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The use of verbalization does not improve the performance of Visual Working Memory while using unfamiliar items

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Thesis project for MSc Applied Cognitive Psychology

27.5 ECTS

Utrecht University

Academic year 2021-2022

Abstract Visual Working Memory (VWM) is where the visual information becomes stored in our brains. While VWM has limited capacity, it is not used to its fullest most of the time. This study suggests a method to use, to enhance the performance of VWM regardless of its capacity limits. The purpose of this study was to increase VWM's performance by using a method called verbalization, in which items are named descriptively. The results of the experiment report that when needed visual information is not easily available in the external world, individuals prefer to use easier methods to store the required visual information in their VWM to complete their tasks faster (e.g., memorizing the color). However, we can conclude that based on our findings, verbalization was not found to be a helpful method for VWM's performance improvement.

Keywords: Visual Working Memory, Verbalization, Unfamiliar items, Familiarization, Copying Task.

1. Introduction

As we observe the world around us, we can easily internalize the visual information into a mental workspace called Visual Working Memory (VWM). Based on Baddeley and Hitch's (Baddeley, 2010; Baddeley, 2003; Baddeley, 2000; Baddeley & Hitch, 1974) three-component model of working memory, our brain has a system consisting of multiple short-term memory files, containing different input information. This model suggests that the Visuo-Spatial sketchpad is the component that stores both visual and spatial traits of the sensory information from our environment into our memory (Baddeley & Hitch, 1974). For example, if you see a statue in a park and it is interesting enough for you to attract your attention, the statue's shape and color will be filed in your VWM, and its location in the park will be kept in your Spatial Working Memory.

VWM can hold, manipulate, and process the visual information of any item in our surrounding temporarily (Yang, 2017). VWM's functionality and capacity have been the subject of many studies by many neuroscientists and psychologists (Olton, 1979; Colom, Shih, Flores-Mendoza, & Quiroga, 2006). Many specific values have been associated to be the maximum number of VWM's capacity (Miller, 1994; Fukuda, Awh, & Vogel, 2010; Luck, & Vogel, 2013). This capacity does not seem to increase in our lifespan, rather only has a U-shaped development, reaching its peak of performance earlier in life followed by a decrease in performance during adolescence, and a rise into adulthood (Fukuda, Awh, & Vogel, 2010).

Previously, many studies have focused on demonstrating the capacity limitation of VWM (Fukuda, Awh, & Vogel, 2010; Luck, & Vogel, 2013). The capacity of VWM is the ability to maintain a quantity of visual information at once that is available to be used for ongoing tasks (Isbell, Fukuda, Neville, & Vogel, 2015). There is evidence that VWM performs equally well without the influence of the items' complexity (Awh, Barton, & Vogel, 2007). In that case, regardless of how complex the items are, VWM has a fixed number for its capacity, and that does not change whether the item is complicated or simple. Although, according to scientific studies, our nervous system makes a trade-off when using our working memory. This trade-off includes deciding whether to use the internal storage (i.e., working memory) or use the available information in the external world with the use of eye movements. Consuming less capacity, less energy, and high efficiency are the principles when making the trade-off between using working memory or using the external world (Somai, Schut, & Van der Stigchel, 2020; Van der Stigchel, 2020).

Despite VWM's limited capacity, learning to use methods for enhancing its performance can help us learn quicker and get our daily tasks done faster. Enhancing methods for VWM's performance are similar to when we try to remember an external item by its functionality or its visual features. For example, it is easier for a painter to remember a tall tree with forest-green bushy leaves rather than only a tree when painting a landscape. Instead of looking back and forth to ensure the details, the painter can only pay extra attention to one item's visual details from the beginning and decide on how and where that item needs to be drawn. In addition, it is essential to mention that paying extra attention to an additional visual feature recruits extra working memory capacity (Brady, Störmer, 2021). Naming or expressing an item by words is called verbalization. The concept of verbalization traces back to a study written by Robert Fliess (1949) and after on was used as a figure of speech (Balkányi, 1964). For instance, naming an object based on the combination of an item's uncategorized visual traits that we have in our mind.

In a study done by (Brady, Stormer, & Alvarez, 2016) about Working Memory, it is stated that VWM's performance will be enhanced when the stimuli are based on real-life objects rather than simple stimuli. This can be interpreted that having a high degree of familiarity with an item for over years, can enhance its chance to remain in VWM. Therefore, it is easier to keep such a familiar item in our VWM rather than trying to keep an unfamiliar item in VWM (Chen, Yee Eng, & Jiang, 2006). An example of a known item is a table. Practically all individuals have known a table and its concept since the beginning of their perception of their surroundings. They thoroughly know its functionality and approximate shapes. On the contrary, people do not have similar familiarity with a creatively designed bookend. Therefore, when trying to maintain these two items, a table, (i.e., a very familiar shape), can be kept in the VWM rather easily compared to a bookend, (i.e., an unfamiliar shape).

In the present study, the use of verbalization is considered an important element because in the experiment we used unfamiliar items that the participants did not have any previous names or background of what their names were. Thus, they had to familiarize and verbalize the items before doing the experiment. As explained priorly, familiarity with the visual stimuli might influence verbalization, resulting in them becoming maintained in the VWM more quickly. Therefore, it is ideal that the items are not generally common, to ensure that any inferences made regarding keeping them in mind were not actually due to participants' exposure to the items before the experiment.

This study aims to investigate whether verbalization can be used to express the visual and functional traits of an unfamiliar object from our thoughts into words to manipulate VWM into performing noticeably better. To investigate this matter, we designed and used a copying task. A task in which participants are instructed to copy and place a number of given items correctly in their location, based on a model given to them. The task was designed in a way to manipulate the participants to use verbalization. The hypothesis in the current study was that the use of verbalization will help the individuals to perform considerably better. This hypothesis yielded specific expectations about several outcome measures. We expected a faster average completion time for doing the copying tasks, fewer checks of the original grid as participants were more assured of the item and its position on the grid, and fewer errors as they chose the correct item. These hypotheses are assumed because we suggested that verbalization is a beneficial tool to use for VWM's better performance.

This can be the start of suggesting various methods to improve an existing ability's performance without trying to increase its capacity. The idea is to enhance the available ability. These methods can be studied and improved to be used by people regarding their intelligence or memory capacity. It is most likely expected that the results of the present designed experiment, demonstrate an enhanced performance of VWM while using verbalization compared to when VWM is used and performed as it is without the help of verbalization.

2. Methods

2.1. Participants

We asked 36 Participants (22 females, average age range 26-33) to enter the link given to them and complete the experiment. The instructions were given to them prior to the experiment. The experiment was approved by the local Faculty Research Ethics Committee of Utrecht University. Each participant filled out the informed consent form at the beginning of the online experiment. They were informed that their participation in the study does not have any negative consequences for them. They could withdraw at any stage of the experiment if they did not have further intention to continue for no reason. And lastly, their information would only be visible to the experimenter, and it will be kept anonymous.

2.2 Stimuli and apparatus

The experiment was conducted online using JavaScript libraries jsPsych (version 6.3.0) (de Leeuw, 2015) and Fabric (www.fabricjs.com) for programming. The website (www.cognition.run) was used as the host for the programmed online experiment. Participants were encouraged to use a laptop or a desktop computer to conduct the experiment. We encouraged participants to use a computer mouse instead of a trackpad for their own convenience. A calibration procedure was implemented to ensure equal stimulus sizes despite the differences in display sizes. The calibration procedure was that the participants were asked to resize a blue rectangle with their cursor, based on the size of a credit card (or any card that has an 8.56 cm width) by holding the card against the screen. By following this procedure, the experiment would take place within a light gray rectangle measuring 25 cm wide and 8.5 cm high, and in a white box measuring 1 by 1 cm. We used 36 items of the 64 items used in the experimental research done by Horst and Hout (2016) on a collection of images of novel objects from the Novel Object and Unusual Name (NOUN) database (Figures 1&2). The selected images that we used as unfamiliar items, had been photographed of real 3D objects against a white background by Dr. Horst and other members of the Word lab team[1]. All the used items were distinct in shapes and colors. They were used since participants had no prior familiarity with them and the items had not already been associated with specific names. This database was originally created for use in word learning experiments, primarily with children. However, it is indicated in the original research that it can also be used by other researchers who require novel objects when investigating different categories and it is freely available to the scientific community (Horst, Hout, 2016). To implement a condition that gives us a chance to track the participants' actions toward checking the original grid, we used a cursor-directed aperture (Anwyl-Irvine, Armstrong, Dalmaijer, 2021). This condition overlayed the display with a black cover, except for the area around the cursor that was visible. The condition is called the spotlight mode (Figures 4 a& b).

[1] http://www.sussex.ac.uk/wordlab/noun

Figure 1. These 12 unfamiliar items were used in the practice trials. 6 of these numbers were randomly chosen for each participant and displayed in the original grid for the two practice trials.

Figure 2. 24 unfamiliar items that were used in the main 40 trials. These items were selected randomly in both conditions for each participant individually.

2.2. Procedure

In total the experiment consisted of 40 trials. In each trial, participants had to do a task that is similar to copying and pasting a puzzle. There were three grids, one on the left and two on the right side of the screen (Figure 3). The grid on left had six pictures that we refer to them as unfamiliar items. The grids on the right side consisted of a blank grid, and another was filled with twelve unfamiliar items including the unfamiliar items from the original grid. The grid with all the unfamiliar items is called the resource grid. Participants had to select and drag items from the resource grid to the blank grid based on their position in the original grid that was located on the left side of the screen. This process is a copying task, and it is repeated in all 40 trials. At the beginning of the experiment, two practice trials appeared, intended to visualize the actual experiment. One of the practice trials was in a visible condition (Figure 3), and the other was in a mode called spotlight mode (Figure 4(a and b)).

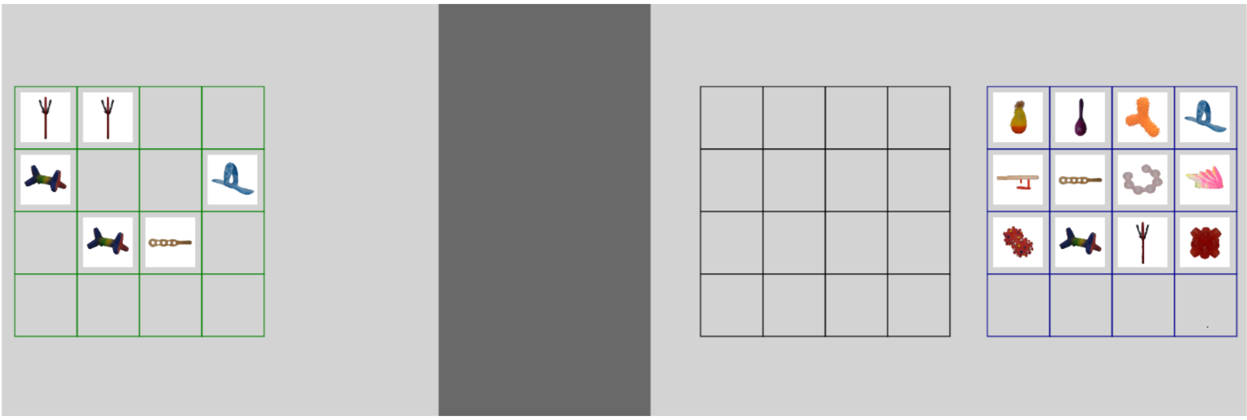


Figure 3. A visible condition in which the whole screen was accessible to view and was only for the first trial of the two practice trials. The grid on the left was the model and it is referred to as “the original grid”. The blank grid on the right side was where the items had to be located based on the original grid. And the next grid was the source grid which contained all the unfamiliar items from the original grid and other items.

Figure 4.a. The original grid on the left side of the screen in the spotlight mode.

Figure 4.b. The blank grid and the resource grid on the right side of the screen in the spotlight mode.

Figure 4(a and b). The condition with the spotlight mode, in which all the trials including the second trial of the practice trials were shown in. The trials displayed in the spotlight mode had the same pattern of the original grid on the left and the blank and source grid on the right as well.

In the spotlight mode, the screen was darkened and only the cursor and its surroundings were visible. Participants had to do the task in this mode in the second practice trial and all the 40 main trials. The aim of having the trials in this mode was to be able to track the time participants spent checking the original grid during the copying task. This mode was implemented to avoid the easy accessibility of the original grid of the copying task. Without this mode, they could simply check the original grid only with their gaze and we could not be able to track how many times they needed to refresh their VWM.

After the practice trials, the main 40 trials began in two different conditions. In one condition, participants were asked to name twelve unfamiliar items one by one by answering the question "If you were to name this item, what would you call it?". This was to force them to use verbalization. All the displayed items shown in all trials were chosen randomly and differently for each participant. Afterward, we asked them to do the copying task with the same verbalized twelve unfamiliar items in 20 trials. At the beginning of the other condition of trials, participants were asked to do simple math equations twelve times, while in each one of them a randomly chosen unfamiliar item was shown to them simultaneously. Then the copying task appeared with the use of the non-verbalized set of unfamiliar items. For clarification, we refer to the condition of the set of trials in which verbalization was used as "verbalization trials", and "non-verbalization trials" as the condition of the set of trials in which verbalization was discouraged to use.

In general, 40 trials consisting of 20 trials per condition appeared. Twelve photographs of unfamiliar items were used for the stimuli practice trials, and another 24 photographs were used as stimuli across the main 40 trials. All the images of the unfamiliar items displayed in the experiment were randomly selected for each participant differently.

The experiment was designed counterbalanced in order of conditions. Half of the participants did the experiment with the verbalization condition first and the non-verbalization condition second, and the other half in the opposite order. This design ensures that effects such as learning do not interfere with the effects we are trying to find (i.e., the effect of the conditions of the trials on the participants' VWM performance).

As a sanity check, at the end of all the trials, we asked the participants whether they remembered the names they gave to the unfamiliar items or not. Among the items shown to them, were both from verbalizing condition and non-verbalizing condition to figure out if they dedicated names for unrequired items or not. These two conditions, verbalizing and not verbalizing unfamiliar items, can help us to figure out whether naming these items can help with storing external visual features in VWM easier or not. At the end of the experiment, we asked the participants to optionally indicate the strategy they used during the copying task and their comments. We will further discuss the answers in the "Discussion" section.

2.3. Data analysis

We evaluated all data analysis in the statistics program JASP. The results were divided into three measures on how we aimed to interpret them. First, we conducted the Shapiro-Wilk test of normality to determine if the data were normally distributed or not. In this test, a p-value above 0.05 indicates that the distribution is normally distributed. For those which were normally distributed we performed a parametric two-tailed paired samples t-test, and for not normally distributed data, the non-parametric equivalent test, the Wilcoxon Signed-Rank test was performed.

3. Results

The hypothesis in the current study was that use of verbalization will help the participants to perform considerably better. This hypothesis is divided into multiple hypotheses. The hypotheses were assumed because we suggested that verbalization is a useful method to use for enhancing VWM's performance. Here are the results:

3.1. The average completion time in verbalization trials and non-verbalization trials:

The results indicate that the null hypothesis of the completion time of verbalization trials (M=25.029, SD=6.705) and non-verbalization trials (M=23.180, SD=5.772) are not equal, and was rejected (t (34) =3.124). And according to the calculated p-value, which is below 0.05, the difference between the results is significant. Thus, the average completion time for the copying task in the verbalization trials was statistically slightly higher than in the non-verbalization trials (Figure 5).

Measure 1		**Measure 2**	**t**	**df**	**p**
Average completion time of copying task in verbalization trials	-	Average completion time of copying task in non-verbalization trials	3.124	34	0.004

Figure 5. Student's t-test to test the difference among the two conditions' means. If based on the level of probability (which in this test is 0.05), the calculated t-value exceeds the t-value from the t-table, we can state that the means of the findings are significantly different at that level of probability.

3.2. The average number of checks in each condition of trials:

To evaluate any discrepancies in the average number of checks participants did in verbalization trials (M=4.357, SD=1.279) and in non-verbalization trials (M=4.257, SD=1.215) of the set of trials the performed Wilcoxon Signed-Rank Test revealed a statistically insignificant difference in checking the original grid (Figure 6).

Measure 1		**Measure 2**	**W**	**z**	**p**
Avg number of checks in verbalization trials	-	Avg number of checks in non-verbalization trials	305.000	0.438	0.668

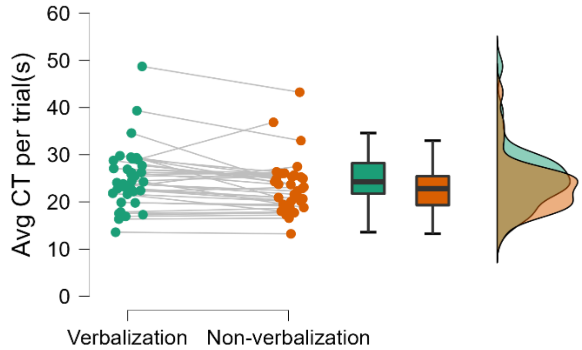
Figure 6. Wilcoxon signed-rank test to test the differences in the average number of checks in both conditions of trials. If the calculated p-value exceeds 0.05, the difference among the conditions is not significant.

3.3 The average errors made in each condition:

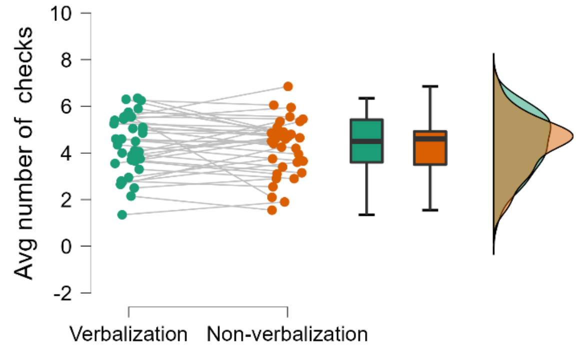
We tested the null hypothesis that the data for the average number of errors made in each condition of the set of trials (verbalization trials: M=0.531, SD=0.340, and non-verbalization trials: M=0.436, SD=0.277) were not equal by performing a paired sample t-test. The test indicated that the results of each condition did not differ significantly (t (34) =1.903) (Figure 7).

Measure 1		**Measure 2**	**t**	**df**	**p**
Avg number of errors made in verbalization trials	-	Avg number of errors made in verbalization trials	1.903	34	0.066

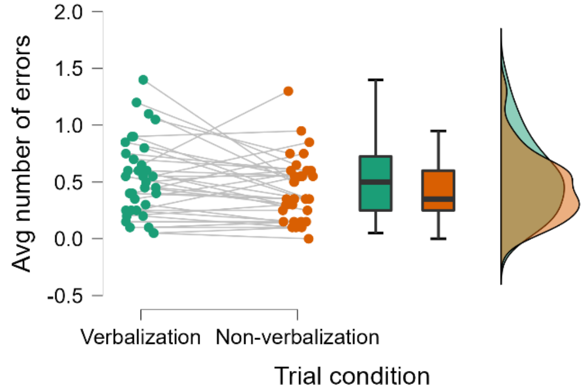
Figure 7. The calculated p-value in the Paired sample t-test is above 0.05, which indicates of an insignificant difference in the results of the performance of participants in both conditions.



A. Raincloud plot of the average completion time in both conditions of trials.



B. Raincloud plot of the average number of checks in both conditions of trials.



C. Raincloud plot of the average number of errors made in both conditions of trials.

Figure 8. Each of the raincloud plots represented above, displays the results of each measurement described in the "Results" section. The linked green and orange dots (raindrops) in plots represent the performance of each participant. The green dots display their performance in the verbalization trials, and the orange dots display their performance in the non-verbalization trials. The two box plots and their green and orange shadows display the interquartile ranges and the medians of the participants' performance in verbalization and non-verbalization trials. The raincloud graphs present the distribution of the participants' performance in green and orange that are in verbalization and non-verbalization trials. These graphs also show how the performance distribution of both conditions overlap. (A) displays all the described details for the average completion time in each trial based on seconds. (B) represents the average number of checks all participants did in both conditions. (C) represents the average number of errors participants did in both conditions.

4. Discussion

Can verbalization improve the performance of VWM? This study was designed to compare the performance of VWM in two conditions. In one condition, participants were encouraged to use verbalization and in the other, they were discouraged to use verbalization. To be clear, participants were discouraged to use verbalization in the non-verbalization trials by answering a math question while each of the twelve items was shown to them. On the contrary in the verbalization trials, they were required to verbalize each of the twelve items while they were shown to them. The results indicate that the average completion time did not differ significantly in both verbalization trials and non-verbalization trials. This means that the opportunity to use verbalization did not help participants to complete the tasks faster. In fact, some participants reacted slower in the verbalization trials compared to non-verbalization trials on average. It can be explained that increased use of VWM by using verbalization rather than using external visual information is not time-efficient in completing a copying task. These results might be consistent with the finding of Somai, et al (2020).

Interestingly, participants' answers to the question we asked them about their strategy throughout the experiment helped us to figure out an important confound in our experiment. Some of them claimed that they found the use of verbalization useful in the verbalization trials and that they started using verbalization even during the non-verbalizing trials, the trials that they were discouraged to use verbalization. We did not expect to have this potential confound and that is maybe because it was going to be accounted for by the counterbalance condition. However, a mistake that we were unaware of by the end of the data collection was that the counterbalance condition was not implemented. This might be an indicator showing that the use of verbalization helped them noticeably in their function that they decided to use it as a help in non-verbalization trials, where they did not have a prior chance to verbalize the items. This might be counted as a cofounding factor, but it can also support the idea that the use of verbalization can improve the performance of VWM, specifically doing a visual copying task.

The outcomes for our second hypothesis show that there were no differences in checking the original grid while doing the copying task in both conditions of trials. With the use of the spotlight mode, we were able to track the average number of times participants checked the original grid to refresh their VWM. Although the original goal of the spotlight mode was to give us the chance to track participants' actions for checking the original grid, this mode also encouraged them to use their VWM more and check the original grid fewer times. For the copying task in both conditions, participants checked the original grid approximately the same number of times. This indicates that the uncertainty rate was practically the same regardless of verbalization in both sets of trials. We can conclude that verbalization did not have a positive impact on their confidence in their copying behavior, therefore they needed to review the original model and reassure themselves that they are choosing the correct item for the correct position on the blank grid. This shows that the manipulations of verbalizing unfamiliar items were neutral in the performance of VWM.

The next analysis indicates no discrepancy between the average number of placing verbalized and non-verbalized items incorrectly in the blank grid. Although this number was expected to be few in both sets of trials, and especially fewer in the verbalization trials. This expectation is due to the hypothesis that verbalization helps with familiarizing an unfamiliar item, therefore helping the individual with the items' maintenance in the VWM. There is evidence that proves our findings that individuals' internal representations are difficult to remember and prone to become forgotten due to incorrect verbalization or coding (Baddeley, & Hitch, 1974). Therefore, the odds of forgetting newly familiarized items were higher and their error rate became considerably higher as well. As for uncertainty, the participants considered seeking reassurance by checking the external source of the copying task.

We designed the pre-trial questions uniquely for each condition to give the opportunity of equalizing the exposure time for all unfamiliar items before doing the copying tasks in both conditions of trials. It was assumed that with the use of pre-trial questions, the exposure times in both conditions will be similar. But surprisingly, the majority of the participants spent twice the time verbalizing the unfamiliar items prior to verbalization trials compared to answering the math questions before the non-verbalization trials on average (answering verbalization questions before verbalization trials: M=16.341, SD=9.280, answering math questions before non-verbalization trials: M=8.523, SD=3.065). Consequently, they were presented with the unfamiliar items in the verbalization trials longer than the unfamiliar items in the non-verbalization trials. These results are consistent with (Chen, Yee Eng, & Jiang, 2006) findings on the fact that familiarity does not improve VWM's performance if the items are recently familiarized. Accordingly, if a series of items are recently verbalized and familiarized, they will not be notably easier to maintain in our VWM. The results indicate that verbalizing unfamiliar items will not help with familiarizing them, and subsequently the performance of VWM will not be improved. However, based on the same literature, by training, the same newly familiarized item the performance of VWM can moderately be enhanced (Chen, Yee Eng, & Jiang, 2006).

We suggest a few minor adjustments that may lead to better findings for improving the performance of VWM in the future. Progress can be made by changing the experiment by performing it under the supervision of an experimenter in person with each participant. Using an eye-tracker will give the chance of tracking the participants' behaviors in completing the copying task better. Applying the counterbalance condition to the trials and accounting for the present study's confound may help resolve the issue of participants verbalizing in non-verbalization studies.

In conclusion, the aim of this project with the two conditions was to have the possibility of comparing participants' performance in both conditions. As for the performance of VWM in this experiment, we focused on how long it takes for them to locate the verbalized and non-verbalized items in their correct position, how many times they checked the original setting, and how many mistakes they did while completing the copying task in each trial. For now, we can state that based on our experiment and previous research done on the relevant subject, verbalization did not have any positive impact on the performance of the VWM from the measurements that we were focused on. However, we believe that this can be a starting point, even though the present experiment has limitations. The experiment has the potential to investigate this subject more profoundly. Further research to focus on implementing verbalization in VWM with different models of experiments can be considered a potential step toward improving the performance of VWM.

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