REM-rebound after sleep deprivation in teenagers

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Problem: Before the 1950s, many people thought sleep was a passive activity in which the body and brain were at rest. "But it turns out that sleep is a period during which the brain is engaged in a number of activities necessary to life—which are closely linked to *quality* of life," says Johns Hopkins sleep expert and neurologist Mark Wu, M.D., Ph.D. (John Hopkins Medicine, 2019). Researchers like Wu are spending years trying to learn more about the concept of sleep and how it affects mental and physical health. Research has found that 73 percent of high school students do not get a healthy amount of sleep causing their GPA to drop by 0.5 (Campbell, 2019). This is because without adequate sleep, cognitive performance will decline due to the lack of time spent in the sleep stages. Sleep is made up of 4 sleep stages, 3 of which are Non-Rapid Eye Movement (NREM) and 1 which is Rapid Eye Movement (REM). While NREM is important for rest and energy replenishment, REM is a crucial part of the sleep cycle as it is associated with brain development, memory consolidation and learning.

Researchers hypothesize REM sleep promotes brain development as the most REM sleep occurs as infants and children, when our brains are still developing. Newborn babies spend eight hours in REM sleep each day which mean 70% of their total sleep is primarily in REM sleep, which decreases in duration with age (Bezerra, 2020). Based on the fact that a significant portion of development occurs during infancy, it seems clear that REM and brain development go hand in hand. Adding to the evidence is that animals born with less developed brains, such as humans and puppies, spend even more time in REM sleep during infancy than those that are born with more developed brains, like horses and birds (Summer, 2021). Furthermore, a study monitored the impacts of sleep on the working memory of healthy college students. Each day, the students were given two tests, with one group taking a nap between the tests and the other group staying awake. The group that napped and had spent more time in the REM sleep stage during their nap had a higher accuracy (Summer, 2021). This is because the brain actively replenishes neurotransmitters during REM sleep, which arrange neural networks crucial for memory, learning, performance, and problem solving—much like how files arrange documents. This brain processes consolidates new information and transfers it from short-term to long-term.

During this sleep stage an area at the base of the brain called the pons sends signals that shut off neurons in the spinal cord that will temporarily paralyze the muscles and limbs, with two exceptions: the eyes and the muscles that control breathing. This is called REM atonia, a safety mechanism to prevent the body from physically acting out the dreams (Ungless, 2023). Even though dreaming can occur in other sleep stages, they are more intense and vivid during REM contributing to emotional processing due to the intensity. This is because the amygdala, the part of the brain that processes emotions, activates during REM sleep. When the body enters REM sleep, the brain does not have the anxiety-triggering molecule noradrenaline, allowing the limbic system to re-process upsetting memories in a safer and calmer environment (walker, 2017). As our brain processes different experiences, emotions and memories, we are able to create more unique connections and associations, which are essential for creativity. A 2013 study by Sara Mednick and her colleague, published in the journal "Psychological Science", found that REM sleep and dreaming can enhance creativity. Participants who experienced REM sleep were better at solving creative problems compared to those who did not. This suggests that the dream state during REM sleep may encourage creative thinking and problem solving (Mednick, 2003).

REM is linked to a variety of cognitive functions including the consolidation process which is thought to be particularly important for students who are studying for exams or working on complex projects important for teenagers. However, REM sleep is especially important as adolescence is a crucial period marked by significant growth and development within the teenage brain. During this time, the brain undergoes a pruning process where unused connections in the grey matter are removed while strengthening other connections. This process enhances the brains efficiency helps streamline the brain's neural network, making it more efficient by getting rid of unnecessary connections and reinforcing those that are important for cognitive function and learning. Notably, the pruning process starts at the back of the brain and progresses to the prefrontal cortex, responsible for decision-making and impulse control, which continues developing into early adulthood. As the prefrontal cortex is still maturing during adolescence, teenagers may rely more on the amygdala, associated with emotions and instinctive behaviours, to make decisions and solve problems. This reliance on the amygdala underscores the significance of REM sleep, particularly for teenagers undergoing puberty. REM sleep is crucial for processing new experiences and emotions associated with puberty, aiding in their ability to navigate and comprehend these changes effectively. Therefore, this report will investigate the hypothesis "if the total hours of sleep increase, REM sleep will also proportionally increase".

Hypothesis: If the total hours of sleep increases, REM in minutes will also increase.

Explanation of hypothesis:

Sleep is made up of four stages. Three Non-Rapid Eye Movement (NREM) and one Rapid Eye Movement (REM). Researchers believe that a balance between each stage NREM and REM are essential for healthy sleep. REM sleep is defined by the presence of desynchronized (low-voltage, mixed-frequency) brain wave activity, muscle atonia, and bursts of rapid eye movements. "Sawtooth" wave forms, theta activity (3 to 7 counts per second), and slow alpha activity also characterize REM sleep (Summer, 2021). REM sleep occurs the first 90 min after falling asleep, when you've entered this stage the eyes move rapidly, heart rate increases, and breathing is irregular. During the initial cycle, the REM period may last only 1 to 5 minutes; however, it becomes progressively prolonged as the sleep episode progresses (Colten and Altevogt, 2022). REM sleep occurs at the end of each sleep cycle. The first sleep cycle of the night usually has a shorter REM phase. This is due to the interaction between the homeotic sleep drive and the circadian rhythm, which influences sleep architecture. As you sleep longer, especially during extended periods of uninterrupted sleep (e.g. full night's sleep), your sleep cycles naturally progress through more cycles. Each sleep cycle typically starts with NREM (N1, N2, N3) and then transitions to REM sleep before repeating. When you extend your sleep duration, you allow your body to progress through more sleep cycles, increasing the likelihood of experiencing more REM sleep. Therefore, the lack of total hours sleep hinders the body from entering serval sleep cycles per night. This investigation will discover the relationship between REM and number of hours of sleep.

Independent variable:

The independent variable is the total hours of sleep. I will measure my regular sleep patterns for a week and then I will be manipulating this variable by deliberately sleeping less than my regular sleep patterns. I will do this by reducing my sleeping hours by 3-4 hours as the difference needs to be significant if I want to see a noticeable change. I will do this by putting an alarm 5 hours after I lie down to sleep. 5 hours is appropriate as the time the body takes to fall asleep is about 10-30 min, giving me around 4.30 hrs of sleep. I will do this for 4 days, due to small time frame I have available and this will give me sufficient data to analysis. By manipulating the amount of sleep, I get, I hope to observe a change in the duration of REM sleep. To collect more data, I will have 5 participants that will also measure their regular sleep patterns. This will give me enough data to analysis as I have 5 different data sets showing the relationship between the total hours of sleep and REM sleep.

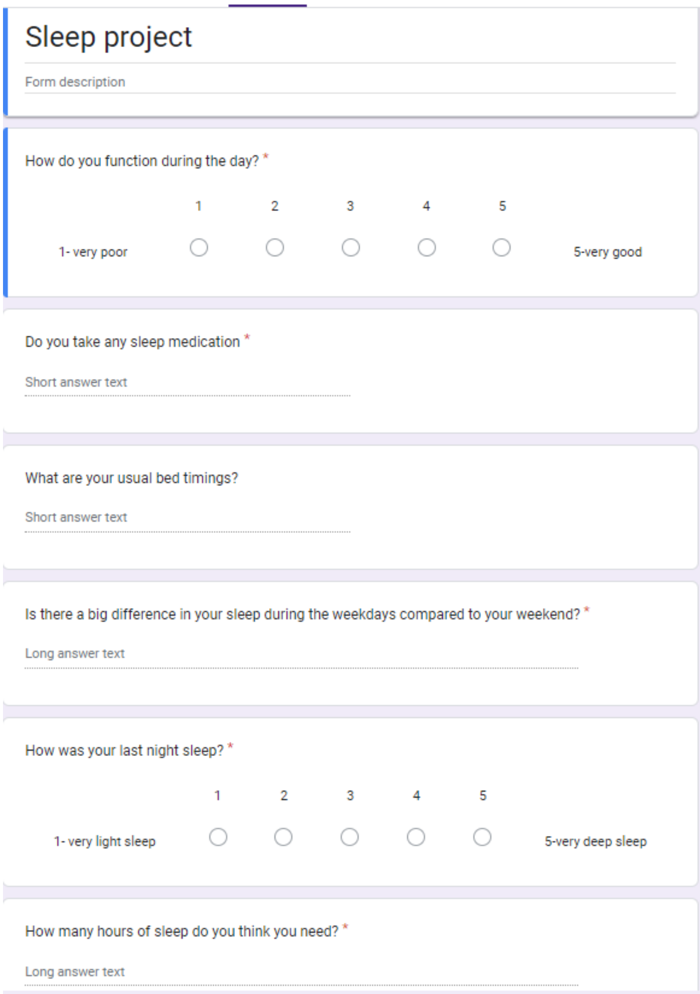
Dependent variable: The dependent variable is the duration of REM sleep. The minutes of REM will be measured through a Fitbit (a sleeping tracker). I will have access to Hypnograms, which are sleeping graphs that will be connected to the Fitbit app. The app has features showing the amount of REM in min, percentage of REM, the time spent in each sleep stage and how long you have been awake during your sleep hours. I will measure the amount of REM during my regular sleep hours and then measure the amount of REM after 3-4 hours reduction. The hours will have to be converted into decimals. By comparing the data before and after altering my sleep patterns, I will be able to determine if there is a proportional decrease in REM sleep when I get less sleep.

Control variables:

Age: All participants are healthy teenagers 15 to 16-year-olds. This must be controlled as sleep pattern naturally change as individuals age. For example, older adults tend to experience more fragmented sleep, have a reduced total sleep duration and spend less time in deep sleep stage like REM. In addition, younger individuals typically have a more robust circadian rhythm, while older individuals may experience changes in their internal clock. Furthermore, hormonal changes are associated with age such as changes in melatonin production which can influence sleep. Melatonin is a hormone that plays a key role in regulating sleep-wake cycles. Changes in melatonin levels can affect the duration and quality of REM sleep. Adults may also experience reduced sleep efficiency, meaning they spend more time awake during the night, resulting in shorter REM sleep duration. This means that if the participants are varying ages, these natural age-related differences can introduce variability to the data.

Health: All participants must make sure that no medication is taken as these can affect regular sleep patterns. For instance, individuals with sleeping disorders like sleep apnoea, insomnia or restless leg syndrome may experience disrupted sleep, altered sleep architecture and changes in the duration and distribution of REM sleep. In addition, if participants take medications such as antidepressant can contributed to the suppression of REM sleep, while others may increase its duration. If participants are taking medication with sleep altering properties, it can influence REM sleep patterns, which can affect the results.

These variables will be controlled by through a google form which participants must answer before participating.



Sleep project

Form description

How do you function during the day? *

1- very poor 1 2 3 4 5 5-very good

Do you take any sleep medication *

Short answer text

What are your usual bed timings?

Short answer text

Is there a big difference in your sleep during the weekdays compared to your weekend? *

Long answer text

How was your last night sleep? *

1- very light sleep 1 2 3 4 5 5-very deep sleep

How many hours of sleep do you think you need? *

Long answer text

Location:

Different locations can have varying environmental conditions that can affect sleep quality. Factors such as altitude, humidity, air quality and even the proximity to sources of noise can differ significantly from one place to another. By controlling the location, you can ensure that environmental conditions remain consistent, making it easier to analyse data. For example, noise level in a noisy urban area is much louder compared to quiet rural area. These changes in noise level can affect the quality and length of sleep. It will also be hard to determine whether the scatter in data was due to location-specific factors. This will be controlled by contacting each participant when arrived from vacation and giving a week's time, so jetlag won't affect their regular sleep patterns. This way the participants is sleeping in an area where the environmental condition is consistent, giving more reliability to the data.

Method:

I. All participants will be sent a form to fill to get consent and see if any of participants use sleep medication.
II. They will then sleep regularly with the Fitbit device for as many days as the participant's desire
III. I will then collect their data and start on my own experiment
IV. I will have to have tracking device- Fitbit
V. The Fitbit must be linked to a device.
VI. I will sleep with my Fitbit on for a week.
VII. I will then collect the hypnograms of my regular sleeping hours.
VIII. I will then reduce my sleeping hours by 3-4 hours by putting an alarm 5 hours after I fall asleep.
IX. I will then continue this for 4 days.

Materials:

- Sleeping tracker – a Fitbit

Safety: I must make sure that I am able to stop the experiment if my condition becomes critical, serious health issues must be avoided.

Results:

Raw quantitative data

Figure 1 represents my regular sleep data shown on the Fitbit app:

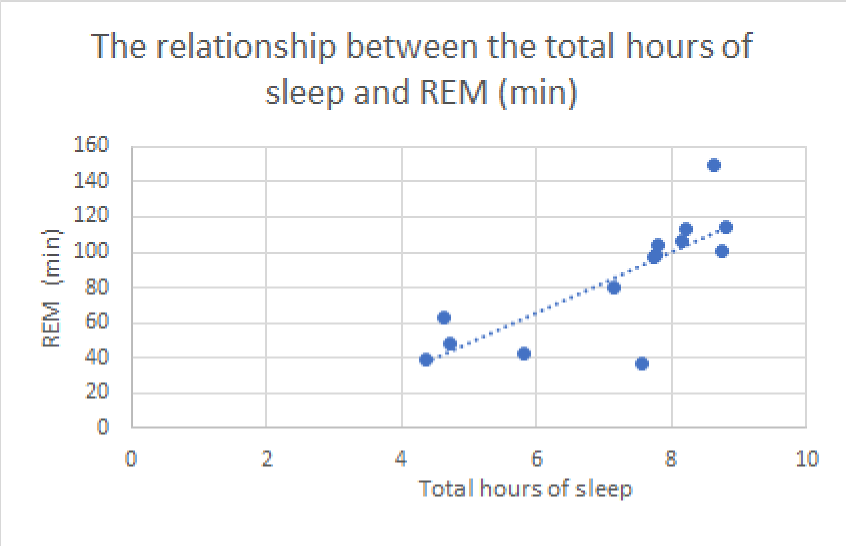
Total Sleep (hours)	REM (minutes)
7.73	97
8.17	106
8.22	113
8.8	114
7.8	104
8.63	149
7.78	98
8.75	101
7.15	80
7.57	37

Figure 2 represents my sleep data after reducing hours shown on the Fitbit app:

Total Sleep (hours)	REM (minutes)
4.73	48
4.35	39
4.63	63
5.81	43

Figure 3:

Graph from figures 1 and 2

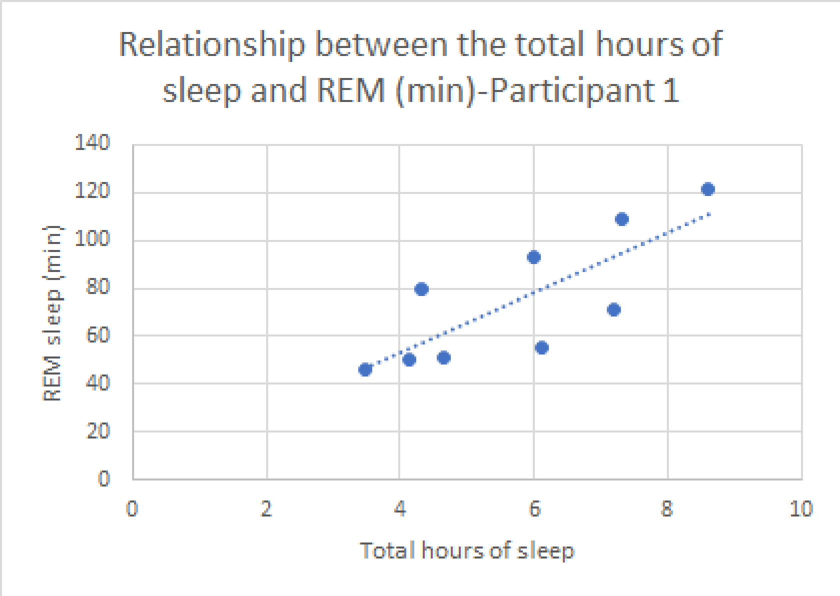


Participant 1 regular sleep data

Figure 4:

Total hours of sleep	REM sleep (minutes)
4,15	50
8,6	121
6,1	55
3,47	46
7,18	71
4,32	80
7,3	109
6	93

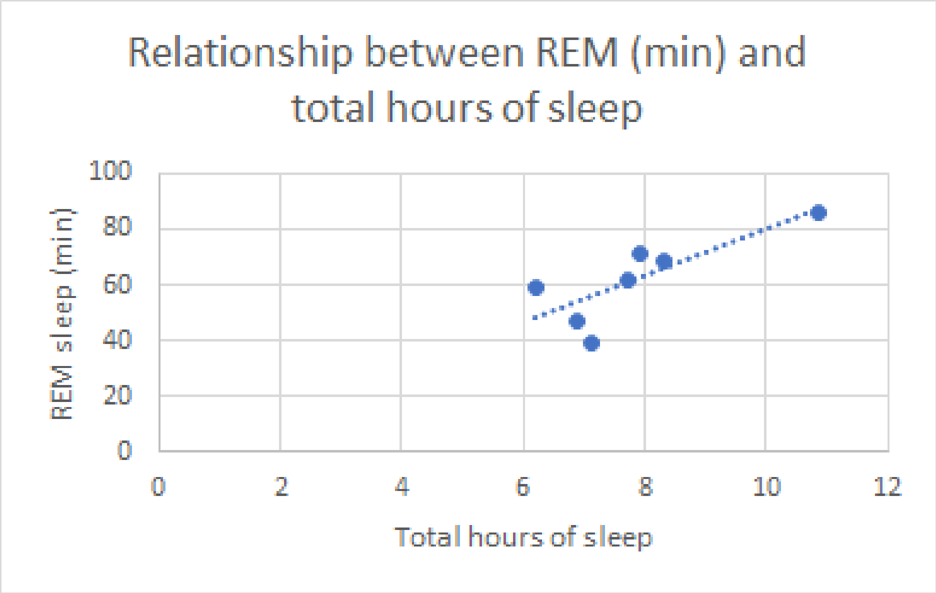
Participant 1: Figure 5:



Participant 2: Figure 6:

Total (hours)	REM (minutes)
7,12	39
7,93	71
6,87	47
8,32	69
6,2	59
7,73	62
10,85	86

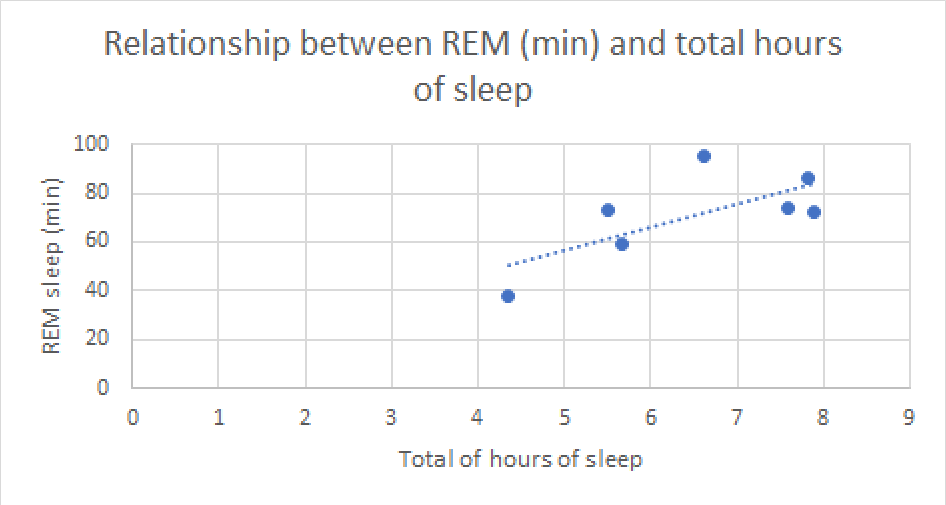
Participant 2: Figure 7:



Participant 3: Figure 8:

Total (hours)	REM (minutes)
5,68	59
7,6	74
7,9	72
4,35	38
5,5	73
6,62	95
7,83	86

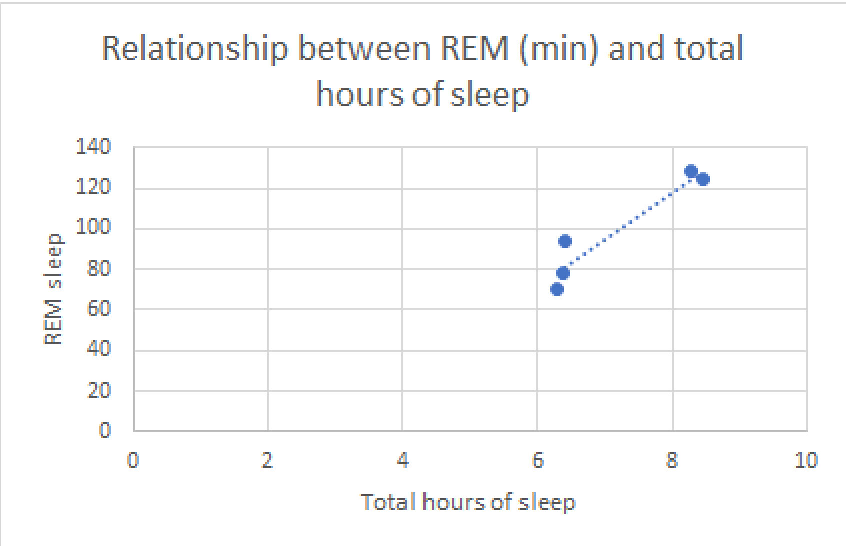
Participant 3: Figure 9:



Participant 4: Figure 10:

Total hours	REM (minutes)
8,45	124
6,3	70
6,42	94
6,38	78
8,27	128

Participant 4: Figure 11:



Results:

Figure 1 shows the raw quantitative data of my sleep data from the Fitbit app where it measures my regular sleep patterns, including the regular total hours and REM in minutes. Figure 2 shows the raw quantitative data of my sleeping data after reducing it by 3-4 hours. Figure 3 represents the data from table 1 and 2 in a graph. Figure 4 shows the raw data of participant 1's sleep from the Fitbit app that measures their regular sleep patterns. Figure 5 represents the data from table 4 in a graph. Figure 6 shows the raw data of participants 2's sleep from the Fitbit app that measures their regular sleep patterns. Figure 7 represents the data from table 6 in a graph. Figure 8 shows the raw data of participants 3's sleep from the Fitbit app that measures their regular sleep patterns. Figure 9 represents the data from table 8 in a graph. Figure 10 shows the raw data of participants 4's sleep from the Fitbit app that measures their regular sleep patterns. Figure 11 is representing the data from table 10 in a graph.

Discussion of results:

All figures above show a positive correlation between the duration of sleep and REM sleep in minutes. The quantitative data shown in the graphs in figures 3, 5, 7, 9 and 11 all show that the body proportionally increases REM sleep as the duration of total sleep is increased. However, the data represented in figure 1,2, 4,6,8 and 10 has natural scatter as even with more hours of sleep, the amount of REM isn't always more than when the participants received less total hours of sleep. For example, in participant 1, when they receive 6 hours of sleep, they get 55 min of REM whilst when they slept less, they got 80 min of REM. This finding aligns with established knowledge in sleep science, where it is widely recognized that REM sleep occurs in the later stages of a sleep cycle, which are more likely to be reached during longer periods of sleep. In conclusion the data and figures presented consistently demonstrate a positive correlation between the total hours of sleep and the amount of REM sleep experienced by the participants. These finding highlights that when the body receives more sleep, it's able to get more REM sleep, leading into better sleep quality and cognitive health.

Validity of hypothesis and method:

The data supports the hypothesis. As mentioned, the data presented in figure 1,2, 4,6,8 and 10 has scatter. For example, Figure 1 and Figure 5 are more scattered than Figure 11. The scattered points do make the data less precise but still supports the hypothesis: as the hours of sleep increase the amount of REM also increases. In addition, participant 3 was on vacation during the study, so the sleep data that was measured was not their regular sleeping patterns due to jetlag, which shows the how control variable "location" was not controlled. This was because of the limited time participant 3 had before the semester started and therefore had to send the data available. In addition, the participants measured their own sleep schedules, and I was not there to make sure the variables were controlled, therefore some factors such a Fitbit usage might have not been consistent. Even though these variables lacked control which would affect some of the points in figure 1,2,4,6,8 and 10, these data points can be used to represent a clear trend. Overall, the data is valid enough to support the hypothesis.

Improvements: The data can be improved with better control of the variables as this will give more reliable and valid data. Next time one can make sure the participants are home by contacting them earlier. In addition, if a sleep log were used it could provide more data to help support the hypothesis and provide qualitative date.

Extensions: Once I'd completed this experiment, I wanted to extend it by examining an effect known as REM rebound.

EXEPERIMENT 2:

Hypothesis: After a few nights of sleep deprivation, I will experience an increase in REM sleep duration and intensity during the recovery nights compared to my regular sleep patterns. This is called REM rebound.

This report will be investigating the hypothesis: if sleep is intentionally limited for a few nights, then there will be an increase in REM sleep duration and intensity during the recovery nights compared to regular sleep patterns. According to the literature (Ellis, 2021), when the body doesn't get enough REM sleep, the phenomenon of REM rebound occurs. REM rebound is the body's natural and normal response to sleep deprivation, stressors, and suppression of REM sleep. REM rebound effect is when a person temporarily receives more REM sleep than they normally would after a period of sleep deprivation. REM rebound is one the mechanisms used to restore sleep homeostasis by increasing the length and intensity of REM sleep the following nights after sleep deprivation. Since REM sleep can help us process negative experiences and manage our emotions during stressful times, when people are deprived from REM sleep it can lead to changes in hormones and neurotransmitters in the body, which affects the quality and length of sleep and may lead to insomnia. Just as experts still do not fully understand how sleep works, they also do not fully understand the causes of REM rebound sleep. However, by studying both humans and animals, ranging from rats to fur seals, researchers have identified multiple potential causes and factors related to REM rebound sleep. Several hormones play a role in the effect. This is explained by Summer (2021).

When the body goes through periods of sleep deprivation, the body produces Corticotropin releasing hormone (CRH) which is released by the hypothalamus in response to stress or sleep deprivation. When high level of CRH is produced it reduces REM sleep. The CRH levels tend to decrease during REM rebound, allowing the compensation of REM sleep as the lower the CRH levels are, the more relaxed state is conducive to deeper sleep including REM sleep. The Adrenocorticotropic hormone (ACTH) hormone is released by the pituitary gland in response to CRH, and it stimulates the adrenal glands to produce cortisol, a stress hormone. High level of cortisol can disrupt normal sleep cycles and can reduce REM sleep. After the sleep deprivation and the body has entered the recovery phase, ACTH level tend to decrease. This is because the body returns to a more balanced state, the need of elevated cortisol levels subsides. Lower ACTH levels contribute to reduce cortisol production, allowing for a more restful sleep, allowing REM sleep to intensify. Plasma corticosterone is a stress-related steroid hormone. When high level of plasma corticosterone is released, it can disrupt REM Sleep. It then follows a similar pattern by naturally decreasing, allowing the restoration of REM sleep. These decreases collectively signify a shift toward a more relaxed physiological state, which is conductive to a deeper and more restful sleep, including an increase in REM sleep.

Conversely, several hormones that affect the nerves and sleep regulation tend to increase during REM rebound. Prolactin, known for its role in lactation, rises during the recovery phase and is linked to longer REM sleep episodes. Corticotropin-like intermediate peptide, though not fully understood as other hormones, may contribute to the enhancement of REM sleep during recovery, promoting its duration and intensity. Serotonin, a neurotransmitter linked to mood regulation, may also contribute to the increase of REM sleep during the rebound phase. These hormonal increases work together to aid the body in restoring balanced sleep patterns and ensuring a restful sleep after periods of sleep disruption. More research is required to better understand how these hormones work together to increase REM sleep during a REM rebound effect. (Feriante and Singh, 2023)

After early research connected Rapid Eye Movement with dreaming and established that it made up about 20% of normal human sleep, experimenters started depriving test subjects of only REM sleep, to test its unique importance. Every time a subject's electroencephalogram and eye movements indicated the beginning of REM sleep, the experimenter would thoroughly wake them for several minutes. As this "dream deprivation" continued, tendency to initiate REM increased, and the subjects were woken up more and more times each night. The subjects became irritable, anxious, and hungry, and several left the study early. After five nights, the remaining subjects were allowed to sleep undisturbed, and showed a significant increase in percentage of sleep devoted to REM: from an average of 19.4% to an average of 26.6%. These effects were significant in comparison with a control group woken up on an equal number of occasions each night, at arbitrary times. (Wikipedia, 2022) The fact that REM rebound exists shows that sleep and achievement of specific sleep stages are needed by the brain. Therefore, this report will investigate the hypothesis: "If REM sleep is intentionally limited for a few nights, then there will be an increase in REM sleep duration and intensity during the recovery nights compared to regular sleep patterns" to give greater understanding of the importance and the brain's ability to protect our bodies.

Independent variable

The independent variable is the duration of sleep. There will be three phases: a control week of regular sleep to assess the background state, then the sleep-deprived week followed by the recovery week. During the sleep-deprived week, I will aim to get 4-5 hours of sleep per night for six consecutive days. I will set an alarm 4 hours after I get into bed, this will disrupt the REM sleep cycles. During the recovery phase I will aim to get 8-9 hours per night. By manipulating the sleep schedule, it will create a wide range of sleep duration for analysis.

Dependent variable

The dependent variable is the length of REM sleep measured in minutes. This variable is important as it represents the primary focus of the study whether increasing duration of sleep after sleep deprivation leads to an increase in REM sleep compared to regular sleep patterns. It will be measured using a Fitbit tracker that records sleep patterns. The Fitbit app shows the amount of REM (minutes), percentage of REM, the time spent in each sleep stage and how long you have been awake during your sleep hours. I will measure the duration of REM in my regular sleep patterns. Then I will measure the duration of REM sleep during sleep deprivation. After that I measure the duration of REM sleep during the recovery phase with extended sleep.

Control variable:

Sleep environment:

Environmental factors such as room temperature, lighting and noise can affect sleep quality. Inconsistent sleep environments can introduce variability into the results. Variations in noise levels in sleeping environments can disrupt sleep patterns and reduce sleep quality. High noises can lead to awakenings or interruptions in the sleep cycle, impacting the measured sleep variables such as sleep stages and duration. In addition, changes in light exposure during sleep can interfere with circadian rhythms and the production of melatonin, a hormone that regulates sleep. Variations in temperature can alter sleep stage and cause an uncomfortable environment to sleep in, which can result in frequent shift of positions. By keeping the same sleeping environment, it can give more consistent results and sleep patterns will not very much. Maintaining a controlled sleep environment helps ensure that the observed changes in sleep variables are more likely to be attributed to the independent variable and not to other factors related to sleep environment. This will be controlled by making sure the sleep environment is consistent with its conditions. The temperature will be maintained, and blackout curtain will be used. To avoid certain light distraction an eye mask will also be used. In addition, the room will be set to the same temperature throughout the experiments.

Fitbit usage:

Inaccurate or inconsistent use of Fitbit trackers can lead to unreliable data, which can confound the results. The accuracy and reliability of these devices can vary, and they may not always provide highly precise sleep data. However, by controlling the usage of Fitbit device, I can ensure that the data is consistent, reducing the potential for measurement error. Fitbit devices rely on sensors to track sleep metrics. When used inconsistently, the quality of data collected can vary widely. For example, wearing the device loosely or incorrectly can lead to inaccuracies in sleep stage detection or sleep duration measurements. This will be controlled by making sure the Fitbit is correctly adjusted and is well charged before each experiment. This can ensure the Fitbit is not taken off during the experiment in order to charge.

Sleep schedule:

Variation in the sleep schedule can impact the sleep patterns. If there are inconsistent sleep schedules during the study, the observed differenced in sleep quality or duration may be due to their varying sleep schedule rather than the experimental conditions. Inconsistent sleep schedule can introduce unwanted variability. This will be controlled by making sure an alarm is set every day, expect the recovery phase.

Method

i. Measure regular sleep pattern for a week and collect the REM duration.
ii. Set a strict sleep schedule that will only allow 4 hours per night for 6 consecutive days.
iii. During this period, record the REM sleep duration using Fitbit tracker.
iv. Then increase the duration of sleep by prioritize sleep as much as possible (8 hours+)
v. Continue recording the REM sleep duration using the Fitbit tracker
vi. Calculate the average daily REM sleep duration during the sleep deprivation week and the recovery week.
vii. Compare the REM sleep duration between the two weeks.

Materials:

Fitness watch

Safety:

I must make sure that I am able to stop the experiment if my condition gets critical, this way serious health issues are avoided.

Results:

Figure 1: representing the regular sleep data

Regular sleep		
Total hours	REM (minutes)	Percentage
7.38	80	18,07
6.09	78	21,35
6.83	85	20,74
7.04	75	17,76

7.98	79	16,5
7.03	55	13,03

Figure 2: a graph of Figure1

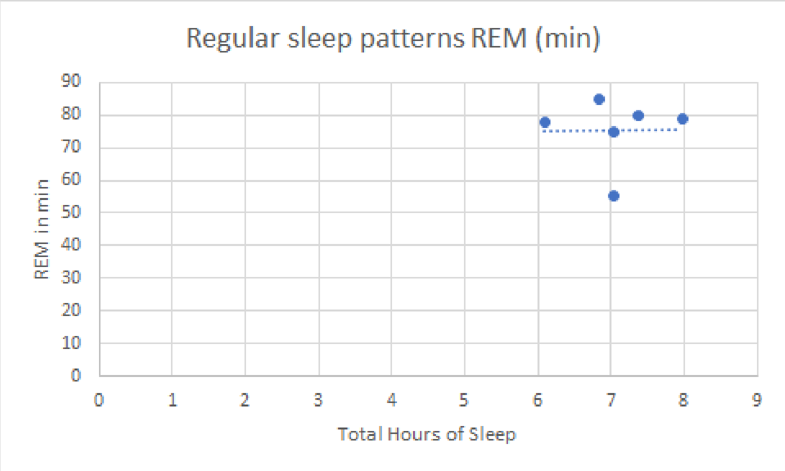


Figure 3: representing the sleep deprived data

Sleep deprived week		
Total hours	REM (minutes)	Percentage
3.92	41	17.43
4.45	48	17.98
4.73	69	24.31
4.23	50	19.7
4.63	75	26.1
3.98	54	22.61

Figure 4: a graph of Figure 3

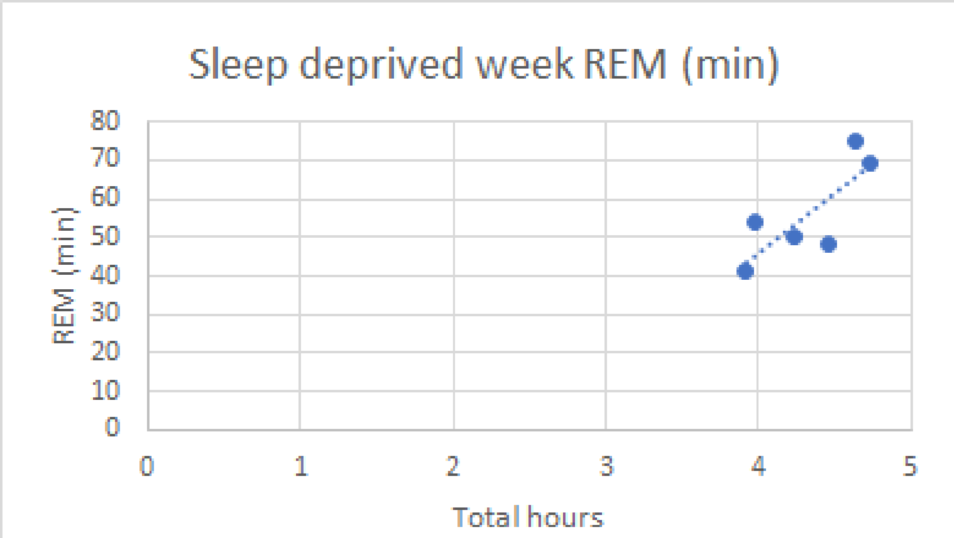


Figure 5: a graph of the recovery sleep data

Recovery		
Total hours	REM (minutes)	Percentage
9.58	120	20.88
9.01	123	22.76
9.85	134	22.67
8.89	134	25.12

Figure 6: a graph of Figure 5

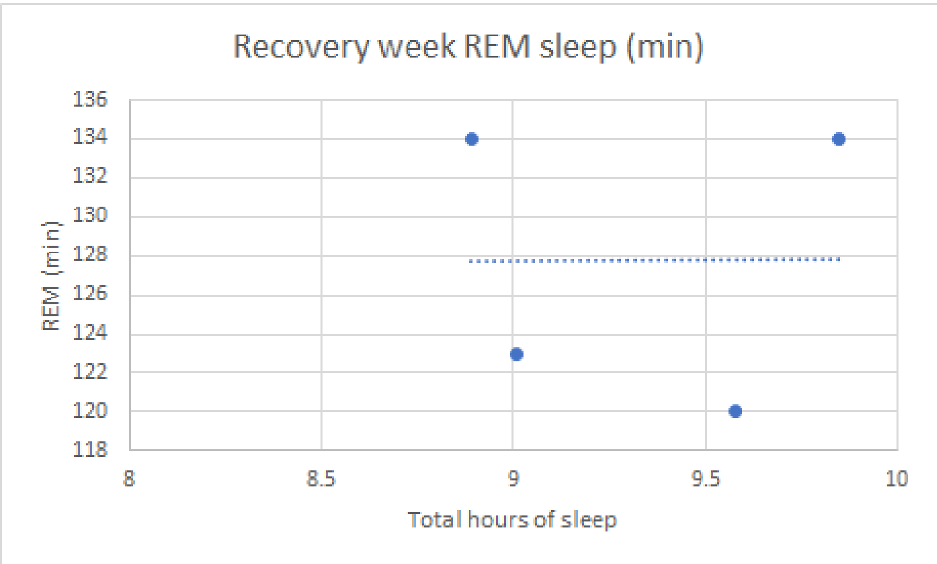


Figure 7: A table of averages.

REM sleep before deprivation	REM sleep during deprivation	REM sleep after deprivation	Difference of REM sleep before and after:
Average time in REM (minutes)			
75.3	56.1	127.8	52.6 minutes (69.72 %)
Average number of REM cycles per night			
2.8	4.3	7	2.4 minutes (52.17 %)
Average percent of total sleep spent in REM			
18%	21%	23%	5 % (a 28 % increase)

Figure 8 is A graph of the all the points and the average of REM sleep in minutes throughout the experiment:

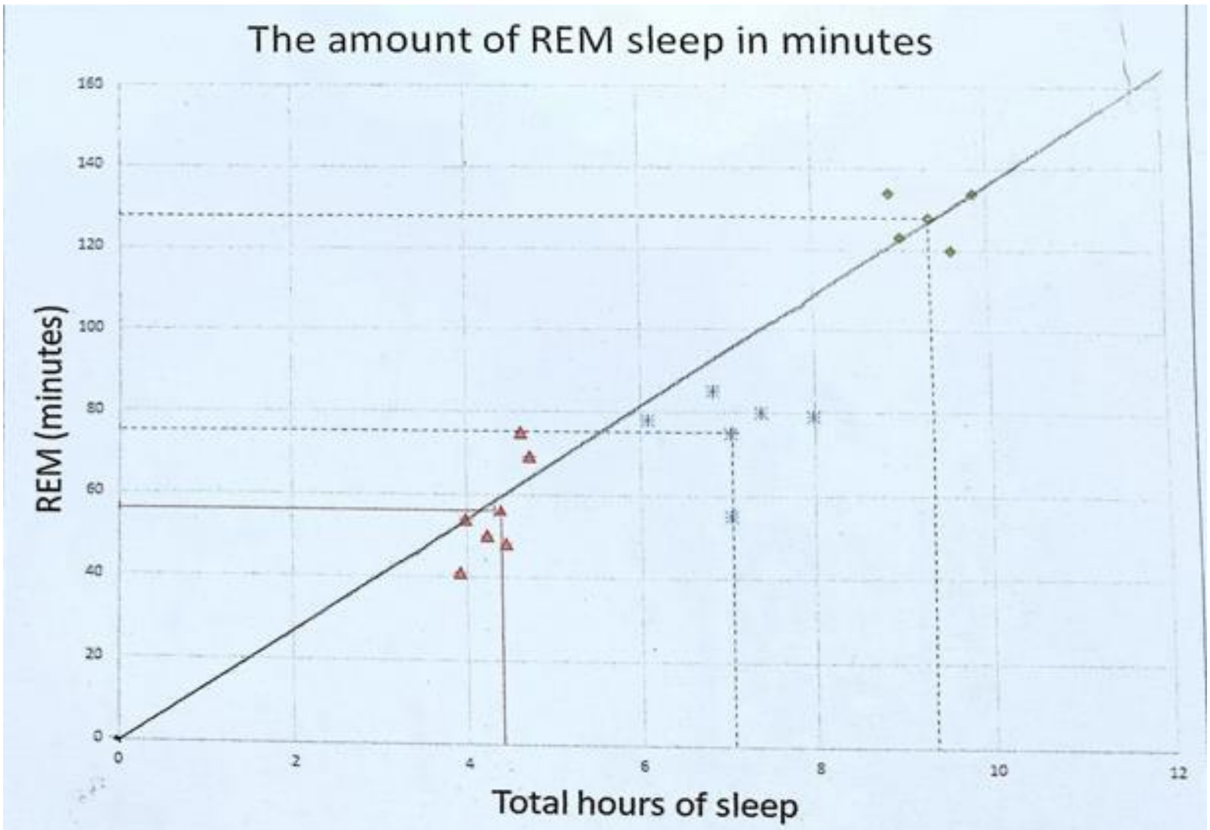


Figure 8 is A graph of the all the points and the average of REM sleep in minutes throughout the experiment. The red triangles show the amount of REM in minutes during sleep deprivation and the red vertical and horizontal lines indicate the means of all those points. The blue crosses show my regular sleep pattern, and the blue horizontal and vertical lines indicate represent the mean. The green diamonds show the sleep pattern during the recovery phase and the green horizonal and vertical lines indicate the mean.

Figure 9 a graph of the number of cycles throughout the experiment:

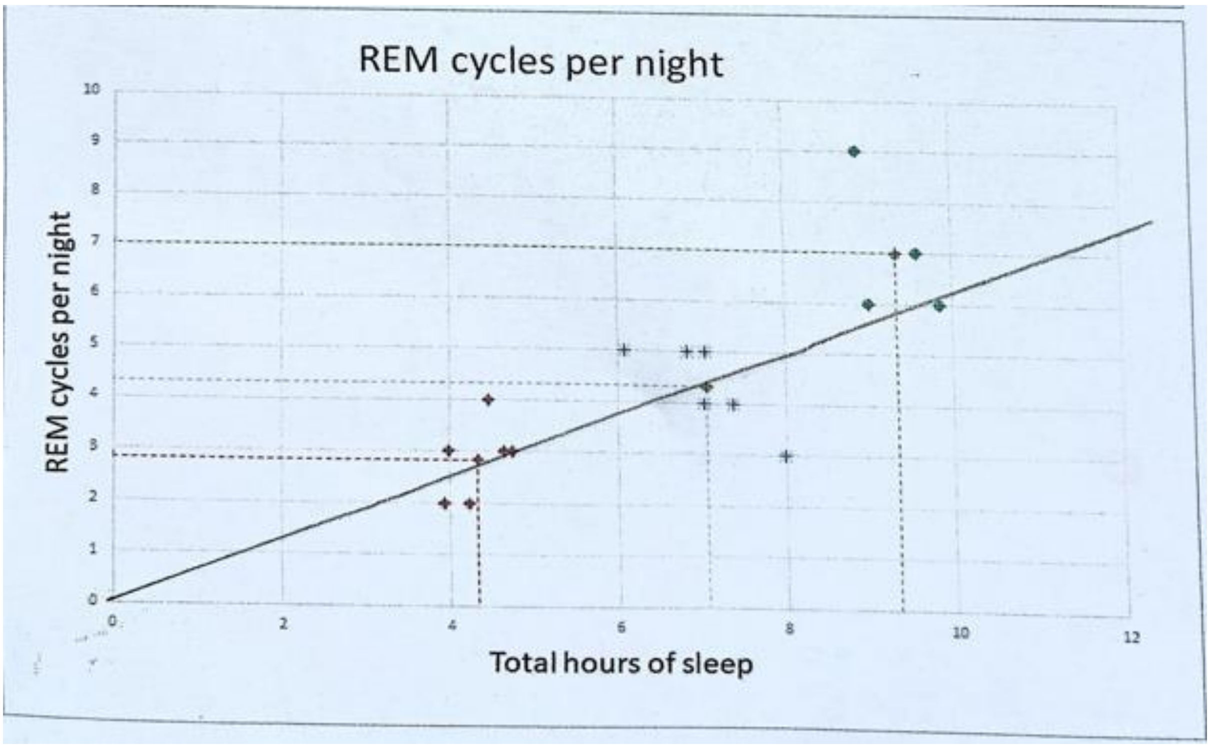


Figure 9 is a graph of the all the points and the average of REM cycles per night during the whole experiment. The dark red triangles show the amount of REM cycles during sleep deprivation and the red vertical and horizontal lines indicate the means of all those points.

The blue crosses show my regular sleep pattern, and the blue horizontal and vertical lines indicate the mean. The green diamonds show the sleep pattern during the recovery phase and the green horizonal and vertical lines indicate the mean.

Results: Figure 1 shows the raw quantitative data of the regular sleep patterns, the amount of REM in min and the percentage of REM in a table. Figure 2 represents the table from Figure 2 on a graph. Figure 3 shows raw quantitative data of the sleep deprived patterns, the amount of REM in min and the percentage of REM in a table. Figure 4 represent the table from Figure 3 on a graph. Figure 5 shows raw quantitative data of the regular sleep patterns, the amount of REM in min and the percentage of REM in a table. Figure 6 represent the table from Figure 5 on a graph. Figure 7 represents raw quantitative data of the average REM min before the REM rebound, during sleep deprivation, during recovery and the difference. The average number of REM cycles per night before REM rebound, during sleep deprivation, during recovery and the difference. The percentage of REM before REM rebound, during sleep deprivation, during the recovery and the difference**.** Figure 8 represents Figure 7 in a graph, showing the number of REM cycles during each phase. Figure 9 shows the amount of REM in minutes during each phase

Discussion of results:

The results summarized in Figures 7, 8 and 9 show that the amount of REM sleep in the recovery phase has increased compared to my regular sleep patterns. There are increases in (i) the average time in REM, (ii) the average number of REM cycles the body entered per night and (iii) the average percentage of REM sleep. The results presented in these figures provide compelling evidence supporting the existence of REM rebound. The data in Figure 8 show that during the recovery phase there was a 5 % increase in the average time spent in REM compared to my regular sleep pattern. The average percentage of time in REM varied from 18% to 23%. During sleep deprivation, the reduced total amount of time spent in REM sleep can be attributed to the findings from our previous investigation in experiment 1, which indicated that the lack of total hours of sleep results in less REM sleep. Conversely sleeping longer during rebound resulted in more REM sleep. The REM increased from the regular level of 18% up to 23% during rebound, however it had also increased to 21% during sleep deprivation. This reflects a limited ability of the body to compensate by adding REM sleep during a time of stress. The trendline representing 21%, drawn into Figure 8, crosses the two average points on the graph for during and after deprivation. This indicates that the average time spent in REM sleep during recovery not only increased but is proportional to the average time of spent in REM sleep during sleep deprivation. The percentage of REM sleep in minutes during sleep deprivation was 21% and during recovery was 23%, which is similar. This phenomenon could perhaps be explained by the body's regulatory mechanisms in response to sleep deprivation. During sleep deprivation, the body experiences a significant reduction in REM sleep, leading to a subsequent rebound effect during the recovery phase. As a result, the average REM duration during recovery tends to be proportional to the average REM duration during deprivation, as the body compensates for the REM sleep deficit. This proportional relationship between REM duration during deprivation and recovery periods highlights the body's adaptive response to sleep disturbances. It suggests that the body maintains a certain level of consistency in REM sleep regulation, even in the face of sleep deprivation, to ensure essential functions associated with REM sleep, such as memory consolidation and emotional processing, are adequately addressed during the recovery phase.

Furthermore, when we look at Figure 9, we can see that the longer the body sleeps, the more REM cycles it enters, hence the findings from experiment 1. The data shows that during the recovery phase there was an increase by 2.4 cycles, which corresponds to a 52.2% increase of the number of REM cycles the body enters. The average length of each sleep cycle varies from 1.3 hours during recovery to 1.6 hours for regular sleep. Even with this flexibility in general longer sleep will result in more cycles. However, the Rebound phase has the shortest time spend in each sleep cycle. Whereas regular sleep and during sleep deprivation the average length of each sleep cycle is just over 90 minutes, during rebound this is average reduced to 80 minutes. Perhaps this be because the more cycles there were, the less amount of time spent in each cycle. Moreover, what’s interesting is that the number of REM cycles my body enters is proportionally the same for my regular sleep and when sleep deprived (they are on the same line). I have not found research into this but possibly it could be because the body maintains a homeostatic balance in sleep cycles, even during sleep deprivation. While sleep-deprived, the body still follows the same length of each sleep cycle increasing the proportion of time spent in REM during each cycle, despite the overall reduction in total sleep time. This proportional entry into REM cycles during sleep deprivation could be a manifestation of the body's attempt to preserve essential functions associated with REM sleep, such as memory consolidation, emotional regulation, and cognitive processing. In other words, even when sleep-deprived, the body prioritizes REM sleep to some extent, ensuring that crucial processes linked to this sleep stage are not entirely compromised. This proportional allocation of REM sleep cycles may reflect the body's adaptive response to sleep loss, aiming to maintain some level of cognitive and emotional functioning amidst challenging sleep conditions.

In conclusions, the three increase in total time, in proportion of time spent in REM, and in the number of sleep cycles strongly suggest REM rebound. These findings suggest that the body and brain have a regulatory mechanism for ensuring a stable amount of REM sleep and after sleep deprivation, there is a compensatory increase in REM sleep. Investigating the existence of REM sleep reflects the importance of REM sleep for the brain. However, after more in depth analysis the data shown in Figure 8 and 9 shows compelling insights. Nevertheless, it's important to keep in mind, sleep is a complex topic, and many factors can come into play such as genetics and age. The current dataset is limited to a single trial in one individual so is insufficient for predictive analysis. Consequently, further data collection is essential to facilitate a comprehensive investigation into this phenomenon.

Validity of hypothesis and method: The data is overall valid to support the hypothesis for one individual on one trial as the quantitative data shows there is a clear increase of REM during the recovery phase by comparison to the regular sleep patterns. The points on the graph are scattered but can still be used to draw connections and patterns. The scattered points are expected because variables were not consistent throughout the whole experiment. Variables such as having the same sleeping environment as some night I forgot to wear a sleep mask. However, the data is still interesting as a trial study that tentatively supports the hypothesis.

Improve: The research needs to be carried out on many more subjects with many repetitions for valid conclusions. To further improve more control variables could be set in place such as have exact sleep schedule timing. This can be done by setting alarms and strict sleep timing.

Extensions: To further investigate into sleep cycles and REM rebound, an experiment can be conducted where one has a longer period of sleep deprivation to get a more significant difference of compensation of REM and even test memory consolation during the deprivation phase and recovery phase. This will give more reliable data when we say that sleep deprivation affects the memory consolidation. In addition, a Sleep log could be used to collect qualitative data about mood to give a batter understanding between REM and its associations with emotions. Furthermore, an experiment could be conducted to understand whether there is a relation between the average number of REM cycles the body enters during sleep deprivation and regular sleep patterns. As well as to whether the increase of REM in minutes has a relation between sleep deprivation and the recovery phase.

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