An experiment on state-dependent memory induced by aerobic exercise

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Introduction

This report details the results of two experiments on state-dependent memory and the research and prior knowledge that led to this topic becoming the focus of this investigation. The purpose of the experiments was to measure the students' state-dependent memory and determine whether it was significant enough to become a new learning tool.

State-dependent memory is a hypothesis associated with the superior recall of a specific memory when small prompts linked to emotional and physical states are equal during recall and encoding. (Mcleod, 2021). According to this hypothesis, when memories are encoded, a neural pathway connects brain cells. Cells can be trained to communicate while the brain is in a distinct state. Training the brain in this manner helps the cells recognize and intertwine certain physiological indicators within a memory's neural pattern, resulting in a superior recall (Practical Psychology, 2019)

The history of state-dependent memory can be traced back to 1784 when a French aristocrat named Marquis de Puysegur conducted experiments on hypnosis and realized his subjects had no recollection of events that occurred during their hypnotic state. However, when they were placed back in a hypnotic state, they recalled all the previously forgotten events.
Centuries later, in 1910, Morton Prince hypothesized why dreams are difficult to recall. He believed dreams were not difficult to recall solely due to poor memory but because dreams are so very different from the real world. (Tulving, Roediger and Craik, 1989)

State-dependent memory results from the strengthening of particular synaptic pathways. A neural synapse is the space between neurons that allows for the transmission of chemical signals between two or more neurons. Chemicals or neurotransmitters travel from one cell, move across the synapse, and are absorbed by the next neuron through a neurotransmitter receptor. This establishes a connection between the two neurons, referred to as a neural pathway. Memory relies heavily on the fortification of neural pathways, connecting one neuron with another.

New pathways are made between neurons that communicate using chemical signals when our brains absorb information. Should those cells be accustomed to sending out certain signals under specific chemical conditions, they are then optimized to work under similar circumstances. State-dependent memory occurs when a new neural connection is made while the brain is in a specific chemical state or when certain conditions in the body, such as heart rate, deviate from the norm.

My two experiments involved 21 students between the ages of 15 and 16, all in the 5th year of the Middle Years Programme at the British International School of Stavanger (corresponding to the penultimate year of secondary school). The class was divided into two groups. Each group was assigned to either a running or a resting state and was asked to recall elements of a story in both states.

This experiment was conducted in an attempt to disprove the null hypothesis stating there is no relation between memory recall and physiological state. The data gathered in this investigation are inconsistent with the hypothesis, meaning that such an association was in fact observed. Possible real-life applications of this link could be in the form of a memorization technique. As exams are often stressful, this technique might allow some students to combine schoolwork with exercise to help their bodies simulate the distressed state.

Background

Prior to coming up with the idea of studying state-dependent memory, I was already familiar with context-dependent memory, a hypothesis very similar to state-dependent memory. The difference between the two hypotheses is that context-dependent memory implies that when events are represented, contextual information is stored along with the memory, and the context can therefore cue memories containing contextual information, while state-dependent memory is more dependent on physiological cues. (Gruneberg and Morris, 1994).

The primary inspiration for this topic came from a scientific article called "*Fear-related state-dependent memory*" (Lang, Craske, Brown, and Ghaneian, 2010). This article suggested a link between state-dependent memory and fear and sparked the idea of using state-dependent memory as a learning technique for school.

The experimental method used in my experiments was greatly influenced by Miles and Hardman (1998). Several other studies that have cited this article have found similar patterns.
For example, Loprinzi et al (2017) conducted a study on 17 teenagers, where 14 were healthy individuals, and 3 individuals were diagnosed with depression. Out of the 17 subjects, 4 employed a chronic training protocol, with 13 utilizing an acute exercise protocol. The 3 subjects in the depressed population all demonstrated a favorable effect of exercise on memory function. Among the 14 subjects in the non-depressed population, 10 (71%) showed a favorable impact of exercise on some aspect of memory function.

The independent variable in this experiment was the two activities the students were performing, running and resting. I observed how the change in physiological state affected the results of the dependent variable, which was the difference in the number of elements each student recalled in the two separate physical states. The control variables in this experiment were the students' age, the volume at which the story was played, and the text read to the participants just before the experiment. These variables were kept as consistent as possible across all experimental trials.

My null hypothesis was that there would be no association between the number of elements recalled and the physical state during encoding and recall.

Method

Two separate experiments were conducted that largely followed the same experimental method, influenced by the method used in Miles and Hardman (1998).

Students were assigned to a random group. To randomize the groups, each student was given a number, and, using a random number generator, groups of 5-6 students were formed for each experimental trial. In each trial, one group ran first, and the other was first at rest. All necessary instruments such as the loudspeaker, computer used to coordinate the audio, and paper for the students were gathered. The pre-written text explaining to the class the task ahead of them was read aloud, and two pieces of paper were given to each student. Students wrote their assigned number on the papers and the physiological state they were in during the recall. After 5 minutes of students adapting to their respective states passed, both groups stopped, and the story was played once.

Next, students in the running group resumed running while both groups counted backward from 60. The consolidation period passed, and both groups wrote down the story elements they remembered. The groups changed places and entered another 5-minute adaptation period. Once this period passed, both groups wrote what they remembered again. When all participants had written the elements they remembered, the pieces of paper were collected, and the experiment concluded.

This experimental method varied slightly between the two experiments, as there were some minor flaws in the original method. During experiment 1, the initially resting participants had trouble hearing the story while it was playing as the exercise group was running simultaneously. Therefore, the running group stayed still while the story was played during the second experiment. Another change I made to the method was having the running group run in circles around the gym instead of running on the same spot during the 5-minute preparation phase when students entered their states. I found that this brought the heart rate up higher and created a more distinct physical state. Despite the changes made to the method, the experimental design remained largely consistent across all trials, and I can, therefore, still utilize evidence found in both experiments when evaluating the validity of the hypothesis.

Another obstacle I encountered before conducting the first experiment was the presentation of the story to the participants. Initially, I planned to read the story aloud during the experiment. However, I realized this might prove to be challenging as, in the case of error or mispronunciation, the results would be less valid as the participants would hear parts of the story more than once. I solved this problem by prerecording the story and using a large loudspeaker to play it.

Time was also a factor that could have influenced the result and caused some of the students to forget certain elements between the first and second recall. This might be partially responsible for the lower number of recalled elements during the second versus first recall. To test this further, I conducted a control experiment that followed the same method; however, the students remained in a constant resting state, meaning the results would display the impact of time between first and second recall without any change in physical state.

Finally, an essential part of the experimental design was to explain the experiment systematically to students. They all had to be given precisely the same information, as providing one group with more information could give them a potential advantage and thereby bias the results. This was addressed by reading a prewritten text to the groups that contained the relevant information, which can be found in the Appendix.

Results

Data description:

The data from the investigation has been primarily represented in two tables (*Table 1* and *2*). These tables are divided into two primary sections: sub-group 1 and sub-group 2. The first column in each section represents the first recall and the second column represents the second recall. The third column represents the total number of elements forgotten. The students' recall is measured in elements. An element in a story is any name, place, character, or environmental description featured in the story. Examples of elements can be found in the Appendix.

The data shows that most students displayed a decline in elements recalled regardless of which state they began in. The distribution of elements forgotten has also been illustrated in the histograms shown in *Figures 1,2, 3, 4,* and *5*.

Experiment 1:

In the first experiment, 12 out of 21 students experienced a decrease in elements recalled. 1 student forgot -2 elements, 3 students forgot -1 element, 6 forgot 1, 5 forgot 2 and 1 student forgot 3 elements. 5 students recalled the same elements and thereby showed no change. In this experiment, students showed an average decline in elements forgotten of 0.68.

Experiment 2:

In the second experiment, 12 out of 21 students displayed a decrease in elements recalled. 4 students forgot -1 element, 7 forgot 1, 4 forgot 2, and 1 student forgot 5 elements. 5 students recalled the same elements and thereby showed no change. However, in both experiments, all students that displayed no change did display a change in formulation, i.e., the word order of the sentences was more dissimilar to that of the story in the students' second recall. The total average number of elements forgotten was 0.77.

Experiment 3 (control experiment):

In the control experiment, students did not change physical states between encoding and recall, in order to verify whether the decline in elements recalled between the first and second recall in experiments 1 and 2 could be explained by the passing of time. Here, 3 students forgot -3 elements, 2 forgot -2, 4 forgot -1, and 6 students showed no change. Adding on, 4 students forgot 1 element and 1 forgot 2. The average number of elements forgotten was -0.50.

Summary:

There are some minor differences in how many students recalled a certain number of elements depending on which state they began in. For example, in *Figures 1* and *2*, 4 students forgot 1 element starting with running, as opposed to the 2 students who began resting. In addition, as can be seen in *Figures 3* and *4*, 1 student forgot 2 elements starting with exercise in contrast to the 3 that began with resting.

Element Recall Experiment 1 ***Table 1***					
Subgroup 1 (Run)			Subgroup 2 (Rest)		
Run (1st recall)	Rest (2nd recall)	Elements forgotten	Rest (1st recall)	Run (2nd recall)	Elements forgotten
10	12	-1	3	1	2
3	2	1	5	4	1
7	6	1	7	7	1
9	9	0	4	4	0
7	7	0	8	6	2
2	0	2	3	3	0
3	1	2	0	2	-2
3	4	-1	2	2	0
2	1	1	8	6	2
3	2	1	3	0	3
6	7	-1	x	x	x
Average elements forgotten		0.45	Average elements forgotten		0.90

Figure 1

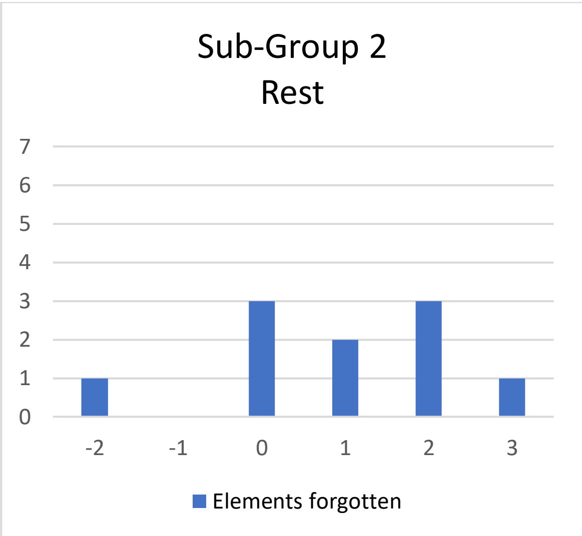


Figure 2

Element Recall Experiment 2 ***Table 2***					
Subgroup 1 (Run)			Subgroup 2 (Rest)		
Run (1st recall)	Rest (2nd recall)	Elements forgotten	Rest (1st recall)	Run (2nd recall)	Elements forgotten
4	4	0	14	12	2
1	2	-1	4	4	0
7	6	1	10	8	2
11	10	1	11	9	2
12	11	1	5	5	0
12	11	1	5	6	-1
4	4	0	7	6	1
11	6	5	4	4	0
7	5	2	6	5	1
12	13	-1	x	x	x
16	15	1	x	x	x
9	10	-1	x	x	x
Average elements forgotten		0.75	Average elements forgotten		0.78

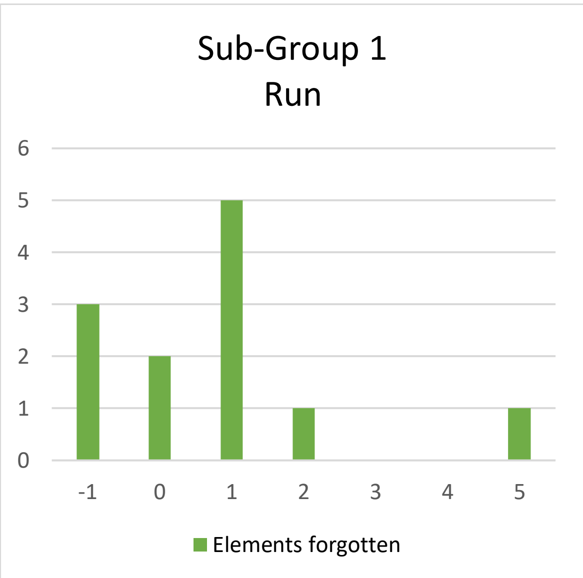


Figure 3

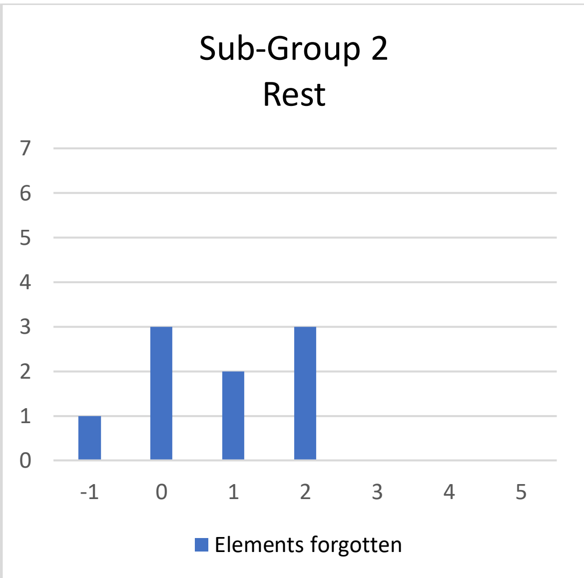


Figure 4

Control Experiment ***Table 3***		
Rest (1st recall)	Rest (2nd recall)	Elements forgotten
8	8	0
9	12	-3
4	7	-3
11	11	0
14	13	1
3	2	1
7	8	-1
10	9	1
8	8	0
5	6	-1
13	14	-1
11	11	0
5	3	2
7	7	0
6	8	-2
6	6	0
11	12	-1
10	9	1
12	12	0
8	8	0
5	8	-3
6	8	-2
Average elements forgotten		-0.5

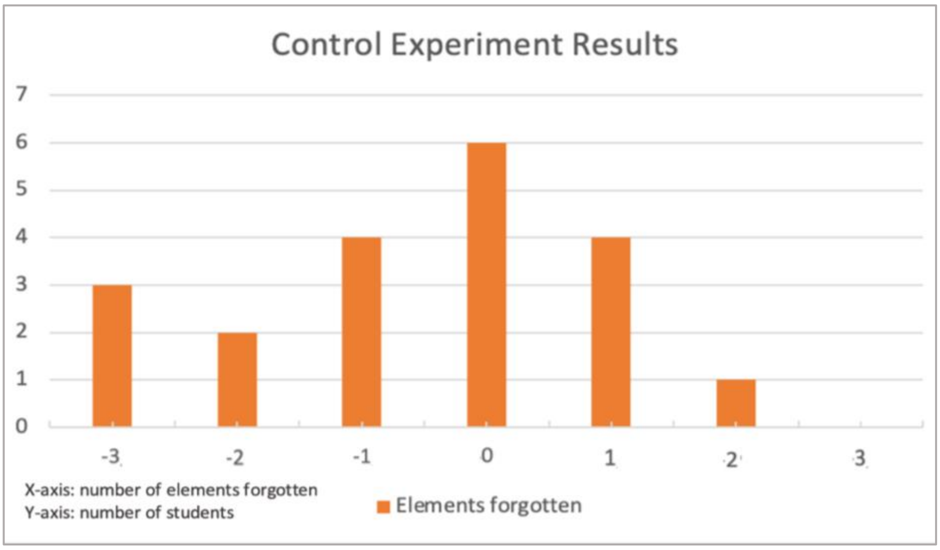


Figure 5

Analysis:

Scientific Explanation:

Our main observation was that the students showed a reduction in elements recalled both when switching from rest to exercise and vice versa in experiments 1 and 2. This was also observed in Miles and Hardman (1998).

The data gathered in the control experiment (*Table 3, Figure 5*) showed that more students increased in elements recalled during the second recall, meaning the time delay was unlikely to explain the reduction in elements recalled between the first and second recall in experiments 1 and 2. This increase further invalidates the null hypothesis by isolating the change in physical state as the cause for the decrease in recalled elements in experiments 1 and 2.

Overall, the average number of elements forgotten remained stable in the original two experiments, with values of 0.68 and 0.77. On the contrary, the average number of elements forgotten was -0.50 in the control experiment where no physical states were changed. This strongly indicates that the drop in elements recalled was primarily due to a change in physical state, and not due to time passing and memories naturally fading.

As stated in the observation, there are some differences in the distribution of elements recalled in the first versus second recall. As seen in *Figures 1, 2, 3, and 4,* more of the 11-12 students who began in a resting state forgot 2 elements, and fewer forgot 1 compared to the 9-12 students who began with running.

One factor that could have caused this difference in distribution to occur could be that those who had initially been at rest while hearing the story found it more difficult to concentrate for second recall compared to those who started by running. This could be due to the elevated heart rate and exhaustion they felt when recalling the story for the second time, after having run for 5 minutes. Conversely, the running group may have found it easier as their concentration would be higher during their second recall because they were resting.

Additionally, in experiment 1, the initially resting participants had trouble hearing the story while it was playing as the exercise group was running simultaneously. This could have caused the increase in average elements forgotten in subgroup 2, experiment 1, as the memory formation and subsequent recalls may have been hindered by the external interference.

Furthermore, on 13 occasions, students who participated in experiments 1 and 2 experienced no change in elements remembered. However, as the degree of state-dependent memory can vary from individual to individual, some students' brains might not incorporate the body's physiological state as substantially in the neural patterns that form during memory encoding. Therefore, it is probable that the students that displayed no change did not have a strong state-dependent memory.

Validity of method:

In order to safeguard the validity of the experiment, I have attempted to build on previous research by following the same principal structure as other scientific studies done on state-dependent memory. One such study is Miles and Hardman (2010). Almost all control variables were also kept consistent throughout the two experiments.

I made sure all students heard the story clearly, at the same time, and at the same volume. This ensured that no students had an advantage because of their proximity to the loudspeaker.

Furthermore, I made sure to time the consolidation period carefully. Should one group have had a shorter or longer consolidation period, their ability to recall the elements would have been impaired or enhanced compared to the other groups. I also made sure both groups engaged in the same exercise. A different exercise could have influenced the participants' physiological state differently from running, elevating the heart rate but not causing equal amounts of perspiration.

I ensured that both groups were given the same information by reading a pre-written text that briefly detailed what the students had to do. By keeping this the same, I prevented giving the two groups different information, which could have influenced their degree of understanding and caused confusion later in the experiment. Lastly, I made sure both groups were played the same story in each experiment. This way, no students were asked to recall elements from a more advanced or less advanced story. Adding on, each story used was a variation of the prompts used in the Wechsler memory scales, a common test used to measure one's logical memory, meaning the stories were all written for the purpose of later recall.

Despite this, there remain sources of error in my method. During the second experiment, I experienced a technical malfunction of the loudspeaker prior to playing the story. This led to some students running for longer than planned, causing exhaustion and difficulty in hearing the story. Additionally, many students left the school over the summer. Therefore, not all the students that were tested before summer were tested after, and if this aspect of the experiment were to be fair, I would have tested the same 21 students twice. However, those that left were replaced with new students, and the results persisted meaning this change could have potentially acted towards strengthening my findings.

Validity of hypothesis:

My initial hypothesis was founded on the null hypothesis, meaning I hypothesized that there existed no link between memory recall and physical state. Generally, the data above (*Tables 1, 2, and 3*) is in favor of rejecting this hypothesis. It shows that students displayed either a reduction in the number of elements recalled or no change at all after a change in physical state. Furthermore, as time was eliminated as a significant factor, the reduction was likely due to the change in physical state, indicating a relation between the number of elements recalled and the physical state during encoding and recall. This association gives grounds for the rejection of the null hypothesis.

<u>Discussion and Conclusion:</u>

In conclusion, the data represented above (Tables *1, 2,* and *3*) provided sufficient grounds for the rejection of the null hypothesis. Subsequently, despite some minor difficulties I faced with keeping the experimental conditions consistent, as discussed above, the experimental method and results gathered allowed us to draw meaningful conclusions.

As an observation of a relation between state-dependent memory was made, it could be transferred to one's daily life in the form of a memorization technique.
Because the recall was conducted as a written exercise, the results of this experiment might generalize to student performance in academic assessments. In that case, it is possible that some

students would benefit from using state-dependent memory as a study tool, and that inducing state-dependent memory through exercise could become a popular tool for students in the future.

However, this needs to be investigated through further studies. Such studies should focus specifically on the effects of exercise and state-dependent memory on student performance in tests and assessments. Several questions remain in this regard – for instance, whether studying should be done simultaneously with exercise, or whether it is sufficient to exercise before studying.

As of now, I would not recommend dedicating time to replicate one's physiological state during an exam as it is not currently an established study technique. However, as data on the effectiveness of this technique is lacking, it could ultimately prove to be useful in the future.

Overall, I believe my investigation was successful, and I hope that more studies are done to study state-dependent memory and its effectiveness as a tool in the classroom environment.

<u>Appendix:</u>

Story from experiment 1 (elements in bold):

Joe Garcia of **San Francisco**, a **retired college English professor**, was **watching** the **news** as he **dressed** to go to the **post office** to **mail** his **electric** and **water bills** which were **three days late**. He put on his **black coat**, **sealed** the **envelopes**, and **left** his **home**. He had **thirty minutes** until the **post office opened** so he decided to **walk instead of drive**.

Story from experiment 2 (elements in bold):

Anna Thompson of **South Boston**, employed as a **cook** in a **school cafeteria**, **reported** at the **police station** that she had been **held up** on **State Street** the **night before** and **robbed of fifty-six dollars.** She had **four small children**, the **rent was due**, and they had **not eaten** for **two days**. The **police** also had a **murder case** that night and so were **unable to help her**.

Story from experiment 3 - control experiment (elements in bold):

Margaret Williams of **Chicago**, a **secretary** in a **law firm**, **drove** to the **hospital early** in the **morning** to see her **niece** being **born**. She **arrived** at the **hospital** with much **excitement** just as her **sister delivered** the **baby**. The **doctor said** it was a **healthy baby girl**. Her **sister** and her **husband** decided to **name** the baby **Sophia** after her **grandmother**.

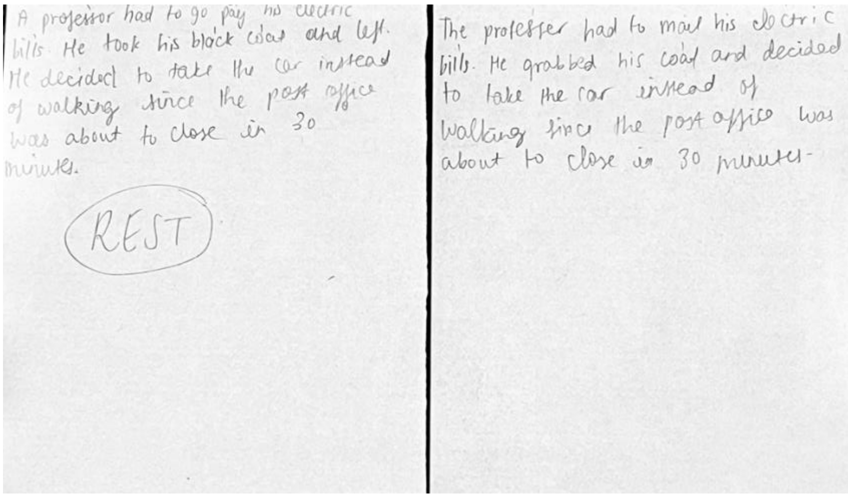
Prewritten instructions:

Today, I will be conducting an experiment on you, which will test your state-dependent memory. For those who are unfamiliar with the concept, it explores how your brain relates specific memories to your body's physiological state. In other terms, when you are intoxicated or under the influence of drugs, and someone reads you a list of numbers or words, you will remember it better while you're in that same state, as opposed to being sober.

To complete this experiment, I will divide this class into two different groups. One group will start running in place to increase the heart rate while the other rests. After the five-minute adaptation period has passed, you will continue to run slower as l play you a short story that you will have to listen to very carefully. After I have played you the story, you will count down from 120, and then I will ask you to write down as much as you remember of the story. Please do not use any memorization techniques. Simply listen to the story and recall what you remember.

After writing down what you have remembered, the groups will switch roles and begin either decreasing or increasing their heart rates. This will occur over a period of 5 minutes. After these 5 minutes have passed, I will ask everyone to recall the story once more to the best of their ability. After this, I will collect all papers, and the experiment concludes.
To clarify, the runners run until they begin writing the story, and the same goes for those who are resting. No speaking is allowed.

Recall example from experiment 1:

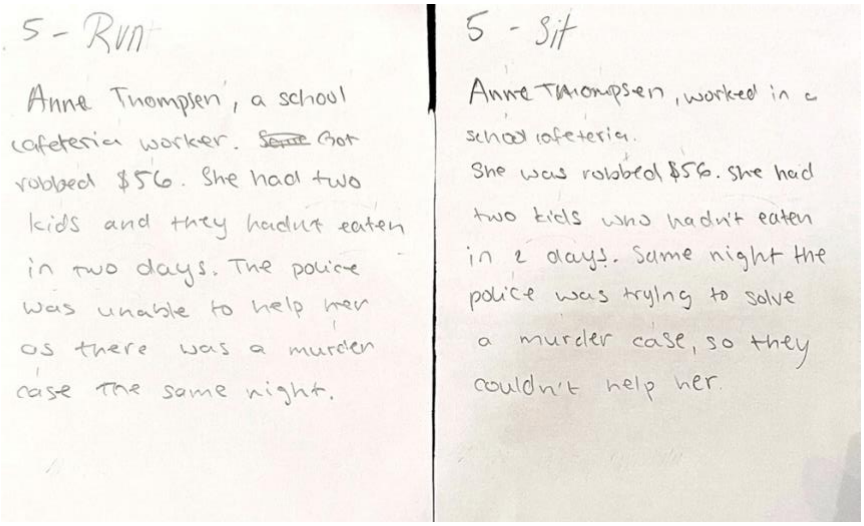


A professor had to go pay his electric bills. He took his black coat and left. He decided to take the car instead of walking since the post office was about to close in 30 minutes.

REST

The professer had to mail his electric bills. He grabbed his coat and decided to take the car instead of walking since the post office was about to close in 30 minutes.

Recall example from experiment 2:



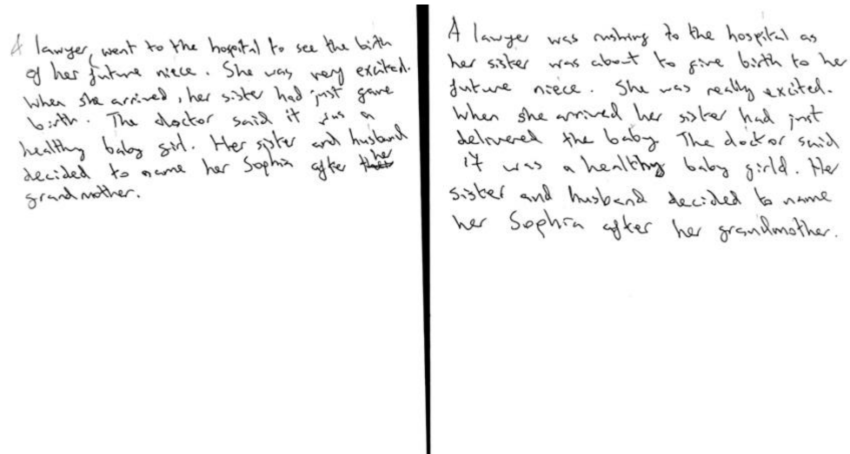
5 - Run

Anne Thompsen, a school cafeteria worker. ~~Some~~ Got robbed $56. She had two kids and they hadnt eaten in two days. The police was unable to help her as there was a murder case the same night.

5 - Sit

Anne Thompsen, worked in a school cafeteria. She was robbed $56. She had two kids who hadn't eaten in 2 days. Same night the police was trying to solve a murder case, so they couldn't help her.

Recall example from experiment 3:



A lawyer, went to the hospital to see the birth of her future niece. She was very excited. When she arrived, her sister had just gave birth. The doctor said it was a healthy baby girl. Her sister and husband decided to name her Sophia after ~~the~~ her grandmother.

A lawyer was rushing to the hospital as her sister was about to give birth to her future niece. She was really excited. When she arrived her sister had just delivered the baby. The doctor said it was a healthy baby girld. Her sister and husband decided to name her Sophia after her grandmother.

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