Spring 2023

Further Investigation Into the Power of Wake and Sleep Incubation in Creative Problem Solving

Henry C. McCullers
Bard College, hm3040@bard.edu

Further Investigation Into the Power of Wake and Sleep Incubation in Creative Problem Solving

Senior Project Submitted to

The Division of Science, Math, and Computing

of Bard College

by

Henry McCullers

Annandale-on-Hudson, New York

May 2023

Dedicated to my family, Scott, Kelly, Caroline, and Midge McCullers for your love and support.

Acknowledgements

I'd like to thank my advisor Thomas Hutcheon, my family, and my best friend Min Purvis for their constant support throughout the completion of this project.

Table of Contents

Abstract

An incubation effect occurs when you "let a problem rest" and then try again to answer it. During this period of rest, it is thought that your brain unconsciously does problem solves. Brodt et al. (2018) investigated if this incubation period is better spent awake or asleep. They introduced participants to different types of tasks, and had them stay awake or sleep before attempting the problems again. They found that sleep was not better than staying awake, and concluded that while incubation may exist, sleep is not a better form than staying awake. In this study, I am proposing that participants be given an **additional** task, do **specific** activities during their wake incubation, and incubate (asleep or awake) for either **20 or 90 min** rather than 3 hours. Due to these changes, I expect different results than Brodt et al. (2018), in particular a difference in performance between the 20 min and 90 min groups for both sleep and wake incubation. This study could provide insight into the role of REM sleep in incubation. It could also provide insight into the role of activity in wake incubation. The brain is constantly working to solve problems and generate ideas. Learning more about the unconscious brain could lead to the enhancement of both of these functions.

Introduction

At times we are presented with creative problems. These are problems that we cannot come up with an answer for right away. These problems take time to solve. They are not problems like *What is 1+1?* or *What is the capital of Spain?*. They are questions like, "come up with a plan to complete x project by x date". These questions are planted in our brains. We often make an immediate attempt to answer them. We often consider the first thoughts that come to mind. We try to formulate an answer as fast as possible. As humans, we have a natural desire to know things. We are curious creatures. But, after a short amount of time with the problem in our head, we get stuck. We've gone through every single possibility of what the answer might be. We know in the back of our minds that eventually we will probably have the answer, but that then and there, we do not. So we do something else. Rather than sitting, waiting, for hours and days on end for the answer to come to us out of thin air, we go and attend to other things. We attend to other things that have obvious answers, or no *answers* at all. We know that we'll return to the difficult problem, just not now.

So we take some time away. We spend this time in various ways. Sometimes this time period is long; it might be a full night of sleep or even an entire day. And sometimes this period is short; It might be 15, 20, or 45 min. We then return to the problem after this period of time. Sometimes the answer to the problem becomes obvious and clear to us and we think to ourselves "how did I not think of that before, the answer was so clear!". Sometimes the answer doesn't come to us, and we worry that maybe the question or problem is too difficult to solve. We might revisit the problem again, but this time force ourselves to not abandon it when we run out of ideas, but rather stick with it and force ourselves to be bored as our brains go blank.

We also spend these time periods *doing* different things; we go and play video games, exercise, socialize, walk, run, shower, eat, clean, or organize. Later we come back to the problem, and we often find the right answer quicker than we were expecting. We think to ourselves that we owe this sudden success to the short break we took. We think "Wow, going out and exercising was just what I needed to get my brain going!", or "Wow, I was in such a slump, I'm glad I went out and socialized!". It seems that the specific actions we take during this period are what we owe our new creativity to.

This phenomenon is called the incubation effect. We know that incubation exists because there is extensive research on it. Incubation is the benefit of a period during which attention is diverted away from the problem (Sio & Ormerod, 2009). Incubation is a key aspect of creative problem solving, and has been incorporated into Wallas's "four stage model" (Wallas, 1926). The model is comprised of a preparation stage (1) followed by a period of incubation (2), which may lead to insight (3) and finally a verification of the solution that's been proposed (4). Preparation and verification rely on explicit processes, while incubation relies on unconscious processing (Hélie & Sun, 2010). Taking time away from a problem before embarking on a second attempt leads to higher solution rates than trying to find a solution continuously (Sio & Ormerod, 2009). Incubation effects are especially prominent in problems containing a broad problem space, for example the alternative or unusual uses tasks, in which participants are instructed to list as many possible uses for everyday items (Baird et al., 2012), or in the Remote Associates Test (RAT) (Mednick, 1968).

We can also spend an incubation period not consciously doing anything, but rather, asleep. This sleep can be a full night or maybe just a nap. One of the most common sayings is to

“sleep on it”. This can work with big problems and also big decisions. Often after a restful night of sleep, we become more confident in the decisions we make, and we come up with more and better answers. We think that sleep may be an effective form of incubation because there is a lot of evidence that sleep after learning aids in the strengthening and stabilization of new memories (Diekelmann et al., 2010). It has been proven that learning-related neural activity is replayed during sleep (Nadasdy et al., 1999) and that a repeated reactivation of hippocampal-cortical cell ensembles drives concurrent reactivation in cortico-cortical networks (Ji et al., 2007). It is thought that this systems-spanning replay supports the reorganization of memory representations on the neural level (Frankland et al., 2005), shifting the substrate that supports new memories from highly plastic hippocampal circuits to more stable neocortical regions. Detailed episodic memories are acquired by the fast-learning hippocampus, while more abstract, semantic information is retained by the slower learning neocortex (Frankland et al., 2005). It is thought that a change in the systems that support the memory may also entail a change in the quality of the memory representation, such as integration with existing knowledge, or the formation of new semantic concepts (Stickgold et al., 2013). A variety of sleep-dependent processes resulting in qualitative changes of memories have been identified. Sleep embeds recent memories into existing cortical networks, for example in lexical integration tasks (Tamminen et al., 2006). It also supports the extraction of common features from different memory elements in order to form new cognitive concepts, which can be observed in a strong but false memory for gist-words in the false memory paradigm (Payne et al., 2009). Sleep has also been shown to facilitate the implicit extraction of statistical patterns from multiple events. After sleep, participants' ability to

solve transitive inference tasks improves, they show superior probabilistic learning, and they may gain explicit access to implicitly learned patterns and rules (Stickgold et al., 2013).

Aside from the previously mentioned studies reporting on the beneficial effect of sleep on the ability to extract common features from multiple memory episodes which can lead to better solutions to similar problems (Stickgold et al., 2013), research on creative problem solving has mainly taken place using the Remote Associates Test (Weisberg, 2015). In the RAT, the participant is presented with three words that are semantically unrelated (ex. dirt, soup, fish) and are instructed to find a word that is related to all three (ex. bowl) (Mednick, 1968). Rapid eye movement (REM) sleep is said to aid problem solving in the RAT (Cai et al., 2009), and it has been proven that detecting difficult associates is easier after a period of sleep compared to a period of being awake (Sio et al., 2013). Only one study has investigated the effect of sleep on logical reasoning problems (Beijamini et al., 2014). In that study, the participants were given increasingly challenging logical reasoning problems in a video game until they were unable to move on to the next level. Then, half of them were permitted to sleep while the others were instructed to stay awake. The group which napped had a significantly higher chance of solving the level which they had been stuck on.

Overall, we as humans find it beneficial to take time away from problems and then revisit them. Rome wasn't built in a day, and the solutions to our problems are not found right away. We have to be patient with them. It would be great if we all knew exactly how we should be spending these periods. If we knew the perfect amount of time, and the perfect activities, and the

perfect questions/problems to use these time periods on, we would all find answers to our creative problems much faster, and we could benefit personally and as a society.

I'm proposing a study that would get us closer to answers to these questions. Brodt et al. (2018) et al took the first steps. In their experiment, they had participants perform three creative problem solving tasks, an anagrams, classical riddles, and visual change detection task, and then had half of the participants sleep for 3 hours, and the other half stay awake for the same amount of time. The participants then had a second attempt at the problems. They found that incubation, sleep or awake, increased scores on the riddles task, but not on anagrams or the visual change detection tasks. They also found that spending the incubation asleep was not more beneficial than spending the incubation period awake. They concluded that their study supports the notion that letting a problem rest is an effective way to find a solution, but that the role of sleep is confined to memory transformations that do not necessarily affect problem solving. While I agree with the conclusions of Brodt et al. (2018), I believe with further manipulations of variables and additions to their work, we could find more interesting information about incubation and creative problem solving that could inspire further research.

Incubation times

Brodt et al. (2018) used the same incubation time for the wake and sleep incubation groups in their study. The naps that the sleep incubation group took were 3 hours, and the wake wake incubation period was 4 hours. Research on effective nap times has shown that 20 min naps or 90 min are the most effective nap time because they allow people to wake up during a stage of light sleep which will result in a fresh sense of energy instead of grogginess ("*Napping, an*

important fatigue countermeasure, Nap duration", 2020). For this reason, I plan to change the incubation time for both sleep and wake incubation periods to 20 min and 90 min. Although these time periods are based on the requirements of effective naps, I think it will be most effective to have the same incubation times for both wake and sleep incubation in order to compare them.

Wake incubation activities

Brodt et al. (2018) did not track anything that participants did during their wake incubation. They warned them against eating heavy meals, engaging with the experimental tasks, engaging in cognitively taxing activities, and napping, but they did not have participants report exactly what they did during their incubation periods. In order to find out more about what types of activities might be most beneficial to perform during these periods, I will have different groups of participants perform different activities during their wake incubation periods. Research shows shared variance between bodily movement and creativity (fluency and originality) that is largely independent from variations in positive-activated affect (Rominger et al., 2020). In other words, bodily movement and creativity have been shown to correlate in people, regardless of whether their affect was positive or negative. For this reason, I plan to have one group of participants exercise (move their body) as a form of incubation, to see if it will enhance their creative abilities in solving the experimental tasks. Research also shows that there is a strong and significant positive relationship between informal as well as organized forms of socialization and creativity (Handzic & Chaimungkalanont, 2004). For this reason, I plan to have

one group of participants socialize during their incubation period to see if it will enhance their creative abilities in solving the experimental tasks.

In addition, natural environments enhance our creativity by making us more curious, better able to generate new ideas, and more flexible in our way of thinking (Plambech & Van Den Bosch, 2015). They also help us with redirecting our attention, which is vital when analyzing and developing further ideas. Natural environments described using the words ``Nature", "Space", and "Serene" seem to be of particular importance to creatives. Research suggests that it is worthwhile to provide natural environments to those involved in creative processes in order to support them. For this reason, I plan on having one group of participants spend time in nature during their period of wake incubation to see if it it will enhance their creative abilities in solving the experimental tasks.

Tasks

One addition I will be making to Brodt et al. (2018) will be to include the use of the Remote Associates Test. Brodt et al. (2018) excluded this test because they wanted to "pinpoint" specific prerequisites of effects of wake or sleep incubation. The RAT however has commonly been used to test creativity in the past, so I plan to include it in this study simply to have another measure of participants' creative abilities.

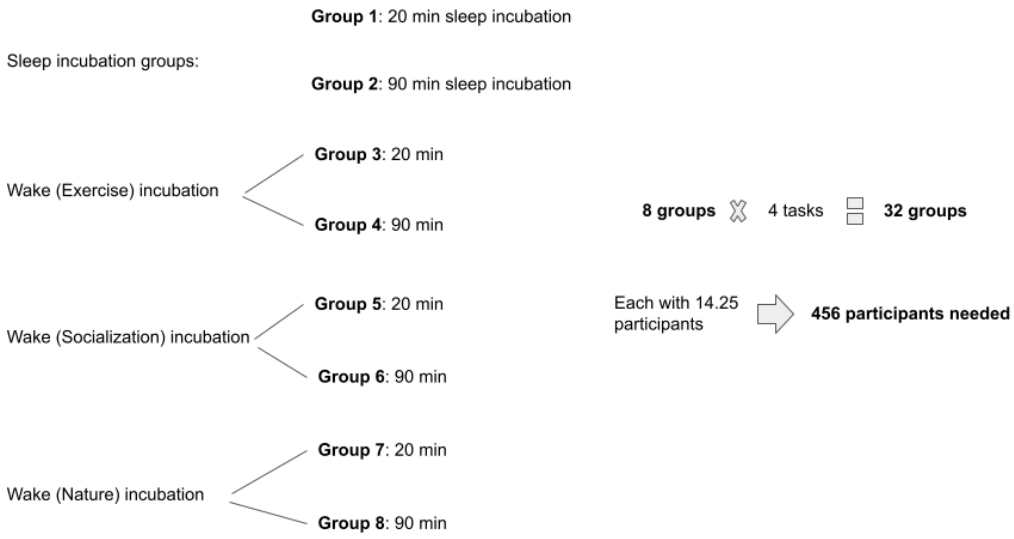
Methods

Participants

I will recruit 456 participants in order to have the same size groups as Brodt et al. (2018) (14.25 per group) since I will have 32 total groups in comparison to their 6. I will also use the same selection criteria as Brodt et al. (2018). Participants will be required to be native English speakers, not have any neurological conditions, and report a regular sleeping pattern of 6-10 hours per night over the last week. I will also use the Munich chronotype questionnaire (see Appendix A) to determine if participants are morning or evening type people, and will exclude participants who fall at either extreme. I expect the average age of participants to be 24+/- 3 years old (Brodt et al. (2018) average age was 23.7+/-2.57 years old).

Participants will be assigned randomly and equally into one of 32 groups. They will first be sorted into their the wake condition or the sleep condition. They will then be assigned to one of 2 “time subgroups”. These two “time subgroups” will be a 20 and 90 min subgroup. Within the time subgroup, they will then be assigned to one of 4 tasks. The task subgroups will be anagrams, riddles, visual change detection, and RAT.

Figure 1.



General procedure

Participants will be assigned to one of 32 conditions. The conditions will be: Wake-Exercise incubation (20 min or 90 min+Task X,Y,or Z), Wake-Socialization incubation (20 min or 90 min+Task X,Y,or Z), Wake-nature incubation (20 min or 90 min+Task X,Y,or Z), sleep incubation (20 min or 90 min+Task X,Y,or Z).

All groups will be presented with and encode one of the 4 creativity tasks, will make a first attempt at solving the task, and will then incubate for 20 min or 90 min. After giving informed consent, participants will be seated in a quiet room, and will receive further instructions verbally and on a computer screen. After making initial attempts to solve the creative tasks,

participants in the wake incubation groups will be given specific instructions based on the group they are assigned to.

Wake-exercise participants will be instructed to engage in some type of exercise during their 20 or 90 min incubation periods. People's definitions of exercise may vary, so we will simply ask participants to record what type of exercise they did during their incubation period.

Wake-socialization participants will be instructed to engage in some type of socialization during their incubation period. It has been shown that informal socialization benefits creativity more than formal socialization (Handzic & Chaimungkalanont, 2004), so we will ask participants before the time of the experiment to be prepared to engage in some type of socialization at the time of the experiment. We will ask participants after the experiment to record what type of socialization they engaged in (how many people, what environment, what intensity, etc.)

Wake-nature participants will be instructed to spend time outside during their incubation period, specifically in an area with lots of sunlight and greenery. We will again ask participants to record the details of their incubation period, (what they did, who was there, other potential social details, what the environment was like).

After making initial attempts to solve the creative tasks, participants in the sleep incubation groups will be hooked up to EEG recording devices and will be timed for 20 or 90 min of sleep. They will be put in a dark room with as little noise as possible, and will be offered sleep tools such as multiple pillows, altered temperature, a sleep mask, etc. After retesting, all participants will be asked if they knew the answer/how to solve any of the tasks beforehand.

Figure 2.1: Proposed order of events

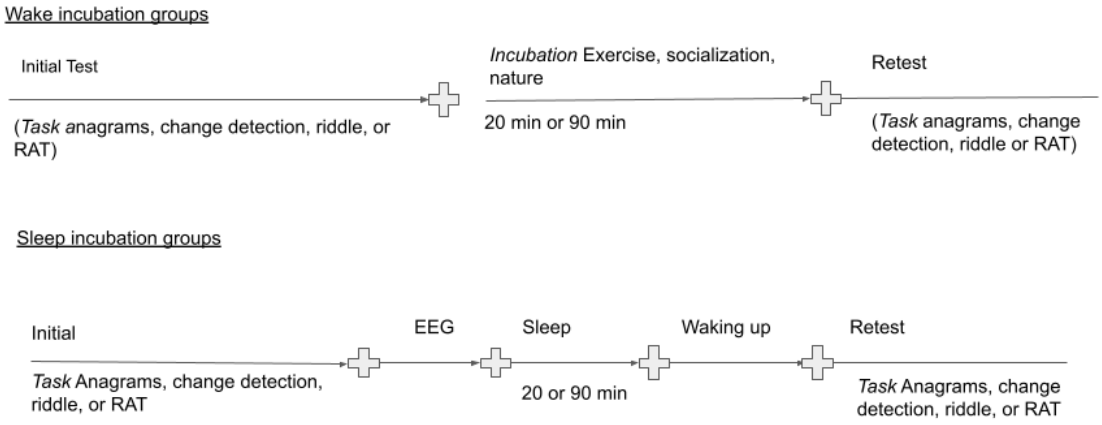
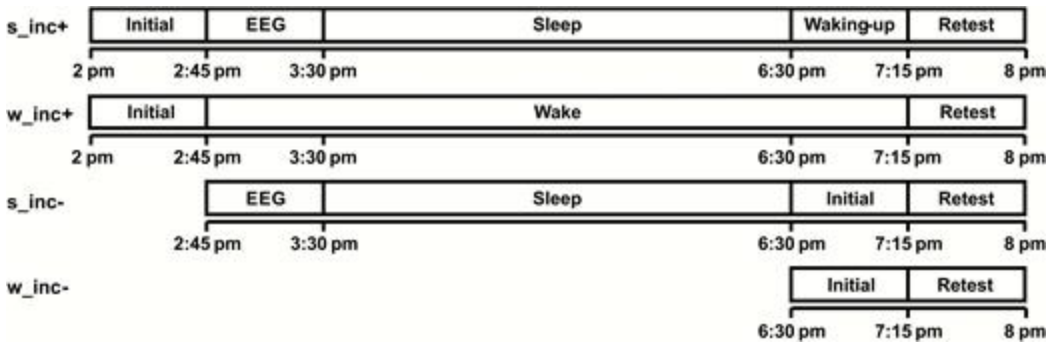


Figure 2.2: Brodt et al's order of events



Creative problem-solving tasks

Participants will be tested using three tasks: the anagrams, visual change detection, and riddles tasks used in Brodt et al. (2018). Descriptions of the three tasks are as follows:

In the anagrams task, participants will be presented with a non-word containing scrambled up letters, and they will use those letters to come up with as many actual words as possible. Anagrams tasks test divergent thinking (thinking of more than one answer), and are an

effective way to demonstrate the emergence of spontaneous associations through spreading activation (Brodt et al., 2018).

Figure 3: Anagrams

In the visual change detection task, participants will be presented with an image for 500ms, a black screen for 100ms, then the same image with one detail altered for another 500ms. They will then be asked to verbally state the change that took place in the image. Visual change detection tasks are commonly used to test visual information processing (Jensen et al., 2013), but also present the participant with an information integration problem that has to be solved on a perceptual level.

Figure 2: Visual change detection scene example

In the classical riddles task, participants will first solve a rebus-like task and classical rhymed riddle. Next, participants will solve a logical riddle, in which they will be asked to identify the wrongdoer in a short story about a broken window. Lastly, their logical thinking will be tested in a way similar to Raven Progressive Matrices, in which they will have to fill the gap in a matrix of symbols, chosen from a given "bank" of symbols. Riddles tasks are commonly used to test convergent thinking, in which there is only one correct solution (Brodt et al., 2018).

Figure 3: Riddles

Lastly, the RAT (Remote associates test), which Brodt et al. (2018) decided to not use in their study. Their reason for omitting it was that they wanted to diversify, and pinpoint the task specific prerequisites for incubation (wake or sleep) to have an effect. The RAT will be included in this study, because it has been proven to be an effective way to test creativity. The RAT is a

creative thinking test that was developed in the 1960's in order to test divergent thinking, or, problems that require participants to think of multiple possible solutions to a problem rather than one single solution. In the test, participants are shown a list of three words, and are asked to provide a word that links the three words together (ex. square/open/cardboard=BOX). The RAT has been shown to be an effective way to test convergent thinking (only one correct answer).

Figure 4: RAT

Square / Cardboard / Open = BOX

Broken / Clear / Eye = GLASS

Coin / Quick / Spoon = SILVER

Time / Hair / Stretch = LONG

Aid / Rubber / Wagon = BAND

Rationale for changed Incubation times

I will use different incubation times than Brodt et al. (2018). Their reasons for using 3.5/4.5 hour incubation wake/sleep periods are unclear, but in this study I want to base these time periods on research.

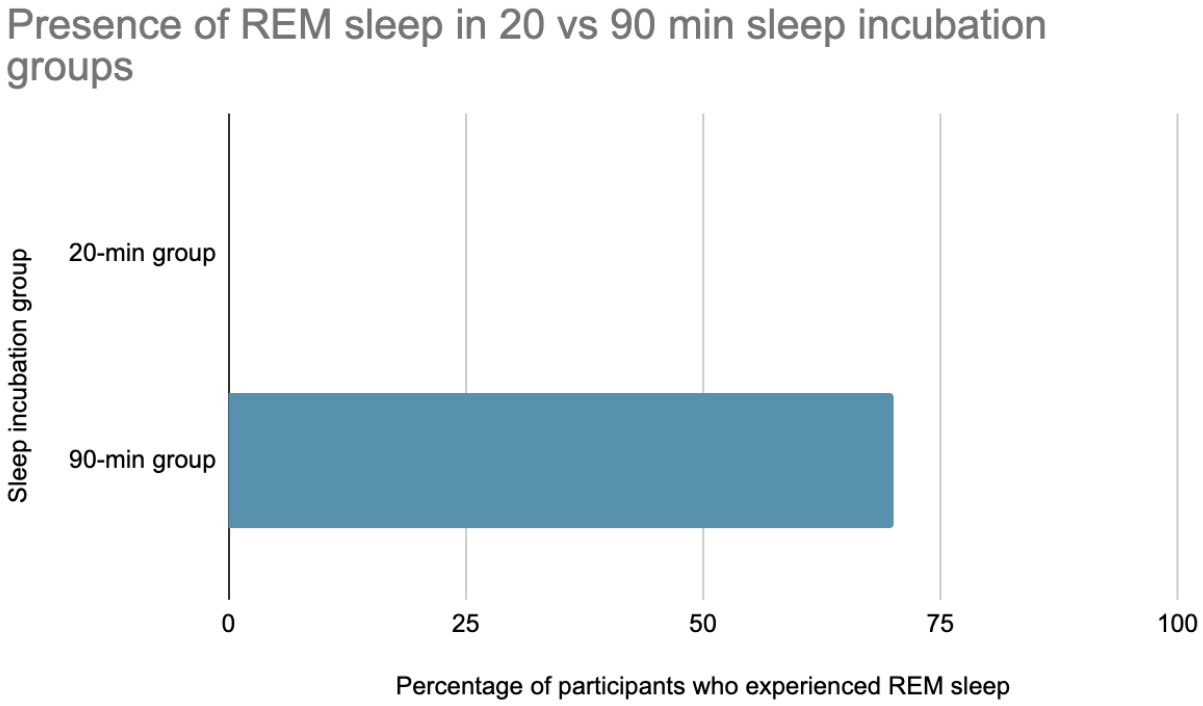
The CDC says that the most effective nap times are either 20 min or 90 min. The reason for this is because in 20 min, you haven't been sleeping long enough to go into deep sleep, and in

90 min, you usually will have completed an entire sleep cycle, so after either of these periods, you will usually not wake up feeling groggy, and will be better able to function with little adjustment time needed (you will feel more rested). For this reason, the sleep incubation groups will sleep either 20 min or 90 min. In addition, the wake incubation groups will perform their respective activities during these time periods too, so that I'll be able to compare their results to those of the sleep groups.

Expected Results

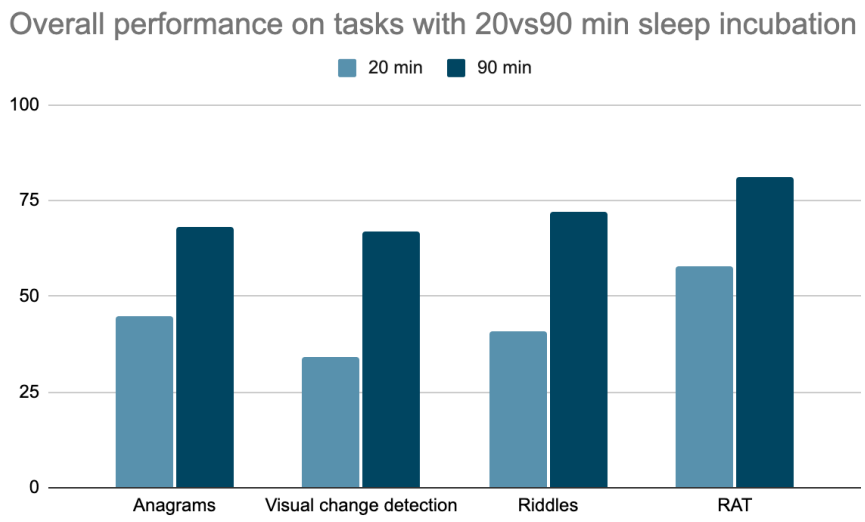
I expect to find a difference between the 20 min sleep incubation group and the 90 min sleep incubation group. Brodt et al. (2018) stated that the presence of REM sleep has been shown to increase participants' scores on an anagrams task. Participants in this study will be more likely to reach REM sleep in the 90 min group compared to the 20 min group (in which REM sleep is not possible). There will of course be some variability, because people sleep differently. Some participants will take longer to fall asleep, while others will be shorter. Some will wake up during the nap, others will not. However, I think overall there will be overall more REM sleep in the 90 min group than the 20 min group, and that will result in a lot more success for the 90 min group on the anagrams task.

Figure 5:



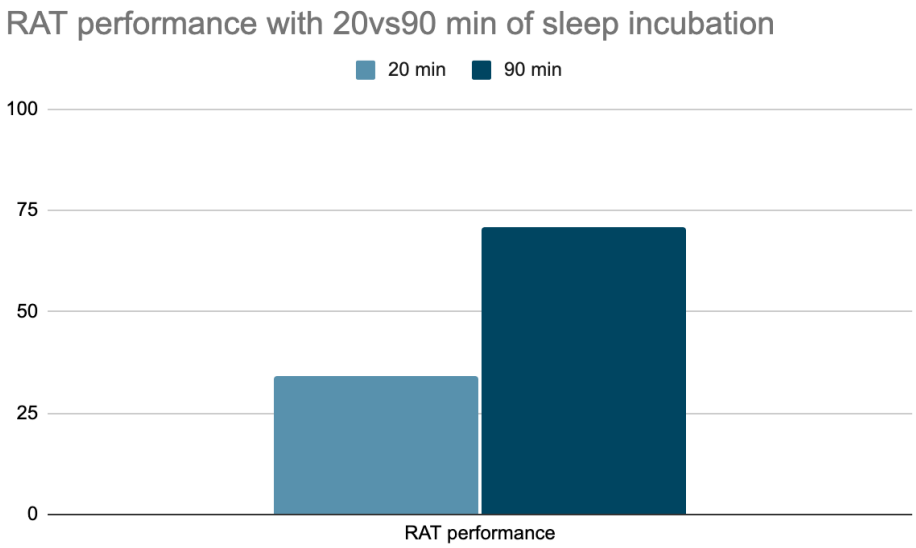
I also expect to see differences in the other groups, not just anagrams, because of this additional REM sleep that the 90 min group will be getting. Brodt et al. (2018) did not mention that REM sleep was a factor in any of the other tasks, but I think it could be in this study, because I'm using the 20 min and 90 min period and not only the 3 hour period that Brodt et al. (2018) used. Brodt et al. (2018) were unable to see this distinction because all the participants in the sleep incubation group in their study slept 3 hours, so everyone was getting REM sleep.

Figure 6:



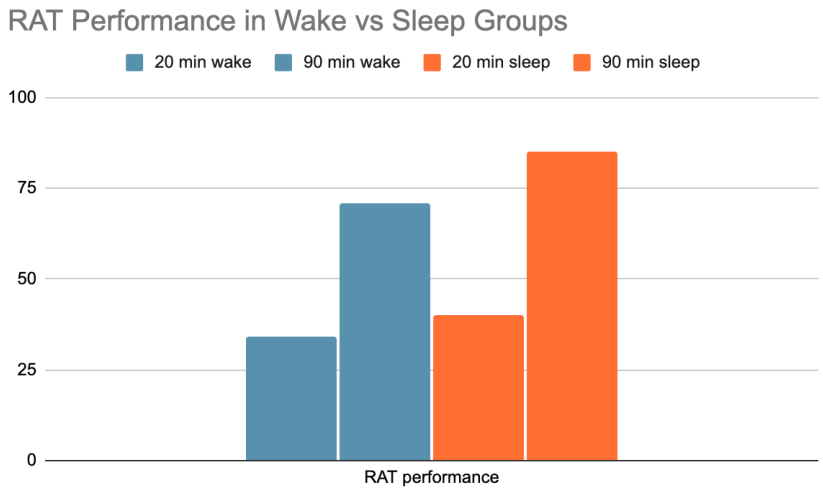
I also expect the 90 min sleep incubation group to perform better on the RAT, because REM sleep has been shown to be associated with better scores on the RAT (Brodt et al., 2018).

Figure 7:



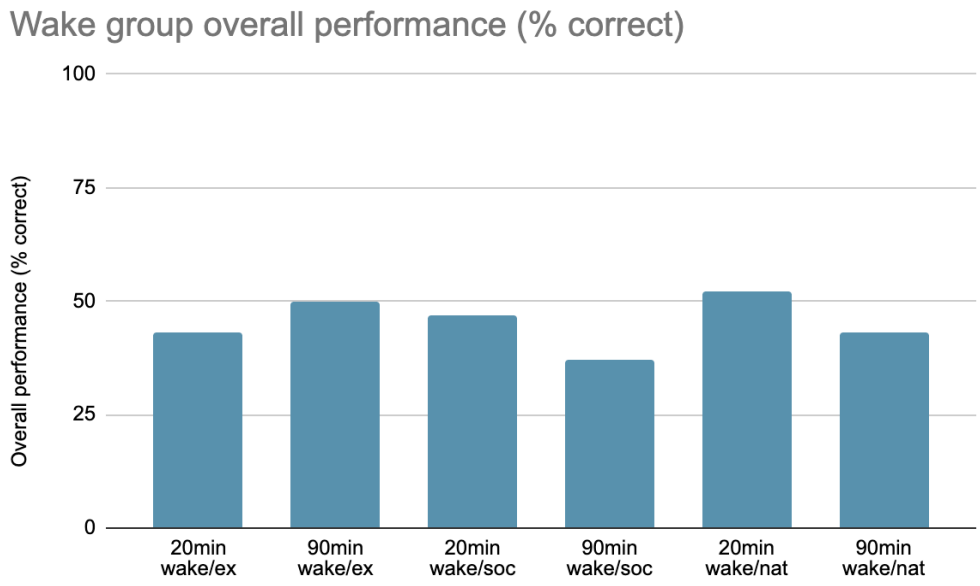
In addition to the 90 min sleep incubation group performing better than the 20 min sleep incubation group on the RAT, I expect both sleep groups to perform better on the RAT overall than the wake groups, as Brodt et al. (2018) states that this association exists.

Figure 8:



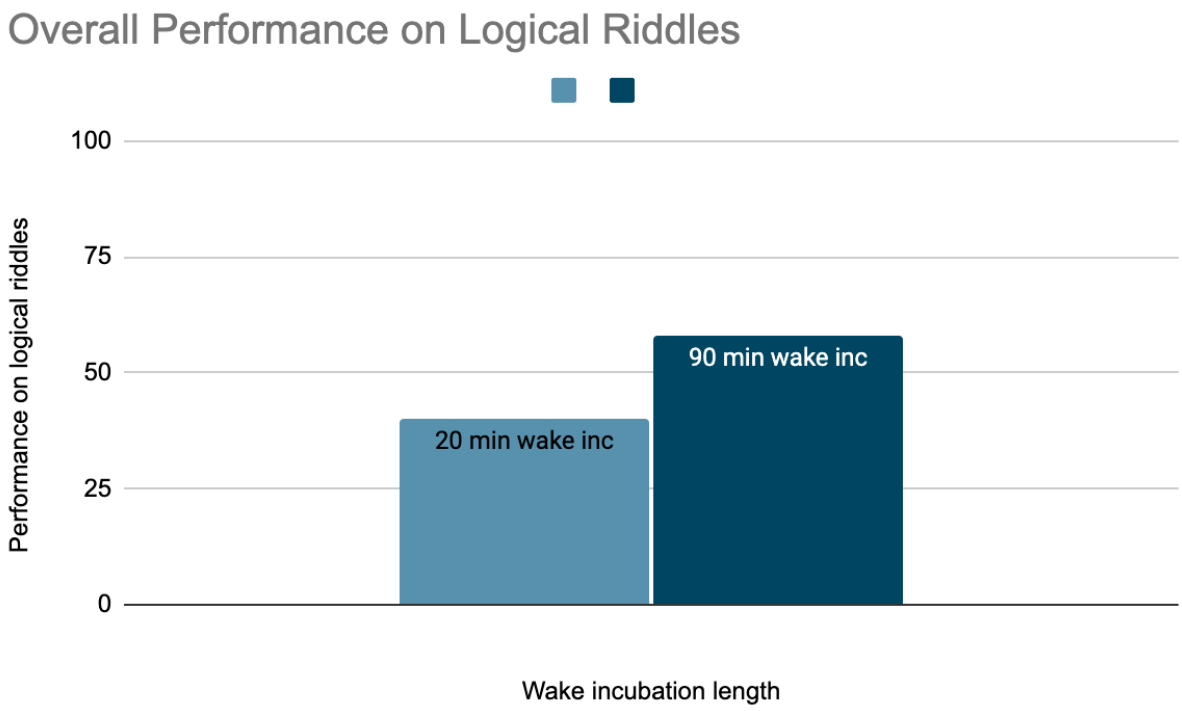
Within the wake groups, I think participants may perform worse in some cases in the 90 min incubation group compared to the 20 min incubation group, simply because they will have more time to face cognitively challenging tasks than those in the 20 min group. In other words, if they distract themselves with cognitively demanding tasks, they can do it for longer in the 90 min group. I think this could specifically be the case in the groups in which "cognitively" challenging situations would be more likely to come up, such as in the socialization or nature groups. I think this is less likely to happen in the exercise group because participants will be engaging with others less, and focusing more on physical tasks than any mental ones.

Figure 9:



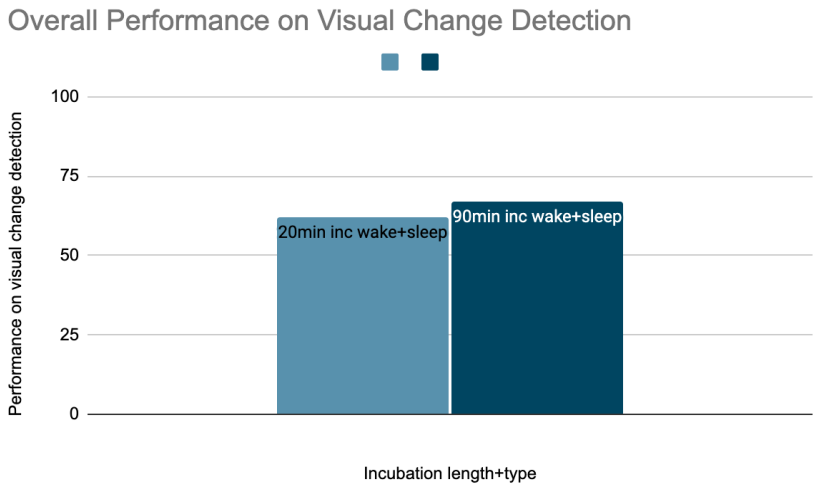
I think the 90 min period will also give participants more of a chance to think about some of the logical riddles. In other words, if they choose to disobey instruction, which is possible, then the 90 min period will give them more of an opportunity because they can settle into whatever activity they're doing enough to shift their attention to the logical riddle.

Figure 10:



Similar to Brodt et al. (2018), I expect to see less difference between wake/sleep on the visual change detection task compared to other tasks. The other tasks, such as riddles, anagrams, and the RAT, allow for thinking between attempts (in other words, allow for participants to run through the problems in their heads. With the visual change task, it's much harder (nearly impossible) to do this, regardless of if you're in the 20 min or 90 min subgroup of the wake/sleep groups.

Figure 11:



Discussion

Incubation is when you are presented with a creative problem, you try to solve it, and then you sit with the problem for a while, and then when you try it again you get closer to an solution or you get the actual solution, due to unconscious work/organization that your brain done during the period in which you took your focus away from the problem.

Brodt et al. (2018) tested this phenomenon, specifically if the incubation effect would be stronger for participants spending incubation periods asleep compared to awake.

They initially introduced participants to three different types of tasks that were each supposed to represent a certain aspect of creative problem solving. These tasks were anagrams, visual change detection, and classical riddles. Participants were given their problem, and were then told to take time away from the problem, either by staying awake for 4.5 hours, or asleep for 3 hours. Participants then came back and had a second attempt at the problem.

They found that a period of incubation improved participants' scores on the classical riddles task, but not on the anagrams task or the visual change detection task. They also found that there was no additional benefit of spending the incubation period asleep compared to spending it awake. They concluded that their results support the notion that letting a problem rest is beneficial, but that the role of sleep should continue to be confined to memory transformations that do not directly impact problem solving ability.

In this study, I am proposing changes to the manipulations in Brodt et al. (2018) et al, as well as additional manipulations of my own. First, I am proposing that participants be additionally tested on the RAT. Brodt et al. (2018) excluded this test because they wanted to use three separate tests that would each test a unique aspect of creative problem solving. In this study, I will use the RAT, as it's been demonstrated to be an effective way to test creative problem solving. Next, the participants in the wake-incubation groups will perform specific activities during their incubation. Brodt et al. (2018) did not monitor the activity of their participants during this period, and stated in their final remarks that this could have had an effect on their results. Furthermore, there is research showing the benefits of exercise, socialization, and time in nature on people’s creative abilities, so including groups that are performing those specific activities will just lead us to more discoveries about how to optimize incubation periods. Next, participants in the sleep-incubation group(s) will be sorted into either a 20 min sleep group or a 90 min sleep group. 20 min and 90 min are the recommended napping periods by the CDC, because they allow people to arise from sleep after a non-heavy sleep period feeling refreshed and ready to function. Additionally, having a 20 min and 90 min group allows for some comparison of the effect of REM sleep vs non-rem sleep. REM sleep does not take place in a 20

min nap, but has a high chance of occurring in a 90 min period, so having these two groups will allow for comparison of how the presence of REM sleep fits into what we know about sleep-incubation. It has been shown in previous research that REM sleep can increase participants' scores on the RAT and anagrams test, and I predict that the same will occur in this study.

Because of the changes I'm proposing, I'm expecting to see different results than Brodt et al. (2018). First, I'm expecting to see a distinction between the 20 min and 90 min groups, for both sleep and wake incubation. I think 20 min of incubation could be beneficial for participants in the wake groups, simply because 20 min of incubation will not allow them the chance to engage in tasks that are too cognitively demanding, tasks that might tire them out mentally, and leave them in a less than ideal state for their second attempt on the experimental task. I think the 90 min incubation period could be beneficial for the sleep-incubation participants, because it will give them a better chance of getting REM sleep, which will improve their chances of doing well on the anagrams task and the RAT. I also think the 90 min incubation period, and the presence of the REM sleep could benefit participants on the other tasks as well, specifically the RAT, since past research has shown that the presence of REM increases scores on the RAT. The 90 min incubation period could also be beneficial for participants that disobey instructions, because if they choose to think about/try to solve any of the tasks during their incubation period, they will have longer to do it than those in the 20 min group.

I think the sleep incubation groups will do better on the RAT overall than the wake groups because it has been shown in past research that scores on the RAT are better when

participants have just woken up from sleep. Similar to Brodt et al. (2018), I don't expect to see any difference in performance on the visual change detection task in the wake groups compared with the sleep groups. I think this task is a lot different than the other tasks, in that it is much harder to think about without having the problem in front of you. I expect to see similar results in the wake and sleep groups for this reason.

Brodt et al. (2018) were not able to account for the presence of non-REM and REM sleep with the groups they used in their study. They were also not able to account for the various activities that people may partake in during their wake-incubation periods. For these reasons, it's not surprising that the most notable data point, or the biggest outlier, they found was that the presence of REM sleep correlated with better performance on the anagrams task. In this study, I've accounted for these differences, and I therefore expect to see much more variation.

The results of this study could provide much more insight into the role of REM sleep in the phenomenon of incubation. Is REM sleep important in incubation? What types of tasks can it help solve? These are questions that this study may help answer. This study could also provide much more insight into the role of types of activities in wake incubation. Is it best to workout, socialize with friends/colleagues, or take a walk in the woods when trying to crack a difficult problem? I think this study could also aid in answering these questions as well.

Whether we are awake and attending to many other problems, or sleeping and not even conscious of our existence, our brains are always working. We face thousands of difficult

problems in our lives, and think of thousands of brilliant creative ideas. Learning to harness the unconscious abilities of our brains could be the key to making the most of our creative capacities, while limiting the burden of difficult problems we may face.

References

Brodt, S., Pöhlchen, D., Täumer, E., Gais, S., & Schönauer, M. (2018). Incubation, not sleep, aids problem-solving. *Sleep*, *41*(10), zsy155.

Sio, U. N., & Ormerod, T. C. (2009). Does incubation enhance problem solving? A meta-analytic review. *Psychological bulletin*, *135*(1), 94.

Hélie, S., & Sun, R. (2010). Incubation, insight, and creative problem solving: a unified theory and a connectionist model. *Psychological review*, *117*(3), 994.

Wallas, G. (1926). *The art of thought* (Vol. 10). Harcourt, Brace.

Baird, B., Smallwood, J., Mrazek, M. D., Kam, J. W., Franklin, M. S., & Schooler, J. W. (2012). Inspired by distraction: Mind wandering facilitates creative incubation. *Psychological science*, *23*(10), 1117-1122.

Dodds, R. A., Ward, T. B., Smith, S. M., & Runco, M. A. (2003). Creativity Research Handbook.

Gilhooly, K. J., Georgiou, G. J., Garrison, J., Reston, J. D., & Sirota, M. (2012). Don't wait to incubate: Immediate versus delayed incubation in divergent thinking. *Memory & Cognition*, *40*, 966-975.

Mednick, S. A. (1968). The remote associates test. *The Journal of Creative Behavior*.

Bowden, E. M., & Jung-Beeman, M. (2003). Normative data for 144 compound remote associate problems. *Behavior research methods, instruments, & computers*, *35*, 634-639.

Diekelmann, S., & Born, J. (2010). The memory function of sleep. *Nature Reviews Neuroscience*, *11*(2), 114-126.

Rasch, B., Büchel, C., Gais, S., & Born, J. (2007). Odor cues during slow-wave sleep prompt declarative memory consolidation. *Science*, *315*(5817), 1426-1429.

Benedict, C., Scheller, J., Rose-John, S., Born, J., & Marshall, L. (2009). Enhancing influence of intranasal interleukin‐6 on slow wave activity and memory consolidation during sleep. *The FASEB Journal*, *23*(10), 3629-3636.

Mograss, M. A., Guillem, F., Brazzini-Poisson, V., & Godbout, R. (2009). The effects of total sleep deprivation on recognition memory processes: a study of event-related potential. *Neurobiology of learning and memory*, *91*(4), 343-352.

Schönauer, M., Pawlizki, A., Köck, C., & Gais, S. (2014). Exploring the effect of sleep and reduced interference on different forms of declarative memory. *Sleep*, *37*(12), 1995-2007.

Schönauer, M., Grätsch, M., & Gais, S. (2015). Evidence for two distinct sleep-related long-term memory consolidation processes. *Cortex*, *63*, 68-78.

Nádasdy, Z., Hirase, H., Czurkó, A., Csicsvari, J., & Buzsáki, G. (1999). Replay and time compression of recurring spike sequences in the hippocampus. *Journal of Neuroscience*, *19*(21), 9497-9507.

O'Neill, J., Senior, T. J., Allen, K., Huxter, J. R., & Csicsvari, J. (2008). Reactivation of experience-dependent cell assembly patterns in the hippocampus. *Nature neuroscience*, *11*(2), 209-215.

Louie, K., & Wilson, M. A. (2001). Temporally structured replay of awake hippocampal ensemble activity during rapid eye movement sleep. *Neuron*, *29*(1), 145-156.

Euston, D. R., Tatsuno, M., & McNaughton, B. L. (2007). Fast-forward playback of recent memory sequences in prefrontal cortex during sleep. *science*, *318*(5853), 1147-1150.

Schönauer, M., Alizadeh, S., Jamalabadi, H., Abraham, A., Pawlizki, A., & Gais, S. (2017). Decoding material-specific memory reprocessing during sleep in humans. *Nature Communications*, *8*(1), 15404.

Ji, D., & Wilson, M. A. (2007). Coordinated memory replay in the visual cortex and hippocampus during sleep. *Nature neuroscience*, *10*(1), 100-107.

Peyrache, A., Khamassi, M., Benchenane, K., Wiener, S. I., & Battaglia, F. P. (2009). Replay of rule-learning related neural patterns in the prefrontal cortex during sleep. *Nature neuroscience*, *12*(7), 919-926.

Maingret, N., Girardeau, G., Todorova, R., Goutierre, M., & Zugaro, M. (2016). Hippocampo-cortical coupling mediates memory consolidation during sleep. *Nature neuroscience*, *19*(7), 959-964.

Frankland, P. W., & Bontempi, B. (2005). The organization of recent and remote memories. *Nature reviews neuroscience*, *6*(2), 119-130.

Gais, S., Albouy, G., Boly, M., Dang-Vu, T. T., Darsaud, A., Desseilles, M., ... & Peigneux, P. (2007). Sleep transforms the cerebral trace of declarative memories. *Proceedings of the National Academy of Sciences*, *104*(47), 18778-18783

Takashima, A., Petersson, K. M., Rutters, F., Tendolkar, I., Jensen, O., Zwarts, M. J., ... & Fernández, G. (2006). Declarative memory consolidation in humans: a prospective functional magnetic resonance imaging study. *Proceedings of the National Academy of Sciences*, *103*(3), 756-761.

McClelland, J. L., McNaughton, B. L., & O'Reilly, R. C. (1995). Why there are complementary learning systems in the hippocampus and neocortex: insights from the successes and failures of connectionist models of learning and memory. *Psychological review*, *102*(3), 419.

Moscovitch, M., Rosenbaum, R. S., Gilboa, A., Addis, D. R., Westmacott, R., Grady, C., ... & Nadel, L. (2005). Functional neuroanatomy of remote episodic, semantic and spatial memory: a unified account based on multiple trace theory. *Journal of anatomy*, *207*(1), 35-66.

Stickgold, R., & Walker, M. P. (2013). Sleep-dependent memory triage: evolving generalization through selective processing. *Nature neuroscience*, *16*(2), 139-145.

Lewis, P. A., & Durrant, S. J. (2011). Overlapping memory replay during sleep builds cognitive schemata. *Trends in cognitive sciences*, *15*(8), 343-351.

Tamminen, J., & Gaskell, M. G. (2013). Novel word integration in the mental lexicon: Evidence from unmasked and masked semantic priming. *Quarterly journal of experimental psychology*, *66*(5), 1001-1025.

Payne, J. D., Schacter, D. L., Propper, R. E., Huang, L. W., Wamsley, E. J., Tucker, M. A., ... & Stickgold, R. (2009). The role of sleep in false memory formation. *Neurobiology of learning and memory*, *92*(3), 327-334.

Ellenbogen, J. M., Hu, P. T., Payne, J. D., Titone, D., & Walker, M. P. (2007). Human relational memory requires time and sleep. *Proceedings of the National Academy of Sciences*, *104*(18), 7723-7728.

Durrant, S. J., Taylor, C., Cairney, S., & Lewis, P. A. (2011). Sleep-dependent consolidation of statistical learning. *Neuropsychologia*, *49*(5), 1322-1331.

Djonlagic, I., Rosenfeld, A., Shohamy, D., Myers, C., Gluck, M., & Stickgold, R. (2009). Sleep enhances category learning. *Learning & memory*, *16*(12), 751-755.

Weisberg, R. W. (2015). Toward an integrated theory of insight in problem solving. *Thinking & Reasoning*, *21*(1), 5-39.

Sio, U. N., Monaghan, P., & Ormerod, T. (2013). Sleep on it, but only if it is difficult: effects of sleep on problem solving. *Memory & cognition*, *41*, 159-166.

Cai, D. J., Mednick, S. A., Harrison, E. M., Kanady, J. C., & Mednick, S. C. (2009). REM, not incubation, improves creativity by priming associative networks. *Proceedings of the National Academy of Sciences*, *106*(25), 10130-10134.

Beijamini, F., Pereira, S. I. R., Cini, F. A., & Louzada, F. M. (2014). After being challenged by a video game problem, sleep increases the chance to solve it. *PloS one*, *9*(1), e84342.

Wu, C. L., Huang, S. Y., Chen, P. Z., & Chen, H. C. (2020). A systematic review of creativity-related studies applying the remote associates test from 2000 to 2019. *Frontiers in psychology*, *11*, 573432.

Centers for Disease Control and Prevention. (2020, March 31). *Module 7. Napping, an important fatigue countermeasure, Nap duration*. Centers for Disease Control and Prevention. Retrieved May 1, 2023, from https://www.cdc.gov/niosh/work-hour-training-for-nurses/longhours/mod7/05.html#print

Rominger, C., Fink, A., Weber, B., Papousek, I., & Schwerdtfeger, A. R. (2020). Everyday bodily movement is associated with creativity independently from active positive affect: A Bayesian mediation analysis approach. *Scientific Reports*, *10*(1), 1-9.

Handzic, M., & Chaimungkalanont, M. (2004). Enhancing organisational creativity through socialisation. *Electronic Journal of Knowledge Management*, *2*(1), pp57-64.

Plambech, T., & Van Den Bosch, C. C. K. (2015). The impact of nature on creativity–A study among Danish creative professionals. *Urban Forestry & Urban Greening*, *14*(2), 255-263.

Jensen, M. S., Yao, R., Street, W. N., & Simons, D. J. (2011). Change blindness and inattentional blindness. *Wiley Interdisciplinary Reviews: Cognitive Science*, *2*(5), 529-546.

Simons, D. J., Franconeri, S. L., & Reimer, R. L. (2000). Change blindness in the absence of a visual disruption. *Perception*, *29*(10), 1143-1154.

Appendix A

Munich ChronoType Questionnaire (MCTQ)

Instructions:
In this questionnaire, you report on your typical sleep behaviour over the past 4 weeks. We ask about work days and work-free days separately. Please respond to the questions according to your perception of a standard week that includes your usual work days and work-free days.

Personal Data

Date: _____

Name: _____

eMail: _____

Age: _____ years

Sex: female ☐ male ☐

Height: _____ cm

Weight: _____ kg

Country: _____

City: _____

Postal Code: _____

Participant ID:

MCTQ, English, Version 2015-01

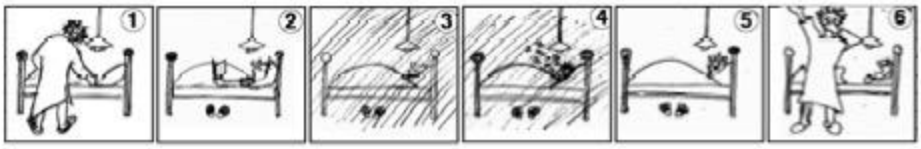
MCTQ

I have a regular work schedule (this includes being, for example, a housewife or househusband):

Yes ☐ I work on 1☐ 2☐ 3☐ 4☐ 5☐ 6☐ 7☐ day(s) per week.

No ☐

Is your answer "*Yes, on 7 days*" or "*No*", please consider if your sleep times may nonetheless differ between regular 'workdays' and 'weekend days' and fill out the MCTQ in this respect.



Please use 24-hour time scale (e.g. 23:00 instead of 11:00 pm)!

Workdays

Image 1: I go to bed at _____ o'clock.

Image 2: Note that some people stay awake for some time when in bed!

Image 3: I actually get ready to fall asleep at _____ o'clock.

Image 4: I need _____ minutes to fall asleep.

Image 5: I wake up at _____ o'clock.

Image 6: After _____ minutes I get up.

I use an alarm clock on workdays: Yes ☐ No ☐

If "Yes": I regularly wake up BEFORE the alarm rings: Yes ☐ No ☐

Free Days

Image 1: I go to bed at _____ o'clock.

Image 2: Note that some people stay awake for some time when in bed!

Image 3: I actually get ready to fall asleep at _____ o'clock.

Image 4: I need _____ minutes to fall asleep.

Image 5: I wake up at _____ o'clock.

Image 6: After _____ minutes I get up.

My wake-up time (Image 5) is due to the use of an alarm clock: Yes ☐ No ☐

There are particular reasons why I cannot freely choose my sleep times on free days:

Yes ☐ If "Yes": Child(ren)/pet(s) ☐ Hobbies ☐ Others ☐, for example:_____

No ☐

Participant ID:

MCTQ, English, Version 2015-01

Work Details

In the last 3 months, I worked as a shift worker.

No ☐ Yes ☐ (please continue with "*My work schedules are ...*").

My usual work schedule …

… starts at _____ o´clock.

… ends at _____ o´clock.

My work schedules are …

… very flexible ☐ … a little flexible ☐ … rather inflexible ☐ … very inflexible ☐

I travel to work …

… within an enclosed vehicle (e.g. car, bus, underground). ☐

… not within an enclosed vehicle (e.g. on foot, by bike). ☐

I work at home. ☐

For the commute to work, I need ___ hours and ___ minutes.

For the commute from work, I need ___ hours and ___ minutes.

Time Spent Outdoors

On average, I spend the following amount of time outdoors in daylight (without a roof above my head):

on workdays: _____ hours _____ minutes

on free days: _____ hours _____ minutes

Stimulants

Please give approximate/average amounts!

		per → day	week	month
I smoke	_____ cigarettes ...	☐	☐	☐
I drink	_____ glasses of beer ...	☐	☐	☐
I drink	_____ glasses of wine ...	☐	☐	☐
I drink	_____ glasses of liquor/whiskey/gin etc. ...	☐	☐	☐
I drink	_____ cups of coffee …	☐	☐	☐
I drink	_____ cups of black tea ...	☐	☐	☐
I drink	_____ cans of caffeinated drinks (soft-drinks) …	☐	☐	☐
I take sleep medication _____ times ...		☐	☐	☐

Appendix B

IRB Proposal

What is the title of your project?

-*Further Investigation Into the Power of Wake and Sleep Incubation in Creative Problem Solving*

When do you plan to begin this project?

-Summer 2023

Describe your research questions(s)

-How do wake activity and REM sleep impact creative performance?

Describe the population(s) you plan to recruit and how you plan to recruit participants

-I plan on recruiting participants with an average age of 24. I plan on using the same selection criteria as Brodt et al. I plan to recruit participants through flyers and online advertisements in my area.

Will your participants include individuals from vulnerable or protected populations (e.g., children, pregnant women, prisoners, or the cognitively impaired)?If your participants will include individuals from the above populations, please specify the population(s) and describe any special precautions you will use to recruit and Consent.

-I will recruit some participants with attention difficulties and learning disabilities. I will warn participants of the challenges they may encounter if they choose to participate in this experiment

Approximately how many individuals do you expect to participate in your study?

-456, but I plan to initially recruit about 500 participants in order to account for participant dropout and/or exclusion

Describe the procedures you will be using to conduct your research. Include descriptions of what tasks your participants will be asked to do, and about how much time will be expected of each individual.

-Participants will be required to complete both the initial and second attempts of whatever task is assigned to them, and they will be asked to complete whatever incubation type/period is assigned to them to perform between these two attempts. They should expect their participation to take up to an entire day

Describe any risks and/or benefits your research may have for your participants

-Risks include temporary cognitive stress and/or fatigue. Benefits include enhancement of knowledge on wake/sleep incubation and practicing of various creative problem solving tasks

Describe how you plan to mitigate (if possible) any risks the participants may encounter.

-The amount of risk participants will experience is largely controlled by them. The most likely form of risk would most likely occur during wake incubation periods in which participants have

the choice of where and how they can spend the period. They will be assigned a specific form of incubation, but they have a choice of how they'd like to interpret that assignment

Describe the consent process (i.e., how you will explain the consent form and the consent process to your participants):

-Participants will be required to sign a consent form prior to participation. They will be given it upon arrival at the study location. It will list the general procedures of the study and what participation will entail. It will also inform participants that any questions or concerns they may have should/are encouraged to be made known to those running the study.

If you are collecting data via media capture (video, audio, photos), have you included a section requesting consent for this procedure(s) in your consent form(s)?

-Participants' answers on some of the tasks will require voice recording. Participants will be made aware of this, and will need to consent before recording can take place

If your project will require you to employ a verbal consent process (no written consent forms), please describe why this process is necessary and how verbal consent will be obtained and Stored

-This study will only require written consent

What procedures will you use to ensure that the information your participants provide will remain confidential and safeguarded against improper access or dissemination?

-Consent forms will be scanned and saved as PDFs on a password protected computer, and all physical (written) copies of consent forms will be destroyed

Will it be necessary to use deception with your participants at any time during this research? Withholding details about the specifics of one's hypothesis does not constitute deception, this is called incomplete disclosure. Deception involves purposefully misleading participants about the nature of the research question or about the nature of the task they will be completing.
If your project study includes deception, please describe here the process you will use, why the deception is necessary, and a full description of your debriefing procedures.

-No deception will be used in this study

For all projects, please include your debriefing statement. (This is information you provide to the participant at the end of your study to explain your research question more fully than you may have been able to do at the beginning of the study.) All studies must include a debriefing statement. Be sure to give participants the opportunity to ask any additional questions they may have about the study.

-"The study you've taken part in today is investigating the effect of wake and sleep incubation on creative problem solving. Specifically, we've looked to manipulate the type of wake activity and the presence (and non-presence) of REM sleep in sleep incubation in order to investigate if they may have an effect on participants ability to solve creative thinking problems. We thank you, as the time and effort you've given today has contributed to data which we will use to further

understand the workings of the unconscious mind. If you have any questions or concerns, feel free to contact us by email at hm3040@bard.edu. Thank you for your participation!”