia, Alzheimers, or dementia. Prior to the study, the participants will fill out a demographics questionnaire to ensure they never have been diagnosed with disorders/illnesses that may affect the way they sleep or their memory (see Appendix A for questionnaire). We will have these participants tested for these types of disorders prior to the start of the experiment. Aside from these tests, participants will also perform a standard physical exam and urine test in order to ensure they are healthy and drug free. The month before the experiment occurs, the participants should maintain their regular sleep schedules. Participants will be told to avoid caffeine, alcohol, drugs, and napping 24 hours prior to the experiment. The female college students should sleep a minimum of 6 hours and a maximum of 10 hours the night before the experiment. The participants will be assigned to one of two sample groups: one group will stay up for 24 hours straight while the control group will get 8 hours of sleep. Informed consent will be acquired from all participants and the study will be approved by the university's Institutional Review Board (see Appendix B for IRB forms). All participants will be treated ethically.

Materials and Procedure

We will use a random number table in order to select which participants belong in which sample. The day of the study, all participants will wake up at 9:00 a.m. Participants will come to the laboratory at 10:00 a.m. and perform their first item recognition test (see Appendix C for item recognition test). Before starting the test, participants will enter their age. The item recognition test features 12 words each being shown individually on a screen for 3 seconds. After all of the words are shown, the test consists of the 12 words previously shown as well as 18 new words. The participant will have to answer whether or not those words appear on their screen, hitting the *y* key if the answer is yes and hitting the *n* key if the answer is no. The more correct answers a participant has, the better their memory will be considered.

After this test, both participant groups will go to their isolated rooms where they can be monitored by researchers. Participants will be allowed to occupy themselves with quiet activities as long as the activities do not activate the autonomic nervous system. This is important because the autonomic nervous system relates to arousal and consciousness. Food and water will be provided for the participants, but they will not contain caffeine or alcohol.

At 9:00 p.m., both groups of participants will be given an item recognition test again, using completely different words (see Appendix D for the second item recognition test). After the test is completed, the control group will go to sleep. The other group will remain awake, continuing their quiet activities. The participants in the control group should sleep 8 hours, waking up at 5:00 a.m. The control group will resume quiet activities until 9:00 a.m. At 9:00 a.m., both groups will be given a final item recognition test that contains different words than both of the previous given (see Appendix E for the final item recognition test). After the final test is completed, the participants will be allowed to leave. The participants who stayed awake for 24 hours will be given the option to be driven home or sleep in the laboratory.

Proposed Analysis, Results, and Discussion

We will be running an independent samples t-test three times to determine if there is significant evidence between the percentage of errors performed by the two groups because it is a between-groups design with two conditions. Due to previous researchers such as Ratcliff and Van Dongen, we believe that the results (see Figure 1) will support our hypothesis that participants who go 24 hours with no sleep will recognize fewer words compared to the group that will sleep for 8 hours. For the first two time periods when the item recognition tests are taken, 10 a.m. and 9 p.m., the two groups will have the same amount of sleep, so their percent of errors regarding words recognized is likely to be similar. However, at 9 a.m., the final test, the sleep-deprived group will have been awake for 24 hours whereas the control group would've gotten a normal 8 hours of sleep. Most likely, there would be a large difference in percentage of errors for the sleep-deprived and control groups at this time, with the percentage of errors being much larger for the sleep-deprived group.

Possible limitations with this experiment could include that participants in the not sleep-deprived group may not be able to fall asleep, resulting in not reaching the 8 hours of required sleep. In addition, a possible limitation will occur if the participants do not refrain from the use of caffeine, drugs, or alcohol prior to the start of the experiment. Future researchers can replicate this study by using different sets of words for the tests, giving the tests to the participants at different times, changing the amount of tests that will be taken and changing the amount of words in the test.

References

Cousins, J. N., Wong, K. F., & Chee, M. W. L. (2019). Multi-night sleep restriction impairs long-term retention of factual knowledge in adolescents. *Journal of Adolescent Health, 65*(4), 549–557. https://doi-org.proxy/10.1016/j.jadohealth.2019.04.030

Drummond, S. P. A., Anderson, D. E., Straus, L. D., Vogel, E. K., & Perez, V. B. (2012). The effects of two types of sleep deprivation on visual working memory capacity and filtering efficiency. *PLoS ONE, 7*(4), Article e35653. https://doi.org/10.1371/journal.pone.0035653

Gosselin, D., De Koninck, J., & Campbell, K. (2017). Novel measures to assess the effects of partial sleep deprivation on sensory, working, and permanent memory. *Frontiers in Psychology, 8,* Article 1607. https://doiorg.proxy/10.3389/fpsyg.2017.01607

McDermott, K. B. & Roediger, H. L. (2020). Memory (encoding, storage, retrieval). In R. Biswas-Diener & E. Diener (Eds), *Noba textbook series: Psychology.* Champaign, IL: DEF publishers. Retrieved from http://noba.to/bdc4uger

Patrick, Y., Lee, A., Raha, O., Pillai, K., Gupta, S., Sethi, S., Mukeshimana, F., Gerard, L., Moghal, M. U., Saleh, S. N., Smith, S. F., Morrell, M. J., & Moss, J. (2017). Effects of sleep deprivation on cognitive and physical performance in university students. *Sleep and Biological Rhythms, 15*(3), 217–225. https://doiorg.proxy/10.1007/s41105-017-0099-5

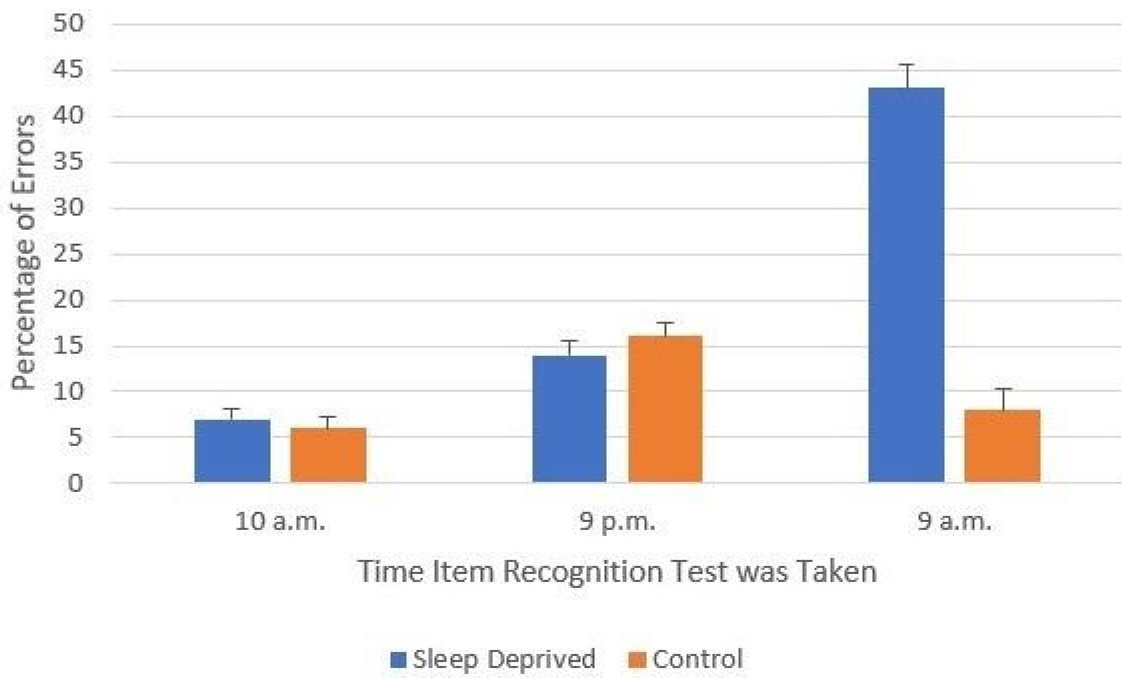
Ratcliff, R., & Van Dongen, H. P. A. (2018). The effects of sleep deprivation on item and associative recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 44*(2), 193–208. https://doi.org/10.1037/xlm0000452

Stepan, M. E., Fenn, K. M., & Altmann, E. M. (2019). Effects of sleep deprivation on procedural errors. *Journal of Experimental Psychology: General, 148*(10), 1828–1833. https://doi.org/10.1037/xge0000495

Van Heugten - van der Kloet, D. (2020). Dissociative disorders. In R. Biswas-Diener & E. Diener (Eds), *Noba textbook series: Psychology.* Champaign, IL: DEF publishers. Retrieved from http://noba.to/93xnbw2f

Figure 1

The Effects of Sleep Deprivation on Memory



Note. The item recognition tests were taken in the time slots listed above. The control group went to sleep after taking the second item recognition test and woke up at 5:00 a.m. the following morning.

Appendix A

Demographics Questionnaire

1. What is your age?
    -
2. What is your sex?
    - Yes - No
3. Are you taking any medications?
    - Yes - No
4. If you answered yes, what are you currently taking?

    ____

5. Do you have any pre-existing medical conditions?
    - Yes - No
6. If you have any medical conditions, would any of them affect the way you sleep or your memory processing skills? For example, are you restless? Do you find yourself sleeping too much or not enough? Are you finding it hard to remember information that you frequently learned?
    - Yes - No
7. If you answered yes to any of these questions, which medical conditions have an impact?

    ____

Appendix B

IRB Form

LONGWOOD UNIVERSITY

Institutional Review Board

Committee Action Form

(To Be Completed By Researcher)

Proposal Title: The Effects of Sleep Deprivation on Memory

Principal Investigator: Kylie Gannon and Kacy Lloyd

(For IRB Use Only)

[ ] Meets the criteria for making research exempt from obtaining written informed consent and Committee review.

[ ] Approved by the Longwood University Institutional Review Board.

[ ] Approved with revisions by the Longwood University Institutional Review Board.

[ ] Rejected by the Longwood University Institutional Review Board.

Date:________________________

Signature of IRB (circle one) Member/Chair:___________________________________

Comments:

Longwood University Institutional Review Board

Research Proposal Submission Form

I. Proposal

All Longwood University administration, faculty, and students conducting investigations involving human subjects, and all other researchers conducting investigations involving human subjects at Longwood University, must submit a research proposal to be reviewed and approved by the Human Subject Research Review Committee prior to the commencement of research. Research involving children should conform to the ethical standards found at http://www.srcd.org/ethicalstandards.html. **Some types of human subjects research are exempt from the provisions of state and federal law, however, even research exempt from these provisions must be reviewed by the committee to determine that they are indeed exempt.** Research proposals submitted to the committee must follow the protocols contained in this form and include the following information. *Check those that are included.*

[x] A description of the research, including:

1) A Title,

2) The purpose of the research, and

3) The methods or procedures to be employed including descriptions of:

a) The human subjects and the criteria for including them in the research,

b) What is to be done with or to them,

c) Any possible risks, stress, or requests for information subjects might consider personal or sensitive, or which may be illegal, and whether or not the only risk to the subjects is the harm resulting from a breach of confidentiality,

d) the steps that will be taken to ensure the anonymity and confidentiality of the subjects,

e) the permissions from other institutions, if required, that will be obtained.

[x] A signed, completed copy of this submission form.

In addition, the research proposal may have to include the following documents. *Check those that are included*.

[x] A copy of the test, survey, or questionnaire, if employed, and if it is not a standardized professional diagnostic tool otherwise specified in the proposal.

[x] A copy of the written statement explaining the research indicating that participation is voluntary, if required. (See III. A. below.)

[x] A copy of what will be said to subjects before and after the research is conducted, if the methodology requires that the subjects be misled in any way. (See III. B.)

[x] A copy of the informed consent statement that will be used, if required. (See Sec. IV. below.) A model informed consent statement can be found at the end of this form.

II. Exemptions

If your research falls into any of the categories of research below, it is exempt from the requirement of obtaining written informed consent and being reviewed by the entire Committee, and only 1 copy of the proposal need be submitted. All others must submit 3 copies of their proposal. If your project conforms to any of the following descriptions, check those which apply:

[ ] Research or student learning outcomes assessments conducted in educational settings involving regular or special education instructional strategies, the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods, or the use of educational tests, whether cognitive, diagnostic, aptitude, or achievement, if the data from such tests are recorded in a manner so that subjects cannot be identified, directly or through identifiers linked to the subjects.

[ ] Research involving survey or interview procedures unless responses are recorded in such a manner that the subjects can be identified, directly or through identifiers linked to the subjects, and either (i) the subject's responses, if they became known outside the research, could reasonably place the subject at risk of criminal or civil liability or be damaging to the subject's financial standing or employability or (ii) the research deals with sensitive aspects of the subject's own behavior, such as sexual behavior, drug or alcohol use, or illegal conduct.

[ ] Research involving survey or interview procedures, when the respondents are elected or appointed public officials or candidates for public office.

[ ] Research involving solely the observation of public behavior, including observation by participants, unless observations are recorded in such a manner that the subjects can be identified, directly or through identifiers linked to the subjects, and either (i) the subject's responses, if they became known outside the research, could reasonably place the subject at risk of criminal or civil liability or be damaging to the subject's financial standing or employability or (ii) the research deals with sensitive aspects of the subject's own behavior, such as sexual behavior, drug or alcohol use, or illegal conduct.

[ ] Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in a manner so that subjects cannot be identified, directly or through identifiers linked to the subjects.

III. Special Types of Research

A. In addition to the above types of research that are exempt from the requirement to obtain written informed consent and full committee review, the committee may waive the requirement that the investigator obtain written informed consent for some or all subjects for the following type of research. If your research conforms to the following description, indicate by checking.

[ ] Research in which the only record linking the subject and the research would be the consent document, and the principal risk would be potential harm resulting from a breach of confidentiality.

In the forgoing type of research, the committee may require the investigator to provide the subjects with a written statement explaining the research and indicating that their participation is voluntary. In addition, each subject shall be asked whether s/he wants documentation linking him or her to the research, and the subject’s wishes shall govern. In the case that the subject agrees to be identified in the research, her or his written permission to do so shall be obtained by the researcher.

B. Some research methodologies may require that the subjects be initially misled regarding the purpose of the research, and so require that the consent procedure omit or alter some or all of the basic elements of informed consent, or waive the requirement to obtain informed consent. If your research conforms to the following description, indicate by checking.

[ ] Research involves no more than "minimal risk" or risk of harm not greater than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests, research could not practicably be performed without the omission, alteration or waiver, and the omission, alteration or waiver will not adversely affect the rights and welfare of the subjects.

In the forgoing type of research, the committee requires the researcher to provide the subjects with an adequate post-investigative explanation of the purpose and methods of the research, or explanatory debriefing procedure to be undertaken immediately after the conclusion of each subject's participation. The committee requires investigators undertaking this sort of research to furnish the committee with copies of the information that will be supplied to the subject before and after the investigation.

IV. Written Informed Consent

Research engaged in all other types of research must obtain written informed consent from the research subjects. Informed consent means the knowing and voluntary agreement, without undue inducement or any element of force, fraud, deceit, duress, or other form of constraint or coercion, of a person who is capable of exercising free power of choice.

The basic elements of information necessary to such consent are:

· 1. A reasonable and comprehensible explanation to the person of the proposed procedures of protocols to be followed, their purposes, including descriptions of any attendant discomforts, and risks and benefits reasonably to be expected;

· 2. A disclosure of any appropriate alternative procedures or therapies that might be advantageous for the person;

· 3. An instruction that the person may withdraw his consent and discontinue participation in the human research at any time without prejudice to her or him;

· 4. An explanation of any costs or compensation which may accrue to the person and, if applicable, the availability of third party reimbursement for the proposed procedures or protocols; and

· 5. An offer to answer and answers to any inquiries by the person concerning the procedures and protocols.

Informed consent must be obtained in the following manners for the following types of human subjects: (a) competent, then it shall be subscribed to in writing by the person and witnessed; (b) not competent at the time consent is required, then it shall be subscribed to in writing by the person's legally authorized representative and witnessed; or (c) a minor otherwise capable of rendering informed consent, then it shall be subscribed to in writing by both the minor and her or his legally authorized representative.

Legally authorized representative means (a) the parent or parents having custody of a prospective subject, (b) the legal guardian of a prospective subject, or (c) any person or judicial or other body authorized by law or regulation to consent on behalf of a prospective subject to such subject's participation in the particular human research.

Any person authorized by law or regulation to consent on behalf of a prospective subject to such subject's participation in the particular human research shall include an attorney in fact appointed under a durable power of attorney, to the extent the power grants the authority to make such a decision. The attorney in fact shall not be employed by the person, institution, or agency conducting the human research. No official or employee of the institution or agency conducting or authorizing the research shall be qualified to act as a legally authorized representative.

A legally authorized representative may not consent to nontherapeutic research, or research in which there is no reasonable expectation of direct benefit to the physical or mental condition of the human subject, unless it is determined by the human subject research review committee that such research will present no more than a minor increase over minimal risk to the human subject.

Notwithstanding consent by a legally authorized representative, no person who is otherwise capable of rendering informed consent shall be forced to participate in any human research.

In the case of persons suffering from organic brain diseases causing progressive deterioration of cognition for which there is no known cure or medically accepted treatment, the implementation of experimental courses of therapeutic treatment to which a legally authorized representative has given informed consent shall not constitute the use of force.

No informed consent form shall include any language through which the person who is to be the human subject waives or appears to waive any of her or his legal rights, including any release of any individual, institution, or agency or any agents thereof from liability for negligence.

Human subject research investigators are responsible for obtaining written informed consent from research subjects in accordance with these specifications, and for obtaining permissions from any other institutions that may be involved in informed consent statement which conforms to these specifications.

The Longwood University Institutional Review Board must be informed of any violation or alteration of the research protocol. Continuing research projects must be re-approved annually.

The undersigned researcher(s) indicate that the information provided to the committee is accurate and true to the best knowledge of the researcher(s), and that the researcher(s) have conformed to the above guidelines to the best abilities of the researcher(s).

Date: 03/30/2020 Signed (legibly): Kacy E. Lloyd

Date: 03/30/2020 Signed (legibly): Kylie R. Gannon

If this research is being completed in partial fulfillment of a Masters degree, the thesis committee must approve of your project prior to submission of these forms. The signature(s) of your committee chair/advisor on the appropriate form constitutes acknowledgement of this prior approval by your committee.

Please indicate the address where you would like the approval form sent (along with phone # and/or e-mail address):

201 High Street, Farmville, VA 23909

Dr. Eric Laws, Department of Psychology; Phone: (434)395-2841; e-mail: lawsel@longwood.edu

Further information of the status of proposals may be found at the following:

Dr. Eric Laws, Department of Psychology; Phone: (434)395-2841; e-mail: lawsel@longwood.edu

DESCRIPTION OF RESEARCH

Title of Research: **The Effects of Sleep Deprivation on Memory**

- Purpose of Research: The goal of this research is **to determine the effects of sleep deprivation on memory**. The research is being conducted as a **research proposal**, under the supervision of **Dr. Eric Laws**
- Methods and Procedures:

  · Participants: Participants will be Longwood University students who agree to voluntarily participate in the research. The purpose of the research will be explained to the students and they will be asked to participate with the provision that they are free to withdraw at any time without penalty.

  · Procedures: **We will obtain a sample of 50 right-handed female college students who must complete a questionnaire to ensure they have never been diagnosed with disorders/illnesses that may affect the way the sleep or their memory. The participants must complete a physical exam as well to make sure they are healthy and drug free. Before the study starts, the participants will be asked to maintain their normal sleeping schedules. We will use a random numbers table to select the number of participants to go into either the control group or the sleep-deprived group. Participants will wake up at 9:00 a.m. and will arrive at the laboratory at 10:00 a.m. to perform their first item recognition test. The item recognition test will feature 12 words that will be shown on a screen for 3 seconds. Once all the words have been shown, 18 new words as well as the previous 12 words will appear again and the participant will have to answer if those 12 words appeared by hitting the *y* key for yes and the *n* key for no. The more words they get correct, the better the participants' memory is. After the first test is completed, both sample groups will go to isolated rooms to occupy themselves with quiet activities in which they will be monitored by researchers. At 9:00 p.m. both groups will be given a second item recognition test, this time with a new set of words.**

After this second test is completed, the control group will be allowed to sleep 8 hours where the other group will remain awake, continuing their quiet activities until 9:00 a.m. At 9:00 a.m., both groups will take their final item recognition test that contains different sets of words from the first two tests. After the participants are finished with the test, they will be allowed to go home. The participants who stayed awake for 24 hours will be given the option to be driven home or sleep in the laboratory.

Possible Risks: Because of the sensitive nature of the study, it is anticipated that participants may experience some emotional discomfort. Participants will be informed of the nature of the study ahead of time, they will be told that they are free to participate or not participate, and that they can withdraw from the study at any time without penalty. No physical harm is anticipated. Nor is it anticipated that participation in the research will place the participants at any risk of criminal or civil liability, or damage the participants' financial standing or employability.

· Assurance of Anonymity and Confidentiality: Participants will be informed of the voluntary and confidential nature of the research via instructions on the data collection instrument. Participants will also be instructed not to put their name or any identifying information on the instrument. When collecting data from participants, the researcher will immediately place the data in a large envelope, and will not examine any of the data until all data have been collected. Once collected, the raw data will only be accessible to **Kylie Gannon, Kacy Lloyd, and Dr. Eric Laws**. In the event that any information provided by a participant should become known outside the research, it is unlikely that any harm would come to the participant.

Longwood University

Consent for Participation in Social and Behavioral Research

I consent to participate in the research project entitled:

The Effects of Sleep Deprivation on Memory

being conducted in the Department of **Psychology** by

Kylie Gannon and Kacy Lloyd

- I understand that my participation in this research is voluntary, and that I am free to withdraw my consent at any time and to discontinue participation in this project without penalty.
- I acknowledge that the general purpose of this study, the procedures to be followed, and the expected duration of my participation have been explained to me.
- I acknowledge that I have the opportunity to obtain information regarding this research project, and that any questions I have will be answered to my full satisfaction.
- I understand that no information will be presented which will identify me as the subject of this study unless I give my permission in writing.
- I acknowledge that I have read and fully understand this consent form. I sign it freely and voluntarily. A copy of this form will be given to me.

Name (Print): ____

Date: __________________ Signed: _________________________

I understand that if I have concerns or complaints about my treatment in this study, I am encouraged to contact the Office of Academic Affairs at Longwood University at (434) 395-2010.

Appendix C

Item Recognition Test Version 1

The initial 12 words the participants studied are: people, baseball, trombone, seven, purple, sunshine, donate, language, water, freedom, office, and pumpkin.

The 18 additional words were: music, circus, monster, story, lemon, alone, mountain, sister, challenge, nothing, river, tiger, iron, secret, candy, evil, forest, and winter.

Appendix D

Item Recognition Test Version 2

The 12 studied words were: turtle, glory, time, doctor, today, hero, talent, science, other, friend, cookie, and treasure.

The words that were not studied were: little, penny, couple, spirit, zero, message, lily, blanket, problem, idea, sandwich, under, lovely, panda, darkness, bottle, honey, and fitness.

Appendix E

Item Recognition Test Version 3

The 12 words the participants studied were: famous, simple, kingdom, wisdom, union, culture, image, garbage, window, bubble, insect, and program.

The 18 non-studied words added in to test the participants memory were: picnic, climate, rhyme, champion, sentence, olive, temple, balance, running, promise, crystal, whisper, thunder, rodent, public, structure, order, and angle.

Journal of Adolescent Health 65 (2019) 549–557

ELSEVIER

JOURNAL OF
ADOLESCENT
HEALTH

www.jahonline.org

Original article

Multi-Night Sleep Restriction Impairs Long-Term Retention of Factual Knowledge in Adolescents

James N. Cousins, Ph.D., Kian F. Wong, and Michael W. L. Chee, M.B.B.S. *

Centre for Cognitive Neuroscience, Duke-NUS Medical School, Singapore

Article history: Received January 10, 2019; Accepted April 24, 2019
Keywords: Sleep restriction; Sleep deprivation; Declarative memory; Long-term memory; Learning; Encoding; Consolidation; Adolescents

A B S T R A C T

Purpose: Sleep deprivation is associated with increased forgetting of declarative memories. Sleep restriction across multiple consecutive nights is prevalent in adolescents, but questions remain as to whether this pattern of sleep impairs memory for material typically learned in the classroom and the time course of retention beyond a few days.
Methods: Adolescents aged 15–18 years (n = 29) were given 5 hours sleep opportunity each night for 5 consecutive nights (sleep restricted group; SR), simulating a school week containing insufficient sleep. After the fourth night of restriction, participants learned detailed facts about different species of arthropod across a 6-hour period. Retention was tested 30 minutes and 3 days after learning and contrasted with a control group (n = 30) who had 9 hours sleep opportunity every night of the study. A subset of participants (SR, n = 14; control, n = 22) completed a surprise test 42 days after learning.
Results: Memory was significantly impaired in the SR group relative to controls, with 26% increased forgetting at the 30-minute test ($t(57) = 2.54$, $p = .014$, $d = .66$), 34% at the Day 3 test ($t(57) = 2.65$, $p = .010$, $d = .69$), and 65% at the Day 42 test ($t(34) = 3.22$, $p = .003$, $d = 1.17$). Vigilance was also significantly impaired after 4 nights of restricted sleep ($p < .05$), but did not correlate significantly with memory ($p > .05$).
Conclusion: Long-term retention of classroom material is significantly compromised when adolescents learn after being sleep restricted, reinforcing the importance of keeping good sleep habits to optimize learning.

IMPLICATIONS AND CONTRIBUTION

Adolescent sleep is often insufficient during the school week when large amounts of information must be learned. This study documented poorer retention of factual information for up to 6 weeks when material was learned after successive nights of sleep restriction, reinforcing the message that adequate sleep before learning is important.

Many adolescents obtain insufficient sleep, tending to curtail sleep during the school week and to "catch-up" on weekends [1–3]. The National Sleep Foundation Sleep in America Poll found that 62% of teenagers (aged 14–17 years) obtained less than the recommended 8–10 hours per night [4,5]. Similarly, in Singapore, only 15% of adolescents reported obtaining sufficient sleep during the week, compared with 80% on weekends [6]. Several factors contribute to this growing trend [7,8], including delayed circadian phase [9], slowed accumulation of sleep pressure [10], and electronic media use [11]. Multiple consecutive nights of sleep restriction result in cumulative deficits in cognition, impaired mood [1], and poorer academic performance [12–14]. It is therefore critical to characterize these impairments, particularly those that influence the ability to learn and retain information in long-term memory. This is important to guide public policy on health and education and determine the efficacy

Conflicts of interest: The authors have no conflicts of interest to disclose.
Data availability: The datasets generated and analyzed during the present study are available from the corresponding author on reasonable request.
* Address correspondence to: Michael W. L. Chee, M.B.B.S., Centre for Cognitive Neuroscience, Duke-NUS Medical School, 8 College Road, 169857 Singapore.
E-mail address: michael.chee@duke-nus.edu.sg (M.W.L. Chee).

1054-139X/© 2019 Society for Adolescent Health and Medicine. Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
https://doi.org/10.1016/j.jadohealth.2019.04.030

OPEN ACCESS Freely available online PLoS one

The Effects of Two Types of Sleep Deprivation on Visual Working Memory Capacity and Filtering Efficiency

Sean P. A. Drummond[1,2,3,4*], **Dane E. Anderson**[2], **Laura D. Straus**[2,4], **Edward K. Vogel**[5], **Veronica B. Perez**[6]

1 Psychology Service, VA San Diego Healthcare System, San Diego, California, United States of America, **2** Research Service, VA San Diego Healthcare System, San Diego, California, United States of America, **3** Department of Psychiatry, University of California San Diego, San Diego, California, United States of America, **4** San Diego State University and University of California San Diego (SDSU-UCSD) Joint Doctoral Program in Clinical Psychology, San Diego, California, United States of America, **5** Department of Psychology, University of Oregon, Eugene, Oregon, United States of America, **6** Department of Psychiatry, University of California San Francisco, San Francisco, California, United States of America

Abstract

Sleep deprivation has adverse consequences for a variety of cognitive functions. The exact effects of sleep deprivation, though, are dependent upon the cognitive process examined. Within working memory, for example, some component processes are more vulnerable to sleep deprivation than others. Additionally, the differential impacts on cognition of different types of sleep deprivation have not been well studied. The aim of this study was to examine the effects of one night of total sleep deprivation and 4 nights of partial sleep deprivation (4 hours in bed/night) on two components of visual working memory: capacity and filtering efficiency. Forty-four healthy young adults were randomly assigned to one of the two sleep deprivation conditions. All participants were studied: 1) in a well-rested condition (following 6 nights of 9 hours in bed/night); and 2) following sleep deprivation, in a counter-balanced order. Visual working memory testing consisted of two related tasks. The first measured visual working memory capacity and the second measured the ability to ignore distractor stimuli in a visual scene (filtering efficiency). Results showed neither type of sleep deprivation reduced visual working memory capacity. Partial sleep deprivation also generally did not change filtering efficiency. Total sleep deprivation, on the other hand, did impair performance in the filtering task. These results suggest components of visual working memory are differentially vulnerable to the effects of sleep deprivation, and different types of sleep deprivation impact visual working memory to different degrees. Such findings have implications for operational settings where individuals may need to perform with inadequate sleep and whose jobs involve receiving an array of visual information and discriminating the relevant from the irrelevant prior to making decisions or taking actions (e.g., baggage screeners, air traffic controllers, military personnel, health care providers).

Citation: Drummond SPA, Anderson DE, Straus LD, Vogel EK, Perez VB (2012) The Effects of Two Types of Sleep Deprivation on Visual Working Memory Capacity and Filtering Efficiency. PLoS ONE 7(4): e35653. doi:10.1371/journal.pone.0035653

Editor: Namni Goel, University of Pennsylvania School of Medicine, United States of America

Received November 14, 2011; **Accepted** March 22, 2012; **Published** April 18, 2012

Funding: This work was supported by a grant from the National Science Foundation (www.nsf.gov; award #0729021 to SPAD). The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

* E-mail: drummond@ucsd.edu

Introduction

Sleep deprivation can have a negative impact on many aspects of cognitive functioning. For example, sustained attention consistently shows performance impairment with sleep loss [1,2,3,4]. Working memory, on the other hand, is a multi-component cognitive process for which impairment appears to vary depending on the exact component of working memory assessed [5,6,7,8,9,10]. Broadly speaking, working memory can be differentiated into separate subsystems for verbal and visual information (e.g., [11]). While verbal working memory is fairly well studied in the context of sleep deprivation, relatively few studies have examined the effects of sleep deprivation on visual working memory.

Visual working memory (VWM) performance is thought to be comprised of two distinguishable component mechanisms. The first, capacity, involves the limits in the ability to simultaneously store and retain multiple pieces of visual information in working memory for short periods of time. Past studies testing VWM capacity have shown individuals are capable of retaining up to 3–4 objects at once, regardless of their complexity [12]. A second aspect of successful VWM involves controlling the flow of information into VWM, by determining whether stimuli are consistent with the individual's current goals. Since VWM capacity is limited, this process allows a person to "filter out" irrelevant information in order to focus on and remember relevant stimuli more efficiently [13]. Since working memory, in general, makes information available for more advanced cognitive processing, it represents one of the main rate limiting factors for higher-order cognitive functions such as fluid intelligence and complex decision making [14,15,16,17,18]. VWM may be particularly important in this fashion, as it is required for almost any cognitive demand involving storing multiple visual stimuli simultaneously or selecting target objects in crowded displays. Thus, to the extent the capacity or filtering components of VWM are impaired by sleep deprivation, this can have significant operational impacts for a wide range of individuals.

There has only been one study, to our knowledge, to examine the effect of sleep deprivation on VWM. Chee and Chuah [8] found one night of total sleep deprivation (TSD) significantly

frontiers in Psychology

ORIGINAL RESEARCH
published: 28 September 2017
doi: 10.3389/fpsyg.2017.01607

Novel Measures to Assess the Effects of Partial Sleep Deprivation on Sensory, Working, and Permanent Memory

*Dominique Gosselin, Joseph De Koninck and Kenneth Campbell**

School of Psychology, University of Ottawa, Ottawa, ON, Canada

Sleepiness has repeatedly been demonstrated to affect performance on a variety of cognitive tasks. While the effects of total sleep deprivation (TSD) have been extensively studied, acute partial sleep deprivation (PSD), a more frequent form of sleep loss, has been studied much less often. The present study examined the effects of sleep deprivation on novel tasks involving classic sensory, working, and permanent memory systems. While the tasks did implicate different memory systems, they shared a need for effortful, sustained attention to maintain successful performance. Because of the novelty of the tasks, an initial study of the effects of TSD was carried out. The effects of PSD were subsequently examined in a second study, in which subjects were permitted only 4 h of sleep. A general detrimental effect of both total and PSD on accuracy of detection was observed and to a lesser extent, a slowing of the speed of responding on the different tasks. This overall effect is best explained by the often-reported inability to sustain attention following sleep loss. Specific effects on distinct cognitive processes were also observed, and these were more apparent following total than PSD.

Keywords: sleep deprivation, cognitive impairment, attention, auditory sensory memory, visuospatial working memory, semantic memory

OPEN ACCESS

Edited by:
Monicque Lorist,
University of Groningen, Netherlands

Reviewed by:
Dimitri Van Der Linden,
Erasmus University Rotterdam, Netherlands
Helen St Clair-Thompson,
Newcastle University, United Kingdom

***Correspondence:**
Kenneth Campbell
kcampbel@uottawa.ca

Specialty section:
This article was submitted to Performance Science, a section of the journal Frontiers in Psychology

Received: *17 May 2017*
Accepted: *01 September 2017*
Published: *28 September 2017*

Citation:
Gosselin D, De Koninck J and Campbell K (2017) Novel Measures to Assess the Effects of Partial Sleep Deprivation on Sensory, Working, and Permanent Memory. Front. Psychol. 8:1607. doi: 10.3389/fpsyg.2017.01607

INTRODUCTION

More than a century of experimental data suggests that sleep is an essential component for optimal cognitive processing and that its restriction can significantly impair performance on many cognitive tasks. In an extensive review, Waters and Bucks (2011) point out that a major contributor to inter-subject variance in a large number of cognitive studies is the fact that many of these subjects will be fatigued and sleepy, often as a result of partial sleep loss. Indeed, restriction of sleep has frequently been employed as an experimental manipulation in cognitive studies to examine the extent to which various cognitive processes are affected by fatigue.

In most of these studies, subjects are totally sleep-deprived. The effect of total sleep deprivation (TSD), the complete absence of sleep over at least 24 consecutive hours, has now been extensively studied (Koslowsky and Babkoff, 1992; Pilcher and Huffcutt, 1996; Philibert, 2005; Alhola and Polo-Kantola, 2007; Lim and Dinges, 2010; Ma et al., 2015; Wickens et al., 2015). There is general consensus that this form of sleep restriction will affect tasks that are dependent on sustained attention and vigilance to maintain performance. Outside of the laboratory, individuals are however rarely totally sleep-deprived. On the other hand, acute partial sleep deprivation (PSD)

Sleep Biol. Rhythms (2017) 15:217–225
DOI 10.1007/s41105-017-0099-5

ORIGINAL ARTICLE

Effects of sleep deprivation on cognitive and physical performance in university students

Yusuf Patrick[1] · Alice Lee[1] · Oishik Raha[1] · Kavya Pillai[1] · Shubham Gupta[1] · Sonika Sethi[1] · Felicite Mukeshimana[1] · Lothaire Gerard[1] · Mohammad U. Moghal[2,3] · Sohag N. Saleh[4] · Susan F. Smith[5] · Mary J. Morrell[2,3] · James Moss[2,3]

Received: 8 August 2016 / Accepted: 23 March 2017 / Published online: 13 April 2017

Abstract Sleep deprivation is common among university students, and has been associated with poor academic performance and physical dysfunction. However, current literature has a narrow focus in regard to domains tested, this study aimed to investigate the effects of a night of sleep deprivation on cognitive and physical performance in students. A randomized controlled crossover study was carried out with 64 participants [58% male ($n=37$); 22 ± 4 years old (mean $\pm$ SD)]. Participants were randomized into two conditions: normal sleep or one night sleep deprivation. Sleep deprivation was monitored using an online time-stamped questionnaire at 45 min intervals, completed in the participants' homes. The outcomes were cognitive: working memory (Simon game© derivative), executive function (Stroop test); and physical: reaction time (ruler drop testing), lung function (spirometry), rate of perceived exertion, heart rate, and blood pressure during submaximal cardiopulmonary exercise testing. Data were analysed using paired two-tailed T tests and MANOVA. Reaction time and systolic blood pressure post-exercise were significantly increased following sleep deprivation (mean $\pm$ SD change: reaction time: 0.15 ± 0.04 s, $p=0.003$; systolic BP: 6 ± 17 mmHg, $p=0.012$). No significant differences were found in other variables. Reaction time and vascular response to exercise were significantly affected by sleep deprivation in university students, whilst other cognitive and cardiopulmonary measures showed no significant changes. These findings indicate that acute sleep deprivation can have an impact on physical but not cognitive ability in young healthy university students. Further research is needed to identify mechanisms of change and the impact of longer term sleep deprivation in this population.

Keywords Student · Acute sleep deprivation · Reaction time · Cognitive · Submaximal exercise

✉ James Moss
james.moss@imperial.ac.uk

1 Imperial College School of Medicine, Imperial College London, South Kensington Campus, Sir Alexander Fleming Building, London SW7 2DD, UK

2 Academic Unit of Sleep and Breathing, National Heart and Lung Institute, Imperial College London, London, UK

3 NIHR Respiratory Disease Biomedical Research Unit, Sleep and Ventilation, Royal Brompton and Harefield NHS Foundation Trust, Sydney Street, London SW3 6NP, UK

4 Faculty of Medicine, Imperial College London, South Kensington Campus, Sir Alexander Fleming Building, London SW7 2DD, UK

5 Medical Education Research Unit, Faculty of Medicine, Imperial College London, South Kensington Campus, Sir Alexander Fleming Building, London SW7 2DD, UK

Introduction

Sleep deprivation is common amongst university students whom live in a culture that promotes reduced sleep, due to the burden of academic work and social pursuits. The reasons for poor sleep hygiene include alcohol and caffeine intake, stimulants, and technology, which prevent students achieving sufficient sleep time and quality [1]. A cross-sectional survey found that 71% of students did not achieve the recommended 8 h of sleep, with 60% classified as poor sleepers [2]. An average of 5.7 h sleep has been reported for students studying architecture, and sleepless nights due to academic work throughout the night—defined by the Oxford English Dictionary as an all-nighter—occurred, on average, 2.7 days a month [3].

Journal of Experimental Psychology:
Learning, Memory, and Cognition
2018, Vol. 44, No. 2, 193–208

0278-7393/18/$12.00 http://dx.doi.org/10.1037/xlm0000452

The Effects of Sleep Deprivation on Item and Associative Recognition Memory

Roger Ratcliff and Hans P. A. Van Dongen
The Ohio State University and Washington State University

Sleep deprivation adversely affects the ability to perform cognitive tasks, but theories range from predicting an overall decline in cognitive functioning because of reduced stability in attentional networks to specific deficits in various cognitive domains or processes. We measured the effects of sleep deprivation on two memory tasks, item recognition ("was this word in the list studied") and associative recognition ("were these two words studied in the same pair"). These tasks test memory for information encoded a few minutes earlier and so do not address effects of sleep deprivation on working memory or consolidation after sleep. A diffusion model was used to decompose accuracy and response time distributions to produce parameter estimates of components of cognitive processing. The model assumes that over time, noisy evidence from the task stimulus is accumulated to one of two decision criteria, and parameters governing this process are extracted and interpreted in terms of distinct cognitive processes. Results showed that sleep deprivation reduces drift rate (evidence used in the decision process), with little effect on the other components of the decision process. These results contrast with the effects of aging, which show little decline in item recognition but large declines in associative recognition. The results suggest that sleep deprivation degrades the quality of information stored in memory and that this may occur through degraded attentional processes.

Keywords: diffusion model, reaction time and accuracy, total sleep deprivation, drift rate, recognition memory

Sleep deprivation has profound effects on human brain functioning. For example, sleep deprivation is associated with large-scale changes in the activity of neurotransmitters and neuromodulators, such as dopamine (Volkow et al., 2009) and adenosine (Urry & Landolt, 2014). Sleep deprivation leads to significant shifts in the dominant frequencies in the waking EEG (Torsvall & Akerstedt, 1987). Furthermore, it changes evoked potentials, indicative of altered stimulus processing (Corsi-Cabrera, Arce, Del Río-Portilla, Pérez-Garci, & Guevara, 1999). Not surprisingly, sleep deprivation also has substantial impact on cognitive performance (Jackson & Van Dongen, 2011). Yet, the effects of sleep deprivation on different cognitive tasks are ostensibly widely different (Lim & Dinges, 2010). Cognitive, pharmacological, neuroimaging, and genetic approaches have been put to use in the search for underlying mechanisms. This search has been hampered, however, by reliance on methods not specifically designed to test the effects of sleep deprivation and use of global outcome measures (Whitney & Hinson, 2010).

Recently there has been a focus on experimental and modeling studies of component processes of cognitive functioning (Gunzelmann, Gluck, Price, Van Dongen, & Dinges, 2007; Chee & Chuah, 2008; Ratcliff & Van Dongen, 2009; Tucker, Whitney, Belenky, Hinson, & Van Dongen, 2010). This has yielded new insights, indicating that distinct cognitive processes can be differentially affected by sleep deprivation (Jackson et al., 2013). One (qualitative) theory about the underlying mechanism posits that the effects of sleep deprivation are use-dependent, involving degraded information processing in neuronal networks that are most intensively used during performance of the task at hand (Van Dongen, Belenky, & Krueger, 2011). The diffusion decision model (Ratcliff, 1978; Ratcliff & McKoon, 2008; Ratcliff, Smith, Brown, & McKoon, 2016) provides an account of decision making that has been explicitly related to neuroscience measures (Forstmann, Ratcliff, & Wagenmakers, 2016; Gold & Shadlen, 2007; Smith & Ratcliff, 2004) and as such offers measures that can be related to neuronal processing theories.

There has been a long history of the use of item and associative tasks to examine processing and representation in memory. In an item recognition task, words or pictures are presented and the subject is to decide if the test item was in the study list. In associative recognition, pairs of words are presented and the subject is to decide if a test pair was composed of words studied together or whether the words were from different study pairs. Murdock (1974) reviewed and distinguished these as different forms of memory that operated in different ways and required different model-based approaches. Following the early work, a

This article was published Online First September 21, 2017.

Roger Ratcliff and Hans P. A. Van Dongen, Department of Psychology, The Ohio State University, and the Sleep and Performance Research Center, Washington State University.

The authors thank the staff of the Sleep and Performance Research Center at Washington State University for their help conducting the study, and Russ Childers for assistance with data processing. This work was supported by NIH Grants R01AG041176 and R01HL105768 and by CDMRP Grant W81XWH-16-1-0319.

Correspondence concerning this article should be addressed to Roger Ratcliff, Department of Psychology, The Ohio State University, Columbus, OH 43210. E-mail: ratcliff.22@osu.edu

American Psychological Association
Journal of Experimental Psychology: General

0096-3445/19/$12.00
2019, Vol. 148, No. 10, 1828–1833
http://dx.doi.org/10.1037/xge0000495

BRIEF REPORT

Effects of Sleep Deprivation on Procedural Errors

Michelle E. Stepan, Kimberly M. Fenn, and Erik M. Altmann
Michigan State University

In a large sample ($N = 234$), we tested effects of 24-hr of sleep deprivation on error rates in a procedural task that requires memory maintenance of task-relevant information. In the evening, participants completed the task under double-blind conditions and then either stayed awake in the lab overnight or slept at home. In the morning, participants completed the task again. Sleep-deprived participants were more likely to suffer a general breakdown in ability (or willingness) to meet a modest accuracy criterion they had met the night before. Among sleep-deprived participants who could still perform the task, error rates were elevated, and errors reflecting memory failures increased with time-on-task. The results suggest that sleep-deprived individuals should not perform procedural tasks associated with interruptions and costly errors—or, if they must, they should perform such tasks only for short periods.

Keywords: sleep deprivation, procedural error, memory maintenance

Supplemental materials: http://dx.doi.org/10.1037/xge0000495.supp

Sleep deprivation is known to affect attention and vigilance (e.g., Lim & Dinges, 2008; Norton, 1970; Wimmer, Hoffmann, Bonato, & Moffitt, 1992), but questions remain about its effects on higher-order cognitive processes (see Killgore, 2010 for review). Some studies found that sleep deprivation impaired working memory (Chee & Choo, 2004; Chee et al., 2006; Choo, Lee, Venkatraman, Sheu, & Chee, 2005; Durmer & Dinges, 2005; Habeck et al., 2004; Mu et al., 2005) or executive function (Durmer & Dinges, 2005; Nilsson et al., 2005), whereas others found no effect on higher-order processes (Binks, Waters, & Hurry, 1999; Nilsson et al., 2005; Tucker, Whitney, Belenky, Hinson, & Van Dongen, 2010; Wimmer et al., 1992). Some studies even found divergent effects using the same task (Chee & Choo, 2004; Chee et al., 2006). These equivocal findings may be a function of relatively small sample sizes.

Here we studied effects of sleep deprivation on error rates in a procedural task, focusing on the role of memory maintenance. In our task, participants perform a set of steps in a prescribed sequence. Every few trials—a trial being a performed step—the participant is interrupted for about 20 s. After the interruption, the participant must resume the interrupted sequence with the correct step. To know which step is correct, the participant must remember the last step performed before the interruption. Maintaining a memory for that step is made difficult by interference from the interrupting task.

The theoretical question we address is whether sleep deprivation affects memory processes and, if so, whether the effects are mediated by global cognitive impairments or impairments of memory-related processes specifically. We isolate effects on memory processes by comparing two trial types that differ only in the need for memory maintenance. A postinterruption trial follows an interruption, whereas a baseline trial follows another trial. The processing for the two trial types is identical except that a postinterruption trial requires recall of the step performed before the interruption, and therefore depends on memory maintenance during the interruption. Both trial types should show effects of global factors, such as increased fatigue or wake state instability (Doran, Van Dongen, & Dinges, 2001; Lim & Dinges, 2008). Only postinterruption trials should show effects specific to memory maintenance. Deprivation studies involving higher level tasks (e.g., Caldwell & Ramspott, 1998; Hack, Choi, Vijayapalan, Davies, & Stradling, 2001; Thomas et al., 2000) typically do not include measures such as our baseline trials that allow effects on higher-order processes to be isolated like this. We can also measure time-on-task effects specifically on memory maintenance because there are many postinterruption and baseline trials per session. Time-on-task effects after reduced sleep are well documented in vigilance tasks (e.g., Doran et al., 2001; Van Dongen, Maislin, Mullington, & Dinges, 2003) but have not been widely studied for higher-order cognitive processes. Finally, we aimed for conclusive results by testing a large sample. To our knowledge, ours is the largest

This article was published Online First September 27, 2018.
Michelle E. Stepan, Kimberly M. Fenn, and Erik M. Altmann, Department of Psychology, Michigan State University.
This research was supported by Grant N000141612841 from the Office of Naval Research to Kimberly M. Fenn and Erik M. Altmann.
Correspondence concerning this article should be addressed to Michelle E. Stepan, Department of Psychology, Michigan State University, 316 Physics Road, East Lansing, MI 48824. E-mail: stepanmi@msu.edu