Does the capacity of visual working memory affect the degree to which information matching its content is prioritized for consciousness?

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Abstract

Studies have found that the visual working memory (VWM) plays a role in the selection of visual input, prioritizing information that matches information already present in the VWM. This study investigates the effect of VWM capacity on prioritization of information matching the content of VWM. VWM capacity was measured by a single probe recognition task. Using a b-CFS-task combined with a delayed match to sample task, prioritization for consciousness was studied using probes that matched items held actively or passively in VWM. The results of this experiment showed no significant effect of VWM capacity on prioritization for consciousness of information matching actively or passively held items in VWM. Together these results show that VWM capacity has no effect on prioritization of information matching items held in VWM.

1. Introduction

An artificial intelligence (AI) device is any device that acts towards achieving a goal by perceiving its environment and adapting itself to the environment if needed (Poole, Mackworth & Goeble, 1998). For it to be able to achieve a certain goal, the AI-device must know which information from the environment to use and which information to disregard. This is similar to human information processing: not everything that is visually sensed is also consciously experienced (Lamme, 2003). Irrelevant information is disregarded, but to be able to disregard irrelevant information, it must first be known that it is irrelevant.

1.1. Visual working memory

The concept of the visual working memory, from here on called VWM, is of importance in the selection of relevant information. To understand the role of the VWM, it is first relevant to know what this concept is. In this study, VWM refers to visually obtained information that is visually held in the working memory, and this visual representation is then used in cognitive tasks (Luck & Vogel, 2013). The visual working memory plays a role in the selection of relevant stimuli because it provides a bias towards stimuli matching content in the visual working memory (Gayet, Paffen & Van der Stigchel, 2013).

VWM capacity

The VWM capacity is the maximum amount of information that can be stored in the

VWM. The working memory capacity differs among individuals but is generally limited to three to five meaningful items (Cowan, 2010). Different theories have been proposed as to how these items are stored in the VWM capacity. One of those is the discrete slots theory (Cowan, 2010; Luck & Vogel, 1997), which assumes that only a limited number of items can be stored in the VWM. Once the maximum capacity has been reached, no other items can be stored. Another theory is the resource-based theory. This theory assumes that the VWM capacity is flexible and does not have a hard limit. Items can be stored in the VWM capacity, but as the set size increases the precision of these items decreases (Luck & Vogel, 2013).

Multiple studies on the discrete slots theory have shown that that precision on tasks that utilize the VWM capacity increases as the set size decreases below the capacity limit. This suggests that having a higher VWM capacity would result in higher precision in tasks that utilize the VWM, because the capacity limit is higher (Anderson, Vogel & Awh, 2011; Zhang & Luck, 2011).

In this study, the VWM capacity has been measured by a single probe recognition task and the discrete slots theory has been adhered to.

Information prioritization

Knowing that the VWM has a limit, it is interesting to know how it is decided what information will be stored in the VWM. Only the most relevant information should be allowed into storage (Myers, Stokes & Nobre, 2017). But how is this decided? The VWM creates an attentional bias towards information that matches information that is already in the VWM (Gayet, Paffen & Van der Stigchel, 2013). For example, when looking for a banana in a fruit basket, you will have an attentional bias towards the color yellow. Attention is guided top-down through the activation in memory of object representations or templates associated with the target stimulus (Soto, Heinke, Humphreys & Blanco, 2005). Without information prioritization, it would take much longer to find the banana in the fruit basket, because every object in the fruit basket would have to be compared individually to the object properties of the banana before being able to determine if it is or is not the object you are looking for. This is an example of why information prioritization is of importance when processing information from the environment.

When looking for something, the availability of working memory for actively maintaining stimulus-processing properties is crucial for directing attention to relevant rather than irrelevant stimuli (Fockert, Rees, Frith & Lavie, 2001). This suggests that if the VWM capacity has been reached, it is easier to get distracted by irrelevant stimuli. So, it is expected that a higher VWM capacity, leads to higher precision in tasks where stimulus properties have to be remembered. Thus, information prioritization in an individual with a higher VWM capacity is expected to be more precise than information prioritization in an individual with a lower VWM capacity.

1.2. Aim of this study

Research has shown that there exists an attentional bias towards information in active working memory, creating information prioritization (Gayet, Paffen & Van der Stigchel, 2013). The current study was performed to find out if the VWM capacity has an influence on the information prioritization by the VWM. The leading research question for this study is: “Does the capacity of visual working memory affect the degree to which information matching its content is prioritized for consciousness?”. Based on the studies and theories mentioned before, the hypothesis is as follows: “Higher VWM capacity results in higher precision in prioritizing relevant information.”.

Information prioritization is an important subject in the field of AI. An example would be search engines, like Google. They process incoming information in a similar manner as the VWM does. You type your search into the search bar and Google matches it to websites containing one or more of the keywords you entered. Prioritizing the website with the most keywords that match your search. Not everyone uses just keywords when using a search engine, it is also possible to type a whole sentence like “Hello, I would like a recipe for pancakes, please.”. In this search, not only keywords are used. If just “I” would be used by Google as a keyword to match websites to, you would not be getting a pancake recipe anytime soon. The VWM and search engines both select relevant information from the information that is accessible to them and disregard information that is not important in that situation.

Once it is known how information is prioritized in humans, this information could be used to optimize AI-devices. Even though Google has developed algorithms that still give you the correct information when you type in a whole sentence with irrelevant keywords, the VWM capacity of the typical college student is 3 to 4 items (Vogel & Luck, 2013), that is probably a lot less than the amount of memory a search engine like Google uses for its searches. This is just one example of how knowledge on information prioritization could be used in an AI setting. AI research is a growing field of interest, understanding how information prioritization works in humans will be a stepping stone to creating more optimal AI-devices.

A breaking continuous flash suppression (b-CFS) task was used to delay the time it takes for the stimuli to reach consciousness combined with a delayed match to sample task. The time it takes for the stimulus to reach consciousness can be used as a measure of prioritization for conscious access (Gayet, Paffen & Van der Stigchel, 2013). The delayed match to sample task was used for either passively storing the stimulus or actively using the stimulus. Following this task, a single probe recognition task was used to determine the visual working memory capacity of the participant.

1.3. Active and passive VWM

In this study, an experiment is used where the stimulus was either actively or passively held in the VWM. Acquiring visual information typically happens during short periods of fixation, with a duration of about 200 to 500 ms (Luck & Vogel, 2013). In the active working memory, this information is used to select relevant information. It does this by creating an attentional bias towards matching information that is already in the active working memory (Gayet, Paffen & Van der Stigchel, 2013).

Remember learning about something interesting and suddenly it seemed like the topic of interest was everywhere? That was the attentional bias making you notice it. In this study, use of the active working memory was called upon by making the participant consciously recall the earlier shown stimulus.

Information that is observed, but not directly used, is stored in passive working memory (Olivers, Peters, Houtkamp & Roelfsema, 2011). The best way to understand passive working memory, is through an example. Say, you are looking at a sunset while on the beach. You are not actively trying to memorize the scene, you are just looking at the sunset. This information gets stored in the passive working memory, because you are not actively using the information.

In this study, the passive working memory was called upon by making the participant actively recall one earlier seen stimuli, but making the participant do the task with the other earlier seen stimuli they are not recalling and thus not consciously accessing.

Unsworth and Engle (2007) have shown that individuals with lower VWM capacity are poorer at maintaining items in the active working memory and are poorer at using cues too guide the search process of the passive working memory. It is thus expected that participants with a lower VWM capacity will score lower on the delayed match to sample task as well as on the b-CFS-task, suggesting that they are less precise at information prioritization than individuals with higher VWM capacity.

2. Method

For testing the hypothesis, two experiments have been carried out. The first experiment was a b-CFS-task combined with a delayed match to sample task and the second experiment was a single probed recognition task.

The b-CFS-task was used to measure when a stimulus enters consciousness. Because this happens really fast, the b-CFS-task was used to slow this process down and use the participant's reaction time to calculate when the stimulus had entered consciousness (Gayet, Van der Stigchel and Paffen, 2014). The delayed match to sample task was presented prior to the b-CFS-task and was continued after the b-CFS-task, see Figure 1. The goal of the delayed match to sample task was making the participant keep the colors presented prior to the b-CFS-task either passively or actively in their working memory. All participants were presented with an active, passive and neutral condition. The neutral condition served as a control condition, as a baseline for comparing the passive and active condition (Gravetter & Wallnau, 2016). The second experiment was a task to determine the visual working memory capacity of the participant.

Prior to the study, every participant was informed about both experiments and all participants have executed the experiments in the same way (See Annex 1: Protocol).

2.1. Participants

In this study, 19 subjects participated. Out of those 19, 17 were female and 2 were male. All participants had normal or corrected to normal vision. The participants were acquaintances of the researchers and were personally asked to participate in the experiment. All participants were students in higher education, ages ranging from 19 to 27 years old.

Prior to participating, the subjects were asked if they had any eye diseases and/or epilepsy. When the answer was no, the participant was tested on colorblindness using Ishihara's color deficiency test. After that the participant's stereoscopic vision was tested.

If the subject passed these tests and had no eye diseases and/or epilepsy, they were allowed to participate in the experiment after signing an informed consent form (See Annex 2: Informed Consent Form).

2.2 Experiment 1: The influence of an actively or passively remembered color on access to consciousness

2.2.1 Stimuli and apparatus

The experiment was conducted on an Apple dual 2-GHz PowerPC G5 with a linearized 22-in. LaCie Electron Blue IV CRT monitor (1,024x 786 pixels; 100 Hz refresh rate) and an Apple computer keyboard, that was used to register the responses given by the participants. In the lab where the experiment was conducted, there were no other light sources apart from the computer screen.

The stimuli were created with the Psychophysics Toolbox 3 (Brainard, 1997; Pelli, 1997) in Matlab (Release R2010a; The Mathworks, Natick, MA). The participants saw the stimuli through a mirror stereoscope. The stimuli were presented dichoptic, which means that a different image was presented in each eye. The participant's head was held stable with a forehead rest and a chin rest. This way the distance from the eyes, through the mirrors to the monitor (57 cm), was kept unchanged. All stimuli were presented on a grey circle with a luminance of 24.5 cd/m2. The grey circle was surrounded by a black background (<1 cd/m2. ; > 96% Weber contrast), this made it possible for the different images to be presented to each eye in order to correctly fuse them into a single image.

The black and white dynamic pattern, from now on called a mask, used in the b-CFS-task was created by filtering pink (1/f) noise using a rotationally symmetric Gaussian low-pass filter ($\sigma = 3.5$) and by making the resulting gray-scale image binary with maximum contrast (>96% Michelson contrast) (Gayet, Van der Stigchel & Paffen, 2013).

All colored stimuli were circles with a diameter of 1.2° visual angle. All 15 colors (5 red, 5 blue and 5 green shades) were isoluminant. First saturated red and green were made isoluminant to the maximum intensity of saturated blue (method as described by Gayet et al., 2013). These colors will from now on be called the base colors. Afterwards, of these three base colors the xyY coordinates were measured with a colormeter. After that, 4 variations of red, green and blue were chosen, using the following method: for every base color a line was drawn through the measured xy-coordinates in the CIE-xyY colorspace. The direction component of the lines was -5, -3 and 2 for respectively the colors red, green and blue. Subsequently, on this line 5 points were chosen with a distance of -4, -2, 0, 2 and 4 to the xy-coordinates of the base colors.

2.2.2 Procedure

Pilot study

Prior to the experiment with the participants, a pilot study was conducted in which the researchers performed the experiment themselves. This was to determine if the experiment needed any adjustments. Eventually it was decided to use 108 trials for the experiment itself and 27 practice trials. Conducting the experiment on participants took place in a period of three weeks, from 21-05-2018 to 08-06-2018.

Ethical considerations

Every participant was informed that the experiment was a risk-free experiment done on a computer, where the visual working memory would be used and that it would take about an hour. The participants were also informed all data would be processed anonymously and that they could stop the experiment at any moment without having to give any reason. Lastly, the participants were asked to sign an informed consent form.

The experiment

Before starting the experiment, the participant was asked to adjust their seat to the correct height and to adjust the chin rest on the mirror stereoscope to a position in which they were comfortable and could see the screen clearly. Following that, the participants were asked to adjust the distance between the two circles on the screen by using the left and right arrow keys on the keyboard to ultimately only see the fused image of the two separate images. The participant was told to constantly look at the fixation point in the middle of the circle during the b-CFS-task and to try not to blink. Afterwards, the precise experiment was explained to the participant using Figure 1 and the participant was given the opportunity to do three sets of 9 practice trials.

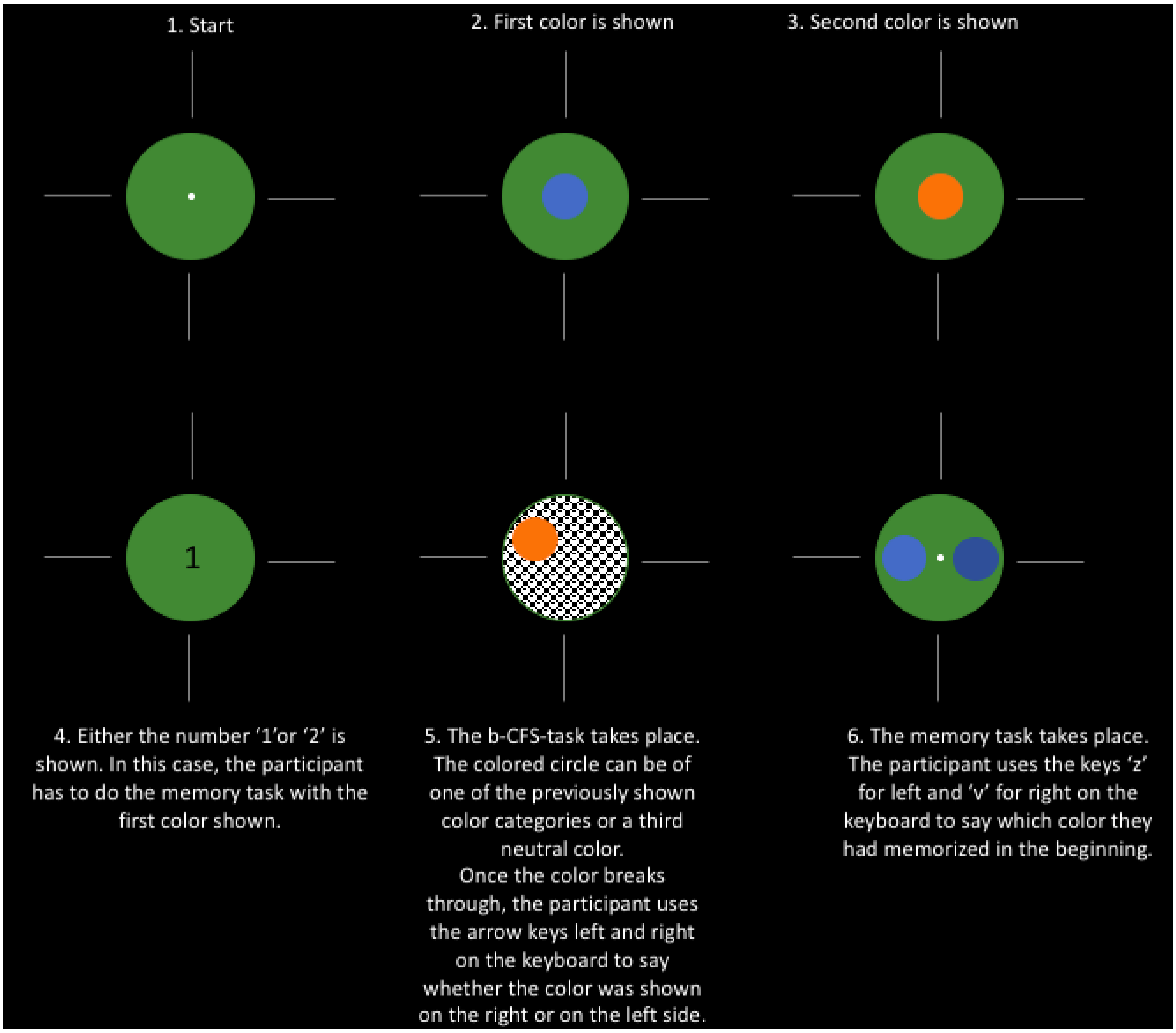

Figure 1 A representation of the instruction for Experiment. 1. An empty circle is shown with a fixation point. 2. Color 1 is shown. 3. Color 2 is shown. Colors are randomly chosen in this example. 4. The number one appears on the screen. This means the first color shown has to be remembered. 5. The b-CFS-task comes on, in this task either one of the two colors shown before or a third, neutral color is shown in a random position. The participant has to press 'z' if the color is on the left side of the fixation point and 'v' if the color is on the right side of the fixation point. 6. The second part of the delayed match to sample task follows. The participant has to press the left arrow button on the keyboard if he thinks the left color shown is the color he remembered earlier, and the right arrow button if he thinks the right color shown is the color he remembered earlier.

Consecutively, the participant completed one set of only the b-CFS-task, one set of only the delayed match to sample task, and one set of these two tasks combined. If the participant reported they had understood the task completely, the main experiment was started. In the experiment the b-CFS-task and the delayed match to sample task were combined into a single task, where a response was asked twice.

The experiment was conducted in 4 blocks, after every block the participant could see the percentage of correct answers they had given on the delayed match to sample task. In each block, per three trials the colors in step 2 and 3 in Figure 1, were only shown once. This was in the first trial. In the second and third trial the participants were only shown a cue, either '1' or ‘2’. In the data analysis, the first trial will be referred to as the first position, the second trial as the second position and the third trial as the third position.

In the b-CFS-task, alternately a mask was presented to either the left eye or the right eye of the participant. In the other eye a circle with one of the earlier mentioned colors in one of the following positions with reference to the fixation point, was presented: upper right, directly right, lower right, upper left, directly left, lower left. It was expected of the participant to immediately press on the keyboard either ‘z’ for the left position or ‘v’ for the right position with reference to the fixation point, once the colored circle was perceived.

The independent variables in the b-CFS-task were the color hues, which side of the fixation point the colored circle was presented and to which eye the colored circle was presented. The dependent variables were the reaction times in the b-CFS-task and the amount of correct responses.

In the delayed match to sample task, right after each other, two colored circles were presented to both eyes. The participant was expected to remember the first color as ‘1’and the second color as ‘2’. Next, either ‘1’ or ‘2’ was shown on the screen, this meant the participant had to use the first or the second color in the second part of the delayed match to sample task, which came after the b-CFS-task. The second part of the task showed two colored circles next to each other to both eyes. The circles were of the same color category but differed in hue. Using the left and right arrow keys on the keyboard, the participant was expected to indicate which color hue they had to remember before the b-CFS-task.

The color presented in the b-CFS-task was either one of the colors the participant had to remember at the start of the trial or a third, neutral color. The color that was shown was not the same hue as in the delayed match to sample task, but it was of the same color category. Which color was shown, was randomized.

2.2.3 Data analysis

Not all data was used in the analysis. The data of the practice trials was disregarded and the wrong response on the b-CFS-task was also disregarded. This was done to exclude erronous responses by the participant.

Ideally the percentage of correct responses on the b-CFS-task and the delayed match to sample task is higher than 50% (because the participant could randomly choose one of the two options, left and right) and lower than 90%. Higher than 90% correct would indicate the experiment was too easy. It should cost some effort to remember the specific color. Because almost all participants scored around 50% on the experiment, the data from the second and third position of the b-CFS-task were not used in the data analysis, because the performance of the participants dropped significantly in these positions. The performance on the first position was 71,1% correct on average. On the second and third position this was respectively 43,7% and 44,3% correct on average.

In the data analysis of the reaction times of each participant, the median is used. The median is used, because this is less sensitive to outliers than the mean. Subsequently, the medians of the three conditions in the b-CFS-task (neutral, active and passive) were compared to each other.

2.3 Experiment 2: Visual working memory capacity

Ethical considerations

Every participant was informed that the experiment was a risk-free experiment done on a computer, where the visual working memory would be assessed and that it would take about fifteen minutes. The participants were also informed all data would be processed anonymously and that they could stop the experiment at any moment without having to give any reason. The consent form was signed prior to Experiment 1.

The experiment

The participant sat in a dark room, with the only source of light being the computer monitor at a distance of around 30 cm. Before the experiment started, the instructions of the experiment were shown on the screen. Once the instructions were understood by the participant, they were to press the spacebar on the computer keyboard in front of them. Then the practice trials started. The participant saw one or more white lines of around 2 cm on a black background. It was expected of the participant to remember the orientation of the white lines on the screen. A short black and white dynamic pattern followed and another black screen with white lines was shown, either identical to the first screen or with one line having a different orientation. One of the white lines on the screen was surrounded by a red square. The participant had to press the letter ‘A’ on the keyboard, covered by a red square piece of paper to say that the orientation of the line in the red square had indeed changed, or the participant had to press the letter ‘L’ on the keyboard, covered by a green square piece of paper, to say that the orientation of the line in the red square had not changed.

The participant first did 10 practice trials and after that four blocks of 20 trials. The set sizes were 3, 4, 5 and 7 items. There were 18 to 22 trials per set size, adding up to a total of 80 trials excluding the practice trials. After every block a message appeared on the screen, letting the participant know how many trials they had answered correctly. By pressing the spacebar, the participant could go on with the experiment.

During this task the orientation of the line was the independent variable and the participant's answer was the dependent variable.

3. Results

3.1 VWM capacity

The formula proposed by Cowan (Rouder, Morey, Morey & Cowan, 2011) was used to calculate the visual working memory capacity of the participants in the single probed recognition task (Wheeler & Treisman, 2002).

$$\hat{k}_c = N\left(\hat{h} - \hat{f}\right).$$

Equation 1 Formula for calculating the visual working memory capacity. N = set size, h = hits, f = false alarms. With $k \leq N$ and $h \geq f$ (Rouder et al., 2011).

Using this formula on the set sizes of 3, 4, 5 and 7 items resulted in four different VWM capacities per participant. In order to obtain a single value for the VWM capacity, some adjustments were made based on Morey's (2011) explanation of Cowan's formula. When the capacity is greater than the set size, the maximum capacity that can be obtained through this formula is equal to the set size, this is called the ceiling. For this reason, whenever the VWM capacity was equal to the set size, that value was disregarded unless it was the ceiling, which was 7 in this experiment. When the VWM capacity was smaller than the set size, these results were averaged to obtain a single value for the VWM capacity per participant.

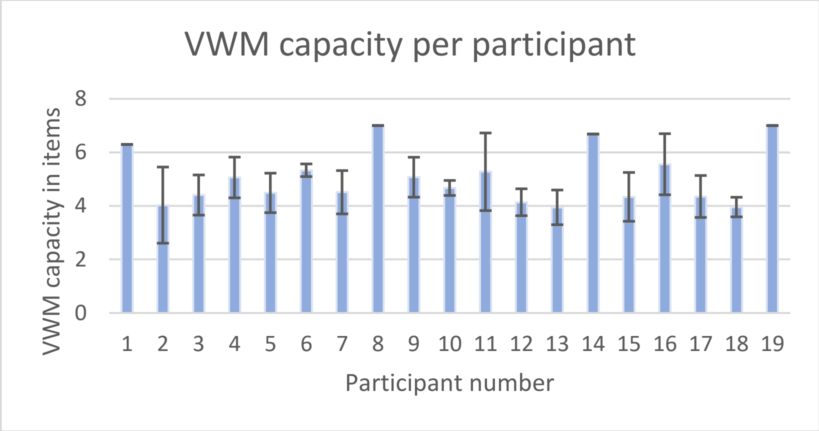

Figure 2 VWM capacity per participant. The standard deviation per data point is included.

The mean VWM capacity of the participants in this experiment is 5.06 with σ = 1.02. This does not correspond with literature, which states that the VWM capacity of the typical college student is 3 to 4 items (Vogel & Luck, 2013). Of course, individual differences and attentional differences also play a role in the VWM capacity, which could explain the difference (Adam, Mance, Fukuda, & Vogel, 2015).

3.2 Data exclusion

The reaction times for the active, passive and neutral conditions in the b-CFS task on the second and third position have been excluded from the data analysis, because of poor performance on these positions. Not excluding these positions would result in the performance on the task to be at chance level. Thus, only the results from the first position of the three conditions in the b-CFS task have been used in the data analysis. Data from the second and third position on the delayed match to sample task have also been excluded for the same reason.

3.3 Statistical analysis

To be able to determine if VWM capacity has an effect on information prioritization for active and passive visual working memory, two measures have been used from the three conditions. The first measure was the reaction time of the neutral condition minus the reaction time of the active condition and the second measure was the reaction time of the neutral condition minus the reaction time of the passive condition. Subsequently, the Pearson correlation coefficient for each measure and the significance of these coefficients has been determined, to test the strength of the linear correlation.

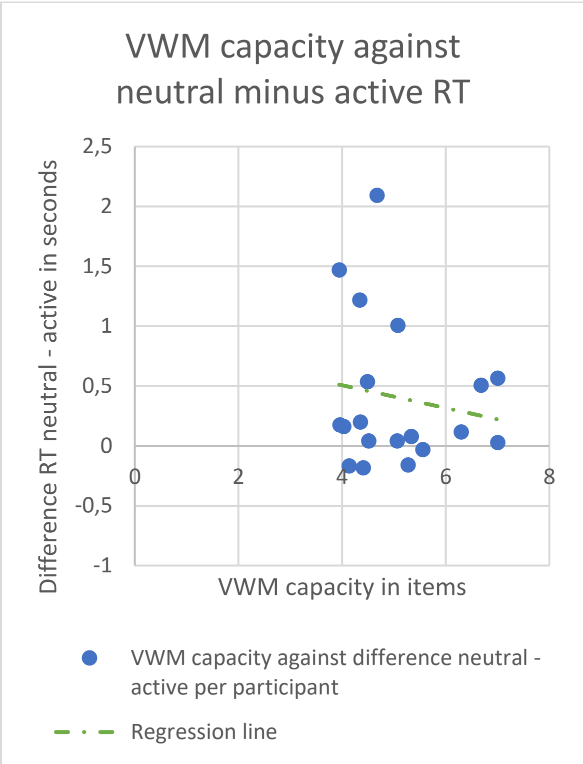

Figure 3 Graph depicting the correlation between VWM capacity and neutral minus active reaction time

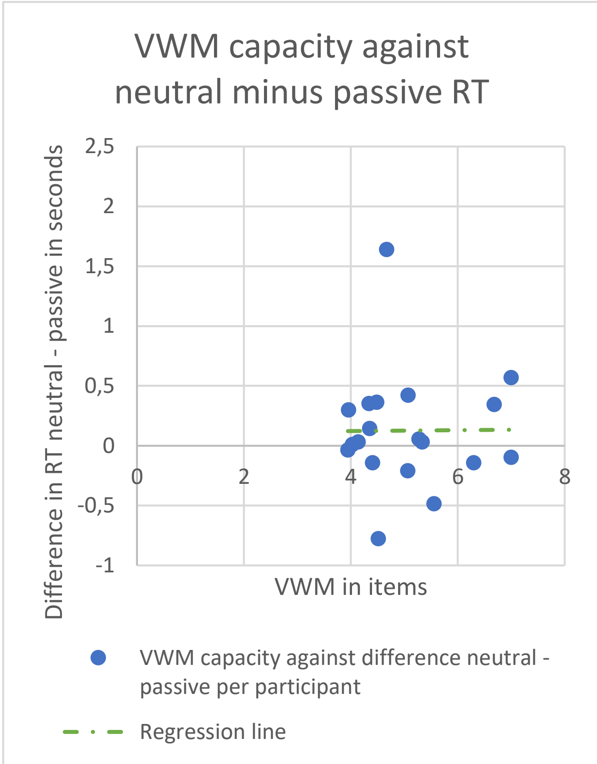

Figure 4 Graph depicting the correlation between VWM capacity and neutral minus passive reaction time

N = 19	*r*	p-value
VWM capacity against neutral minus active condition	0.18	0,45
VWM capacity against neutral minus passive condition	0.02	0,92

Table 1 Pearson correlation coefficient and p-value of the correlation coefficients per measure.

In Figure 2 and 3 the correlation between the reaction times difference and the VWM capacity can be seen. The Pearson correlation coefficient and p-value for the neutral minus active condition is $r(18) = 0.1804$ with *p-value* = 0,4599. This is far greater than the alpha value of 0.05, which makes the correlation between the visual working memory capacity and the reaction time on the b-CFS task in the active condition not significant. For the neutral minus passive condition the Pearson correlation coefficient and p-value is $r(18) = 0.0242$ with *p-value* = 0,9218. This is also far greater than the alpha value of 0.05, which makes this correlation between the VWM capacity and the reaction time on the b-CFS-task in the passive condition not significant.

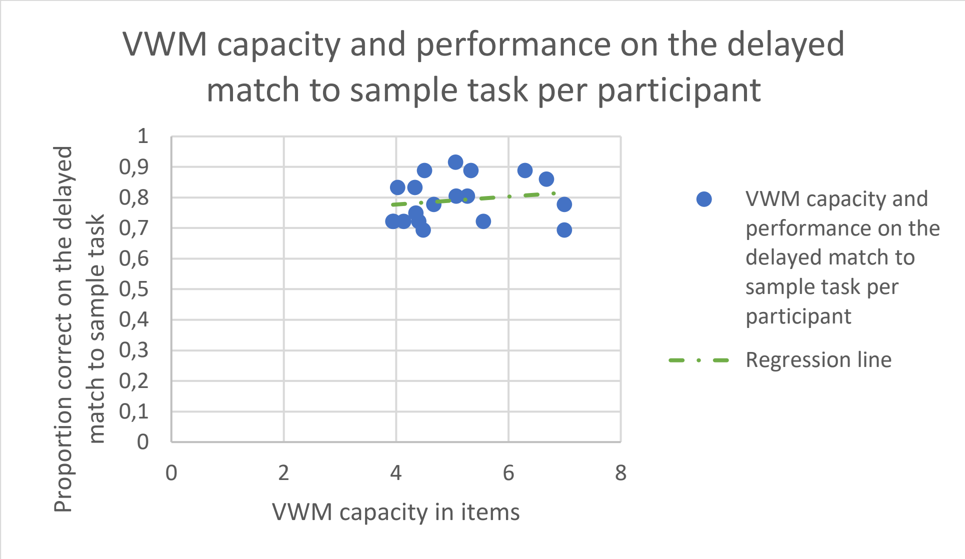

Figure 2 VWM capacity against performance on the first position of the delayed match to sample task

N = 19	*r*	p-value
VWM capacity against first position of the delayed match to sample task	0.18	0,47

Table 2 Pearson correlation coefficient and p-value of VWM capacity against the first position of the delayed match to sample task

According to the discrete slots model, it is suggested that having a higher VWM capacity would result in higher precision on tasks utilizing VWM (Anderson, Vogel & Awh, 2011; Zhang & Luck, 2011). To determine if this is the case, a correlation analysis on the results of the delayed match to sample task against the VWM capacity was performed.

In Figure 3 the correlation between the VWM capacity and the results of the first position of the delayed match to sample task can be seen. Plotting the VWM capacity against the performance on the delayed match to sample task, showed a weak and non-significant correlation. The Pearson correlation coefficient is $r(18) = 0.18$, this indicates there is a very small positive correlation. Testing the significance of this correlation gave *p-value* = 0,47. This is far greater than the alpha of 0,05 and shows that the small correlation between the VWM capacity and the performance on the delayed match to sample task is not significant.

4. Discussion

Previous research has shown that the visual system prioritizes information that matches VWM content, so that it reaches visual awareness faster than information that does not match VWM content (Gayet, Paffen & Stigchel, 2013). The aim of this study was to show what effect the VWM capacity has on prioritization of information matching items that are either held actively or passively in the VWM.

Two measures were used for answering the research question: RTs on the b-CFS-task of neutral minus active and neutral minus passive VWM conditions. The difference between the neutral and active condition and the neutral and passive condition have been chosen to find out if there is a correlation between the active condition and the VWM capacity and between the passive condition and the VWM capacity.

To see if the VWM capacity has any effect on the active or passive VWM, the Pearson correlation coefficient was calculated for both measures. The neutral minus active condition shows a small correlation, but it is not significant. From these results it can be said that the VWM capacity has no effect on the active working memory. The Pearson correlation coefficient for the neutral minus passive condition showed a small correlation, but this was also not significant. So, from these results it is safe to say that the VWM capacity has no effect on the active and passive items held in the visual working memory. Thus, the VWM capacity has no influence on information prioritization through the active and passive working memory.

These results do not correspond with the results of previous studies and theories, which suggested that a higher VWM capacity would lead to higher precision in information prioritization (Anderson, Vogel & Awh, 2011; Zhang & Luck, 2011; Fockert, Rees, Frith & Lavie, 2001). This does also not correspond to the findings of Unsworth and Engle (2007), who found that individuals with a lower VWM capacity are not as good at maintaining information in the active working memory and recalling information from the passive working memory.

The delayed match to sample task used five different hues per color (red, green and blue). By doing this, the participant had to memorize the stimulus visually and not for example, verbally. This way the participant would have to primarily use the VWM.

The results of the delayed match to sample task were plotted against the VWM capacity. The expectation was that participants with a higher VWM capacity would perform better on this task than participants with lower VWM capacity. This study showed no such thing. This does not correspond with other studies that have shown that higher VWM capacity results in higher precision on tasks utilizing the VWM (Anderson, Vogel & Awh, 2011; Zhang & Luck, 2011).

The reason for there not being any significant correlation between the VWM capacity and the performance on this task, could be that the VWM capacity had not been fully used. According to the discrete slots model, once the VWM capacity has been reached, no new information can be added (Cowan, 2010; Luck & Vogel, 1997). The lowest measured VWM capacity in the participants was 3,96 items. In the task, the participant had to remember two items at a time. This is below the lowest measured capacity and could serve as an explanation. Several studies have shown that distractors that could not be ignored in situations with few relevant stimuli, could successfully be ignored in situations when many relevant stimuli were shown (Fockert, Rees, Frith & Lavie, 2001). This further supports the explanation of the VWM capacity not being reached and thus showing no correlation.

The results of this study have shown no significant effect on the influence of the VWM capacity on information prioritization, which could have many reasons. A reason could be that the VWM capacity indeed has no effect on information prioritization, but it is also possible that the experiment was not optimal for answering the research question. When taking a critical look at the study, some discussion points can be brought up.

First of all, a point of concern is the b-CFS experiment itself. A lot of data had to be excluded, because the participants performed poorly on those trials, below or at chance level. Perhaps the experiment was too difficult, or maybe it was not understood as well as desired. It should also be taken into consideration that the duration of the b-CFS experiment was around 30 minutes and the experiment consisted of 27 practice trials and another 108 trials divided over four blocks. It was a rather monotonous experiment and could have caused attentional drift, influencing the participant's performance on the task.

Second, after the experiment many participants mentioned that during some trials no color would break through the b-CFS task. While the colors were chosen carefully in the CIE-xyY color space, the green color was reportedly hard to detect. Randomly taking four samples from the data from the first experiment and comparing the average reaction time of the b-CFS-task when the color green was presented with the average reaction time of the participant overall, gave a significant difference ($p = 0{,}01$ with alpha 0,05). Also taking a look at how many times a wrong key was pressed or no key at all was pressed, on average 62,5% of the time it happened when the color green was shown during the b-CFS-task.

To be able to correctly give an answer to if the VWM capacity has an effect on the active and/or passive working memory, the limitations mentioned above should be taken into consideration. For now, it can be said that the working memory capacity has no effect on information prioritization by the active and passive working memory.

Further research into information prioritization and working memory capacity should take into account the individual differences in VWM capacity between participants. It is important that the VWM capacity is reached to be able to draw a conclusion in this type of research.

Annex 1: Protocol

Instruction

Check-list

Leeftijd	____ jaar
Geslacht	Vrouw X Man X
Links/rechtshandig	Rechts X Links X
Epilepsie	Ja X Nee X
Oogziektes	Ja X Welke _____ Nee X
Kleurenblind	Ja X Nee X
Stereo zicht	Ja X Nee X

Criteria voor uitsluiting van het experiment:
Participant kan niet meedoen aan het experiment als hij/zij een van de volgende dingen heeft:

- Epilepsie
- Oog ziektes (glaucoma, amblyopia, nystagmus)
- Kleurenblindheid
- Geen stereo zicht
- Instructies experiment niet begrijpt.

Protocol

- Bedank de participant.
- Vertel dat het een experiment is op de computer waarbij je visuele werkgeheugen wordt gebruikt.
- Vertel dat het experiment ongeveer een uur duurt, dat het risicovrij is en dat data anoniem zal worden verwerkt.
- Laat participant informed consent formulier ondertekenen.
- Vul de rest van de check-list in (geslacht, leeftijd, links/rechtshandig)

- Kleurenblindheid test
- Stereozicht test: boekje doorbladeren tot en met blz. V
- Als de testen zijn gelukt open het programma in Matlab. Startexp. In het editor scherm slepen en run het programma.
- Participant nummer invoeren. Begin bij 01.
- Zet proefpersoon op stoel en stel de hoogte in. Draai (alleen) de kinsteun omhoog of omlaag indien nodig.
- Laat de proefpersoon zelf de oogafstand instellen op een manier waardoor de twee rondjes samenvallen tot één beeld.
- Proefpersoon mag zijn/haar ogen niet bewegen gedurende de proef en moet naar het fixatiekruis blijven kijken.
- Vertel dat proefpersoon zo min mogelijk met de ogen dient te knipperen gedurende de trials.
- Geef uitleg van de oefentrials en het experiment zelf.
- Vertel dat het niet erg is als de proefpersoon fouten maakt. Het is de bedoeling dat de proef moeilijk is.

Annex 2: Informed consent form

Universiteit Utrecht

Informed consent form

Title of project: VWM capacity and active and passive working memory
Investigator: Madina Habib

I hereby declare that I have been informed by the investigator about the goal of the experiment, its duration and its procedures.
I am aware of the fact that the experiment involves a simple non-invasive computer-task, where responses are given via keypresses. No negative consequences are expected.
My participation in the experiment is voluntary, and I am aware of the fact that I can quit the experiment at any time, without the need to motivate the decision to quit. My withdrawal from the experiment will have no consequences.
I grant permission to use my data for scientific publication and presentation, after they have been made anonymous.
I have been informed about the compensation I receive for participating. I will also receive a copy of this form.

Name: Date:

Signature: Place:

Questions regarding the experiment can be directed at:
Name: Madina Habib
Email: m.habib@students.uu.nl

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