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„Can People Drop Objects from Their Working Memory“

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Introduction

The Objective of the Study

Memory is one of the most important cognitive capabilities of humans and therefore it has been studied a lot by scientists. Many theories were developed on what types of memory we have and how they work.

Working memory (WM) is a memory system that is related to many cognitive functions such as consciousness, attention, reasoning and memory [4], [5], [6], [7], [8], [9], [10]. One of the most influential scientists who work on WM, Baddeley, claims that WM is the core of the consciousness mechanism. [4] Mechanisms of WM and how they function have been the focus of researchers from different disciplines for a long time [4], [11], [12].

The Interdisciplinarity of the Study

This thesis investigates the functioning of one of the subcomponents of WM; Visual working memory (Visual WM) from an interdisciplinary point of view. While trying to tackle the question whether people can forget (drop) objects that they took into their Visual WM by command from a cognitive psychology point of view, it gets help from neuroscientific methods. Therefore, it is a cognitive neuroscience study.

Cognitive neuroscience is a field where the link of functions of a brain to cognitive functions of a mind is researched. George Miller and Michael Gazzaniga established the name cognitive neuroscience at the end of 1970's. It is closely related to the fields such as cognitive science, cognitive psychology, neuroscience and neuropsychology. Theories of how cognition works – theories of cognitive science, cognitive psychology, computational models of the mind- were researched to get support from workings of the brain to those theories. Methods such as Electroencephalography (EEG), Event Related Potentials (ERP), functional Magnetic Resonance Imaging (fMRI), Transcranial Magnetic Stimulation (TMS), Electromyography (EMG), Magnetoencephalography (MEG) Positron

Emission Tomography (PET) and single cell recordings on animals are used for studies in this field. [13]

EEG measures the electrical signals that are produced by brain over the scalp. Measurement of EEG signal in relation to a response to a certain given activity is used in cognitive neuroscience. In this approach, EEG signals are taken for a series of trials for onset of a stimulus or a response and averaged over. This leads to a trace for the brain activity related to the cognitive function, an evoked response called Event-Related Potential (ERP). Averaging out the EEG signal over trials helps deriving the signal that is related to the investigated cognitive activity. [13]

The current master thesis is an ERP study. As a cognitive neuroscience project, to get a clearer understanding of the workings of Visual WM, ERP's of the subjects are recorded and a neurophysiological component that accompanies Visual WM is analyzed in relation to a model of WM.

To explain the research question and how it will be addressed with the help of the experiment more clearly, basic concepts and earlier studies should be explained.

To this end, Baddeley and Hitch's[4] multicomponent model of working memory, its subcomponents and the neurophysiological activity that accompanies Visual WM; contralateral delay activity (CDA) will be defined; and studies on Visual WM will be described. Afterwards, the procedure and methods of the experiment that was conducted to address my research question will be explained, the data will be analyzed and evaluated and future research will be briefly discuss

Basic Concepts

Working memory (WM) is defined as the workspace that temporarily stores and manipulates information for tasks such as Visual search, Visual selection, reasoning, decision-making, etc. [4], [5], [6], [7], [8], [9]. There are several theories on how working memory functions, but the most influential one is Baddeley and Hitch's multi-component model of working memory [14].

The concept of WM has evolved from an earlier concept; short-term memory (STM). STM is a passive information storage that stores information for a short period of time before it either decays or is moved to long-term memory (LTM). Working memory, on the other hand, is a multicomponent system that is more than a simple storage. [7]

According to Baddeley and Hitch model, in contrast to STM WM is an active system of storage and manipulation of information memory [14]. WM is argued to be of limited capacity and composed of four components: the central executive, episodic buffer, the visio-spatial sketchpad, and the phonological loop [7], [14].

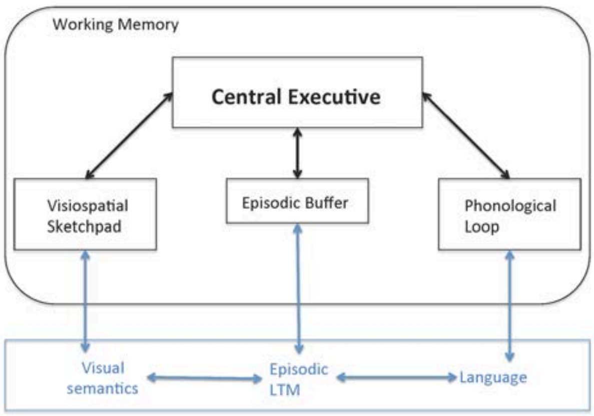

Figure 1. Baddeley's multicomponent model of working memory and its interaction with crystallized cognitive systems (This figure is adapted from [7], [14])

Central Executive (CE) CE is the least understood and studied component of working memory [14]. It is the general processing tool that controls the limited source of attention that is directed to other subcomponents. Although its role is not clearly defined yet, some functions of CE were clarified by more recent research. These functions are focusing attention, dividing attention between two simultaneous stimuli, switching between tasks. However, it should be kept in mind that CE is still not studied thoroughly and its function will be described in more detail with future work on the component. [7], [14]

Another function that was assigned to CE was the role of being a bridge between LTM and WM. However, CE was argued to be an attentional system that manipulates information without any storage [7]. The studies showed the need of another component that acts as a buffer between the two systems. The episodic buffer was added as a component to the model as a result of this need [7].

Episodic Buffer Episodic Buffer a the limited capacity component, which stores information that is integrated from other systems such as subcomponents of WM, perception and LTM [7], [14]. This information is in the form of complex structures like episodes; hence it being episodic [7]. By storing the integrated information that comes from different systems, it acts as a buffer between those systems, linking them together [7]. Episodic buffer has a limited capacity; and as mentioned before, it acts as an interface between WM and LTM [7].

Phonological Loop Phonological loop has two components; the phonological store and the articulatory rehearsal process. Phonological store holds information that is phonological in nature. The information in the store decays in a few seconds. It has limited capacity; it can hold five to eight items at a time. However, the capacity of the component is also dependent on the feature of the information to be maintained. [14]

The articulatory rehearsal process, on the other hand, is like a subvocal speech. It turns information from other modalities such as Visual information to phonological information to be stored in the phonological loop. Another function of this component is to retrieve the information from the phonological store and rearticulate it so that it is refreshed and resists the aforementioned decay. [14]

As it is said before, the capacity of phonological loop is affected by features of the information to be stored. The phonological similarity or the dissimilarity of the letters or the word in the WM affects our ability to remember them. Phonologically dissimilar letter and word sequences are more easily remembered than phonologically similar ones. While the phonological features of the items affect WM capacity, the meaning of items has no effect on it. However, for verbal LTM, meanings of the words have more effect on memory than their phonological characteristics. [14]

The irrelevant sounds that are heard before or after hearing the list of words to be remembered have negative effect on the capacity of the phonological loop. In addition, the length of the word to be remembered affects the capability to remember them. The suppression of articulatory rehearsal process has some effects on the functioning of phonological loop. [14]

Visio-spatial Sketchpad The last component of WM is the visio-spatial sketchpad. This component is used to store Visual and spatial information in our WM. The component consists of separate Visual and spatial subcomponents of which performance is not affected by one another. The studies showed that a Visual interference task has an effect on Visual subcomponent of WM while not affecting spatial subcomponent; whereas spatial interference task does the opposite. The studies furthermore showed that the rehearsal mechanisms for Visual and spatial WM subcomponents are also distinct. [7], [14]

The studies mentioned point in the direction that visuospatial sketchpad is not a unified, single system. It is rather two distinct spatial and Visual subsystems with their own storage and manipulation processes. [14]

The focus of this thesis will be the Visual subsystem of WM. Visual working memory (Visual WM) is a subcomponent of WM that temporarily stores information from the Visual environment. It can be defined as "a limited capacity system which maintains information about objects in the immediate Visual environment"[15]. It has severely limited capacity, which is predicted to be 3-4 simple objects on average for a human being. However, capacity varies among people from 1.5 objects to 5 objects. [15], [1], [2] Studies also show that this number decreases when objects become more complex. Combining these results with the results of other studies showing integrated features of objects can be remembered, it can be concluded that people remember a certain number of distinct features of the objects rather than objects in toto. [14]

Memory has been studied by dividing it into three mechanisms: encoding, storage (maintenance) and retrieval. Encoding is the process where the sensory input from the environment is taken from external world and translated into mental representations to be stored in our Visual WM. It is studied by changing information or how it is taken into memory during learning period. [16], [17]

Maintenance process is the process of maintenance of information in memory for a period of time. This stage is when we do not get the Visual input from external world but the information is kept in our memory. This period is studied by researching if and when the information is forgotten. [16], [17]

The last mechanism reflects the retrieval of the information stored in our memory to make use of it. This is the process where the information that is stored in memory is reactivated to be used. There are two principal methods how retrieval is studied. They are information recall and recognition. [16], [17]

These processes happen in sequence; and considering the nature of Visual WM, they follow each other in a short period of time. Hence it is very hard to separate them from each other, as despite being distinct stages they are seamlesly linked together. One possibility to study these mechanisms separately, is by identifying neurophysiological correlates that accompany these distinct stages of memory. [16], [17]

Visual WM has been studied in terms of its neural correlates that reveal more information on the workings of its mechanisms and its capacity. Studies varied from single cell studies that were conducted on non-human primates to non-invasive neuro-imaging studies such as fMRI and EEG on humans.

Single cell studies on non-human primates showed that prefrontal cortex, posterior parietal cortex and inferior temporal cortex were involved in VM processes. Delay activity was observed in line with those processes. Lateral intraparietal area (LIP) activity was connected to the locations of items to be remembered whereas cells in inferior temporal cortex were involved with identity of items. [15]

Prefrontal cortex seemed to be equally activated for location or identity but they were more sensitive to complex features of objects such as learned associations, maintenance of abstract rules. [15]

This led scientists to focus their search for neural correlates of WM processes in human beings to the mentioned areas.

fMRI studies in humans showed that the posterior parietal cortex activity is related to location of items while activity in inferior temporal cortex seemed to be involved in Visual WM processes that are related to identity and feature of objects. On the other hand, activity in intraparietal sulcus (IPS) is shown to be closely connected with WM load and seems to reach a limit when WM capacity reaches its limits. [15]

Contralateral Delay Activity

ERP studies revealed some more information on brain activity related to WM. Similar to single cell studies and fMRI studies, ERP studies also revealed a neural correlate candidate for Visual WM that is related to WM load. This activity, which will be used as a tool to understand Visual WM better in this thesis, Contralateral Delay Activity (CDA), will be explained in detail.

Vogel and Machizawa [2] measured a negative voltage over contralateral hemisphere to the memorized hemi-field in a lateralized Visual WM test. This voltage occurred approximately 200ms after the onset of target objects and stayed until the end of memory retention period. This activity was recorded over posterior parietal and lateral occipital scalp areas. To make sure that the nonspecific bilateral brain activity was gotten rid of and to focus only on the contralateral delay activity, the ipsilateral activity was subtracted from the contralateral activity. [15], [2]

CDA strongly resembles the delay activity that was recorded at prefrontal cortex, posterior parietal cortex and inferior temporal cortex of non-human primates. Its magnitude is in line with the number of objects to be remembered; meaning, CDA amplitude increased with the number of objects that were kept in WM and it reached an asymptotic limit at around the same time when person's WM capacity limit is reached. The activity is similar for different types of simple objects and the amplitude is lower when people were incorrect with their responses. [2], [15], [3]

CDA was also named as sustained posterior contralateral negativity (SPCN) in some studies. [18], [19] SPCN was reported as a distinct negative activity that occurs 300ms after the target onset that is contralateral to the memorized hemifield. It is distinguished from another negative activity that occurs between 180ms and 280ms after target onset (N2pc - N2, posterior contralateral), which is claimed to be related to visio-spatial attention. [18]

The N2pc is seen at the posterior electrodes sites contralateral to the attended Visual field. A higher negativity at the contralateral side than the ipsilateral side was measured between about 180 and 280ms post-stimulus onset. This activity is not related to memory load and increases when the visio-spatial attention of the person increases. [18]

Studies showed that SPCN is a distinct activity that occurs around 300ms after target onset and persists through the retention period. SPCN, like CDA, increases in amplitude in line with memory load increase. Jolicoeur et al. (2008) claimed that SPCN and CDA are the same neurological component. [18]

CDA is studied in detail by some experiments from different aspects in order to understand the nature of the activity, its relationship to Visual WM and what it reflects. This thesis will also investigate the nature of Visual WM in relation to CDA component. In order to understand the question of this thesis, earlier studies should be explained in more detail.

Earlier Studies on CDA

Vogel and Machizawa [2] reported a negativity that seems to go in line with Visual WM load. They designed a series of experiments to investigate the nature of the relationship between CDA component and Visual WM.

CDA can be measured when people pay attention to one side of their whole Visual field. Thus, in all CDA studies participants are instructed to look in the middle of the screen but pay attention to one side of their Visual field without averting their gaze towards the instructed side.

In the first experiment, they presented people with four squares in different colors at each hemifield. Target stimulus was presented for 100ms. After 900ms delay period, participants were tested with a final screen for which they had to answer whether there is a change in the colors of the squares for the indicated memorized objects. Their ERP's are measured and CDA was observed 200ms after target onset through retention period. [2]

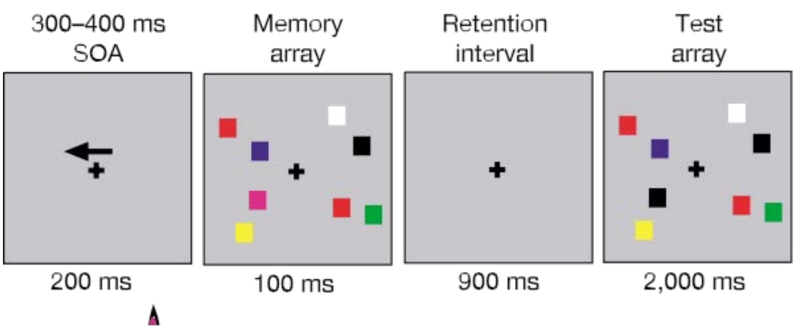

Figure 2. The design of the first experiment of Vogel and Machizawa (2004) (This figure is taken from [2])

To understand if CDA acts in line with WM load, they presented people with different number of objects in different trials and measured their CDA amplitudes for each condition. They observed that CDA amplitude increased as the WM load increased. As people reached their working memory capacity around three objects, they also had the chance to measure CDA for correct and incorrect trials and reported that CDA amplitude is considerably higher for correct trials than incorrect trials. [2]

As it was established that human WM capacity is 3-4 objects in average, CDA amplitude would be expected to come to a limit when the capacity is reached if it reflected WM capacity. Hence, in the third experiment, they measured CDA for two, four and six objects. CDA amplitude increased from two objects condition to four objects condition but stayed at the same level from four to six objects condition. [2]

To be sure of this finding, they applied a WM test for two, four, eight and ten objects conditions. The results led them to the same conclusion that CDA reflects Visual WM load, as CDA amplitude increased from two to four objects condition but not for either four to eight or eight to ten objects conditions. [2]

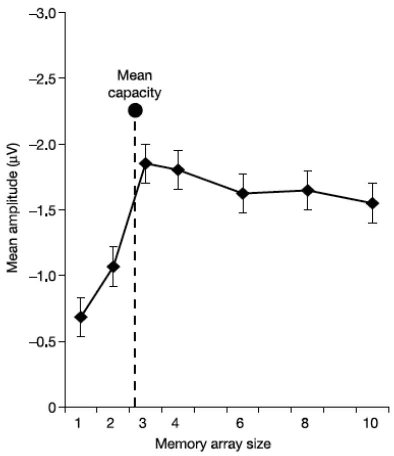

Figure 3. Graph for mean amplitude and Visual memory capacity across experiments two, three and four of Vogel and Machizawa (2004) (This figure is taken from [2])

In a later study, McCollough et al. (2007) further investigated whether the CDA amplitude is related to the number of objects in Visual WM or it is related to the "attentional spotlight" with another set of experiments. [15]

In the first experiment, they designed an experiment that is similar to Vogel and Machizawa's first experiment and tested people for a change detection task for four squares in different colors. They also observed CDA in people accompanying their Visual WM load. [15]

To understand if this component is only sensitive to colors of objects, they tested people for orientations of objects in a change detection task where they presented people with four black rectangles with different orientations. The CDA measurement revealed that CDA also occurs for Visual WM orientation task. [15]

In their third experiment, they replicated the Vogel and Machizawa's (2004) third experiment and presented people with two, four and six objects in different trials. They obtained the same results the earlier study did. They also found a CDA amplitude difference between two and four objects conditions but none between four and six objects. [15]

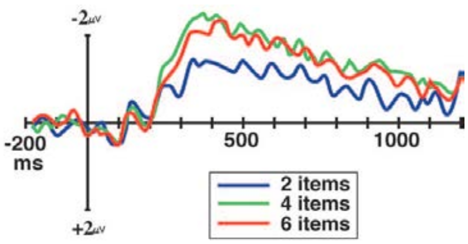

Figure 4. CDA amplitudes (ipsilateral negativity is subtracted from contralateral negativity) for 2, 4 and 6 object conditions (This figure is taken from [15])

The fourth experiment investigated the objection that CDA may be sensitive to the size of the Visual field instead of the number of objects kept in Visual WM. To achieve that goal, they presented their participants with four objects in a smaller or a bigger area while instructing them to remember either two or four objects in each trial. The CDA amplitude measurements showed a difference for two or four objects conditions but no difference for "compact" or "spaced" area conditions. With this result, they eliminated the possibility that CDA reflects "attentional spotlight". [15]

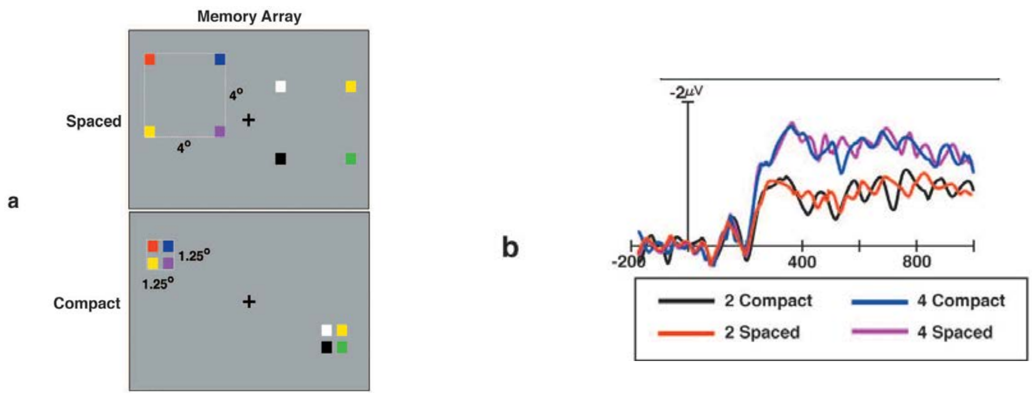

Figure 5. a) Memory arrays in wide and narrow field conditions b) Difference waves for the four conditions of Experiment 4 plotted for an averaged posterior electrode site. (taken from [15])

To strengthen the argument that CDA is a neurophysiological component of Visual WM load, Ikkai et al. (2010) tried to eliminate further possibilities regarding what CDA indexes. In this line, they designed a study that investigates CDA's relationship to possible cognitive tasks. In their first experiment they examined whether CDA reflects task difficulty instead of Visual WM load. In this experiment, they showed people objects in low and high contrast conditions while presenting people with different number of objects. They expected that low contrast condition would be a harder task than the high contrast condition. There was no difference between CDA amplitudes of people for low and high contrast condition while its amplitude increased with WM load increase. This result led them to conclude that CDA amplitude does not index task difficulty. [1]

In the second experiment, they searched if CDA amplitude is sensitive to number of locations remembered, rather than the number of items. They presented half of the objects in a first array and the other half of the objects sequentially either at the same location or at a different location with a 500ms interval. They kept the number of objects as two and four objects. [1]

Hence, they presented four objects but four or two locations in a four objects condition and two objects and two or one location in two objects condition. The CDA amplitudes showed no difference between same and different location conditions, and led to the result that CDA is sensitive to object identity rather than location. [1]

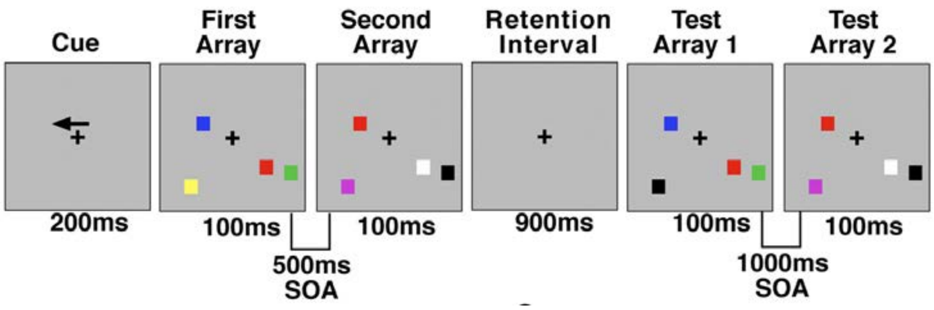

Figure 6. Experiment design for 2nd experiment of Ikkai et al for same location condition for load 4 (This figure is taken from [1])

In a related study, Vogel et al. (2005) studied whether people can filter unrelated information from their Visual WM. They also investigated whether the difference in people's Visual WM capacity affected their ability to filter information. To this aim, they tested people in a general working memory task and divided them into two groups as low-capacity and high-capacity groups and they conducted three experiments with these groups. They also measured CDA amplitudes of their participants to understand the nature of this ability in more detail. [3]

In the first experiment participants were instructed to keep the orientations of the red rectangles in mind. Participants were shown three conditions afterwards: two red rectangles, four red rectangles and two red rectangles (as targets) and two blue rectangles (as distractors).

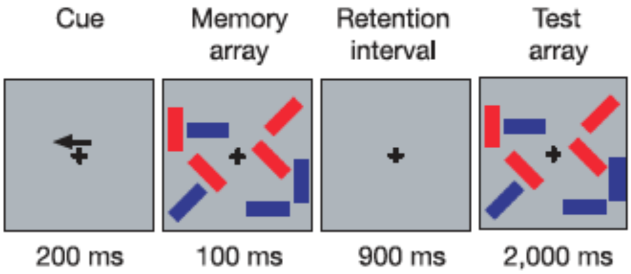

Figure 7. Two target- two distractor condition for 1st experiment of Vogel et al. (2005) (This figure is taken from [3])

They hypothesized that if people can filter the information from their Visual WM, the amplitude of their CDA would be similar to the two objects condition; and if they cannot filter information, then their CDA amplitude would be closer to four objects condition. The CDA analysis, coupled with behavioral analysis, pointed to the possibility that people with low Visual WM capacity were bad at filtering information from their WM while high-capacity group was effective in filtering unnecessary information from WM. The mean CDA amplitude of low capacity group in two target – two distractor condition was the closer to four object condition than the two object condition. However, for high capacity group the mean CDA amplitude in two target – two distractor condition was more similar to two object condition.

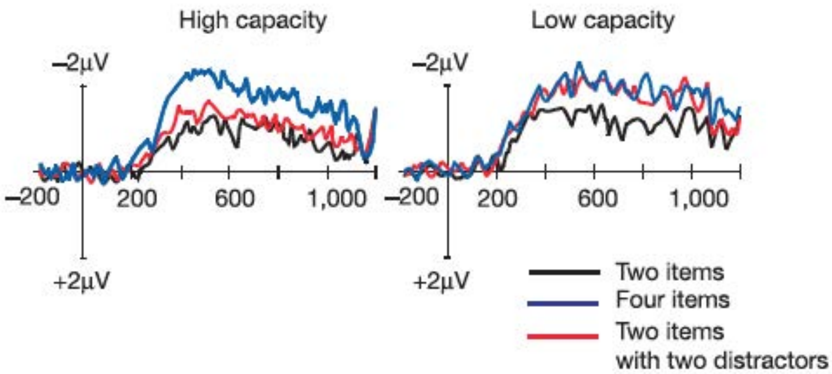

Figure 8. Mean CDA amplitudes for low and high capacity groups in 1st experiment of Vogel et al. (This figure is taken from [3])

The goal of the second experiment was to eliminate the possibility that the difficulty in filtering information was due to color selection. It was reported before that color-based selection is difficult in general. Hence, they designed an experiment that is based on location. They divided the Visual field into four and presented objects in each quarter. They presented a cue that indicates the quarter of the objects people have to remember and used the rest of the objects at the hemifield as distractors. Similar to the first experiment, behavioral data and CDA measurements showed that people with high WM capacity are better at filtering unnecessary information from their Visual WM. [3]

In the third experiment, besides filtering unnecessary information from Visual WM, they also tested their participants for their ability to append information to their Visual WM. The subjects were instructed again to remember the orientations of red rectangles. They were then presented with four conditions: Two of the conditions were showing participants two or four rectangles for them to determine their orientation after a retention period. In the third condition, they were first presented with two red items to reatin in visual VM, after a 500ms delay, they were presented with additional two red items that they were instructed to also remember and take into acount when providing the answer to the final probe display. Fourth condition consisted of presenting participants with two red items to remember and then after a delay of 500ms presenting them with two green items they were told to ignore.[3]

The results showed that low capacity people could append objects to their WM as good as high capacity people could. However, in comparison to high-capacity subjects, low-capacity subject were ineffective in ignoring the distractors. The results of third experiment consolidated the claim that the ability to filter out unnecessary information is related to the general WM capacity. [3]

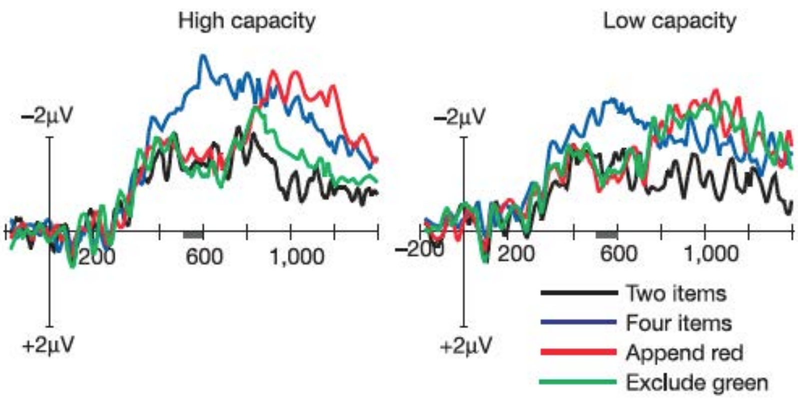

Figure 9. CDA amplitude measurements for high and low capacity groups in 3rd experiment of Vogel et al. (2005) (This figure is taken from [3])

In relation to the last study mentioned, this thesis aims to investigate whether people can drop (forget/un-remember) objects from their working memory or not. In line with earlier analyses, the relationship between general WM capacity and the ability to drop objects from WM will also be investigated and CDA measurements will be evaluated.

Research Question and Hypothesis

Vogel et al. experiments [3] showed a relationship between the ability to filter out information from WM and general WM capacity. It was hypothesized that if people can ignore unnecessary information, they do not encode the information in their WM in the first place, when it is obvious that the information is unnecessary for them. The experiments showed that people can indeed filter out unrelated information and the people who can filter out the unnecessary information are the ones who are better at keeping items in their WM.

The hypothesis of Vogel et al. [3] was that when two target objects and two distractors were shown to people, the CDA amplitude of people who can filter out the unnecessary information would be closer to when they maintain two objects in their WM. CDA amplitude of people who cannot do that would be similar to when they have to remember four objects.

Confirming the hypothesis, a difference between CDA amplitudes of people who can effectively filter out unrelated information and of people who are ineffective at this task was also shown in the experiments that were conducted in the Vogel et al. study [3]. These differences in CDA amplitude measurements along with behavioral results were used as justification for this hypothesis.

In line with this reasoning, this thesis asks the question if people can forget information that is already taken into their WM, considering they can filter out incoming stimuli from WM. In other words, this thesis researches whether people can drop objects (forget) objects that they already encoded into their WM with a command to forget about them. A positive relationship between general WM capacity and ability to drop objects from WM is expected to occur as it was seen between general WM capacity and ability to filter unrelated objects from WM. ERP measurements will be used in investigating the research question.

The hypothesis of the study states that if people can drop objects from their WM, the amplitude of CDA will drop when they are instructed to forget objects that they took into their WM. In addition to this, if the hypothesis is true and the ability to drop objects from WM is positively related with general WM capacity, we should observe a correlation between WM capacity and the CDA marker of removal of objects from WM.

To this aim, we designed an experiment that instructs the subjects to take some objects into their WM and then drop some of them after a relevant cue. ERP measurements were conducted to provide on-line measure of Visual WM load.

Methods

Participants

19 collage students or collage graduates (11 females and 8 males between the age of 19 and 44) participated in the study. Two of the participants were left-handed and 17 of them were right handed. They all had normal or corrected to normal eyesight.

All participants gave their informed consent according to University of Ljubljana ethical committee procedures. Psychology students were given credits for the participation. Others participated in the study on volunteer basis. None of the participants reported any neurological illnesses or conditions.

Materials

The screen was placed 110cm from eyes and 27inches wide. Equal number of stimuli was presented on both sides of the fixation point on a gray background within a 250pixels wide and 250pixels high window. The stimuli were 6 times their radius apart from each other.

Procedure

All of the participants were presented with four conditions in the experiment in randomized order. The conditions were "keep" condition for the load of two items, "drop" condition for the load of two items, "keep" condition for the load of four items and "drop" condition for the load of four items. The number of trials was the same for each condition (72 trials per condition).

In "keep" condition for the load of two items, people were shown two items on each side of their hemifield while they were instructed to pay attention to one side of the screen. After they maintained those two items in their working memory for some time, they were shown a second cue that indicated that they have to keep remembering all of the items they were instructed to remember at the beginning of the trial. The same process was performed with four items in each side of the screen for "keep" condition for the load of four items.

In “drop” condition for the load of four items, people were again shown two items on each side of their hemifield while they were instructed to pay attention to one side of the screen. However, in this condition, with a second cue, people were instructed to forget half of the items they maintained at the beginning of the trial. The second cue indicated the color of the items they were instructed to keep remembering. They were instructed to forget (quit maintaining) items that were not of the indicated color. The process of “drop” condition for the load of four items was the same as well with four items on each hemi-field instead of two items.

The trials were counterbalanced for left and right hemifields by having equal number of trials for each condition on both hemifields. The conditions and directions were randomized so that participants could not know or guess what the upcoming trial was.

Each trial started with a cross sign to show people where they have to keep their gazes. It was followed by a direction cue (left or right) that indicated the side of the screen to pay attention to, which was presented for 400ms. After a delay period of 600ms, objects to be remembered were presented for 200ms. This was followed by a 600ms of a maintenance interval. A second cue that indicated the color of the rectangles that should be maintained further was shown for 600ms and another maintenance interval for 600ms followed this second cue. The trial ended with a response screen for 2.5sec where subjects had to indicate whether the orientation(s) of the indicated rectangle(s) is (are) the same with the shown one(s) or not.

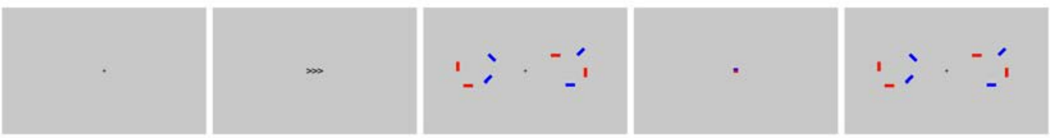

Figure 10. Experiment design of the study at the load of 4 objects for remember all condition

A suppression stimulus was presented in blue letters for 2sec at the beginning of every six trials and a response screen for the suppression task were presented. for 4sec after six trials.

Figure 11. Suppression task in experiment design of the study

According to a general procedure in CDA studies, participants were instructed to keep their gaze in the middle of the screen while paying attention either to their left or right hemifield. They had to see the items with their peripheral vision. This is to maintain CDA occurrence in ERP measurements.

Time course of the study for ERP data was set as follows: The target onset represented time point 0 in the ERP timeline for the experiment. Hence, the first cue onset was presented from -1000 to -600 time point. Target was presented between 0-200ms and the retention period for the first part of the trial lasted from 200 to 800ms. The second cue was presented at 800ms time point and lasted until 1400ms. The second retention period was between 1400ms and 2000ms and the probe screen was presented from 2000ms to 4500ms.

Stimuli were in the form of rectangles. Two or four rectangles were presented on both sides of the screen in every trial. One red and one blue rectangle were presented in each hemifield when the memory array load was two; and two red and two blue rectangles were shown when the load was four.

The target color, orientation of rectangles, number of items in memory load (two or four), “keep” or “drop” tasks and the color of the object they have to forget in “drop” condition were randomized for every trial.

The task was to detect whether there is a change in the orientation of the target rectangle(s). Participants were instructed to use both of their hands to press the appropriate button (same or different), one hand for each of the two buttons. Cedrus RB series response pad was used to record participant responses.

To prevent the subjects from verbally encoding information into their WM instead of encoding it into their Visual WM, a verbal suppression task was given to the participants to make sure that they use their Visual WM instead of their verbal WM.

As a verbal suppression task, participants were shown four letters in blue in the middle of the screen. They were instructed to maintain them in their minds until a verbal suppression probe for a change detection test is presented. Each verbal suppression trial spanned six Visual WM trials. After every sixth Visual WM trial four letters in red were shown to the participants and they were instructed to indicate by a button press whether the letters were the same as the letters previously shown in blue. After the response, a new set of letters in blue was presented to maintain for the next set of six Visual WM task trials.

In Visual WM task, a cross sign in the middle of the screen was presented to indicate where participants should fix their gaze. They were instructed to keep their gaze in the middle of the screen for the full duration of the task. After the cross sign, a direction indicator (arrow) was presented for 400ms to show whether people should pay attention to left or right Visual hemifield.

Following direction indicator, people were presented with either two or four objects in each side of the screen for 200ms. On each side half of those objects were red and half of them were blue.

At this stage of the experiment, the participants were instructed to memorize the orientation of all of the objects shown on the indicated side. They were informed that they will be expected to answer if there was a change in the orientation of the target object(s) when a probe is shown. They were also warned to ignore possible changes in the orientation of non-target rectangle(s).

For a delay period of 600ms a blank screen with three dots in the middle were shown. For this period, people had to keep all the objects they are instructed to memorize in their Visual WM.

Following this, a second cue was presented for 600ms. This was a red, blue or half red, half blue square. This cue was shown to indicate which objects people should keep remembering. If a red square was presented to the participants, they had to keep remembering the orientation of red rectangles on the indicated side, and forget about the blue rectangles. If the color of the cue was blue, they had to keep remembering the blue ones and forget about the red ones. If a half red-half blue rectangle was shown, they had to keep maintaining the orientation of all the items on the indicated side.

After another 600ms delay where they had to keep only the target rectangles in mind, a probe screen for change detection was presented for 2.5 seconds. Participants were instructed to indicate whether there was a change or not in the orientations of the target objects by pressing a button on the response pad.

Two seconds ITI was given between each trial (except for presentation of verbal suppression tasks). After every six trials a probe screen for verbal suppression was presented for 4 seconds. The participants were instructed to indicate if there was a change in any of the four letters that were presented to them by pressing the same buttons on the response pad.

As in the Visual WM task, the test screen waited for the predetermined period and disappeared. It did not wait for the participants to answer and it did not go away when they indicated their answer by pressing a button.

The experiment was designed as 12 blocks, 24 trials in each block. Participants performed 288 trials in total. Each block took around 4 minutes and there were breaks in between every block. The duration of each break was as long as the participant wanted. The experiment took approximately one hour for every participant. Participants were given one or two blocks of practice sessions before starting the actual experiment depending on their performance on these sessions. The number of practice sessions did not exceed three considering the overall length of experiment and participants' concentration and tiredness levels.

EEG Recording

EEG was recorded from 32 electrode sites with an ActiCAP using the International 10/20 system while participants were performing the task. The following electrodes were used: C3, C4, Cz, CP1, CP2, CP5, CP6, F3, F4, F7, F8, Fz, FC1, FC2, FC5, FC6, FCz, Fp1, Fp2, O1, O2, Oz, P3, P4, P7, P8, Pz, PO9, PO10, T7, T8, TP9, and TP10.

Vertical and horizontal eye movements were tracked. The trials with horizontal eye movements where participants followed direction cue with their gaze and looked at the targets instead of paying attention to them peripherally were removed manually.

One participant was rejected because of too many rejected trials due to horizontal eye movements. Another participant were rejected due to too many rejected trials due to noise in the signal.

Signal was referenced to the FCz electrode and then recomputed to average reference off-line. Independent Component Analysis (ICA) was used to remove oculomotor artifacts such as blinks and saccades. Contralateral delay activity was measured by computing the difference between related contralateral and ipsilateral electrode sites.

Analysis

Behavioral Analysis

An in-house program that was prepared in Python was used to order the gathered behavioral data. Statistical analysis was conducted in R. Accuracy rate analysis at loads four and two for distractor change factor, "drop" and "keep" condition factor; and distractor change and nochange conditions at drop condition were plotted. A two way ANOVA with factors task and load was performed on accuracy rates for 19 subjects. The accuracy rates and k values were computed for each participant individually and mean accuracy rates and mean k values were produced from those values. K-values represent estimated memory capacity at a given set size [3], [20], and is computed as $k = S(H-F)$, where S is the size of the memory array, H is the hit rate and F is the false alarm rate. [3], [20]

ERP Analysis

EEGLab and in-house software was used for preprocessing of EEG signal and exporting the ERP data. The EEG signal was checked for noisy epochs visually as well as by the software. The epochs that were checked both manually and with the help of the software. The channels were also checked manually and by software program for their signal and noisy channels were removed. The saccades, were identified by the change in horizontal EOG signal. Epochs in which HEOG suggested that participants followed the cue with their eyes were rejected from further analyisi. One participant was excluded from the study for too many trials with saccades following the direction cue. Independent Component Analysis (ICA) was used to correct blinks. IC's were also checked manually to reject remaining artifacts.

Waveform and scalp map plotting was performed according to the time course set for ERP measurement. The EEG waveform was examined for CDA signal for every bilateral pair of channels for each condition. The CDA signal was observed at the parietal and occipital electrode sites. The grand averaged waveform was plotted for those electrode sites. ERP's were mapped for the time points that are significant for the study over the scalp map.

A two way ANOVA with factors task and load was performed over mean amplitudes for after second cue maintenance time window as well as an ANOVA on mean amplitudes for the first maintenance period.

Results

Behavioral Data

The mean accuracy rate of the participants was 71%. A two-way ANOVA with factors task and load was performed on accuracy rates of 19 participants. There was a statistically significant main effect of memory load [$F(1, 18) = 40.48$; $p < .001$], meaning accuracy rates are significantly higher at the load of two items compared to the accuracy rates at the load of four items; a statistically significant main effect of task [$F(1, 18) = 92.35$; $p < .001$], meaning accuracy rates were significantly higher for “keep” condition compared to the accuracy rates for “drop” condition; as well as a statistically significant task × load interaction [$F(1, 18) = 4.80$; $p=0.04$], meaning the decrease in accuracy rates when load was changed from two items to four items was significantly higher for “keep” condition than for “drop” condition.

The average k values for keep and drop conditions were computed at the load of 2 and 4. The mean k value for “keep” condition was 1.83 and mean k value “drop” condition was 0.48. The mean k value in “keep” condition 1.28 and in “drop” condition 0.33.

The task had a significant effect on false alarm number [$F(1,18) = 107.33$; $p < .001$]. There is also a significant interaction of task and load on false alarm number [$F(1,18) = 4.68$; $p = .04$].

The mean accuracy rates for keep and drop conditions were compared for the load of two and four items is a line plot analysis.

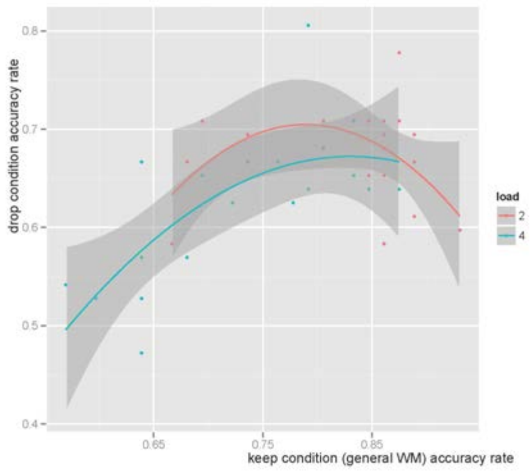

Figure 12. Graph for mean accuracy rate analysis of “keep” and “drop” conditions at the load of 2 and 4.

There was a positive linear increase in accuracy rates for participants when keep and drop conditions were compared at the load of four objects [r(17) = .67, p = .002], keep condition on the x-axis demonstrating general memory capacity. On the other hand, the same relationship could not be observed for the load of two objects [r(17) = . 03, p = .90].

Mean accuracy rates in distractor change and distractor no-change conditions where there was no change in target were compared for loads of two and four and a two-way ANOVA was performed on accuracy rates of target no-change trials with factors distractor and load. The analysis was done for the conditions where target was not done to see the effect of the distractor, which the participants should drop, on accuracy rates independent from the effect of the target.

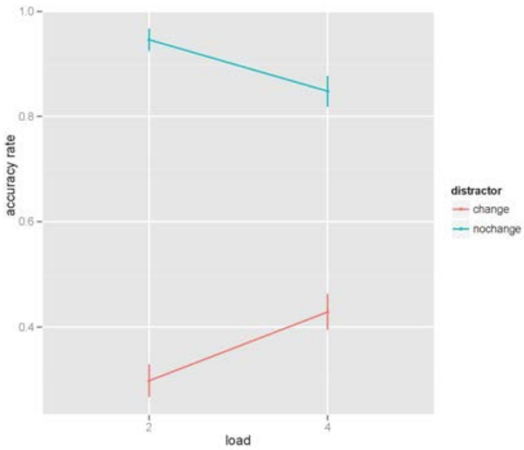

Figure 13. Graph for mean accuracy rates at the load of 2 and 4 for change in distractor and no-change in distractor conditions at no change in target.

The effect of distractor was statistically significant [F(1, 18) = 179.21; p< .001] and there was a significant interaction between load and distractor [F(1, 18) = 33.11; p< .001].

For the cases where there was no change in target, the mean accuracy rate when there was a change in distractor at the load of two was 30% whereas it was 95% when there was no change. In four-load condition, the mean accuracy rate when there was no change in distractor got lower (85%) while accuracy rate when there was a change in distractor got higher (43%). As a result, no statistically significant effect of load on accuracy rates was observed here [F(1, 18) = 0.55; p=.47].

Overall the mean accuracy rate in target no-change trials dropped from 89% to 36% with a presence of a change in distractor. A comparison between "keep" and "drop" conditions was not possible because there was no distractor in "keep" condition for participants had to remember all items they attended to.

The mean accuracy rates were compared also independent of target and distractor conditions for keep and drop conditions at the loads of two and four.

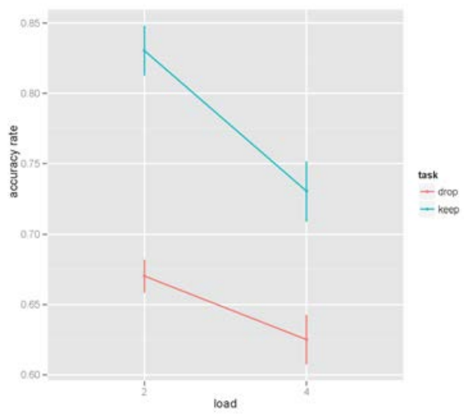

Figure 14. Graph for mean accuracy rates at the load of 2 and 4 for "keep" and "drop" conditions.

ANOVA analysis revealed that task [F(1,18)= 92.35; p< .001] and load [F(1,18)= 40.48; p< .001], as well as their interaction [F(1,18)= 4.80; p= .04] had a statistically significant effect on accuracy rates. Both, "drop" condition as well as increase in WM load reduced participants' accuracy on their task.

ERP Data

Earlier studies suggested that CDA could be observed in posterior parietal and lateral occipital electrode sites over the scalp. [2] For the purpose of current study, EEG signal from 32 electrodes over whole scalp was recorded and preprocessed. The signal ipsilateral to the memory array was subtracted from the signal on the contralateral side before plotting waveforms. Therefore, the CDA signal was observed directly from the plotted graphics. When the computed waveforms were examined for CDA signal, the electrode sites that the CDA occurred were the parietal and occipital electrode sites as it was suggested by the earlier studies. [2], [3], [15] Therefore, parietal and occipital electrode sites were the focus of ERP analysis of the current experiment.

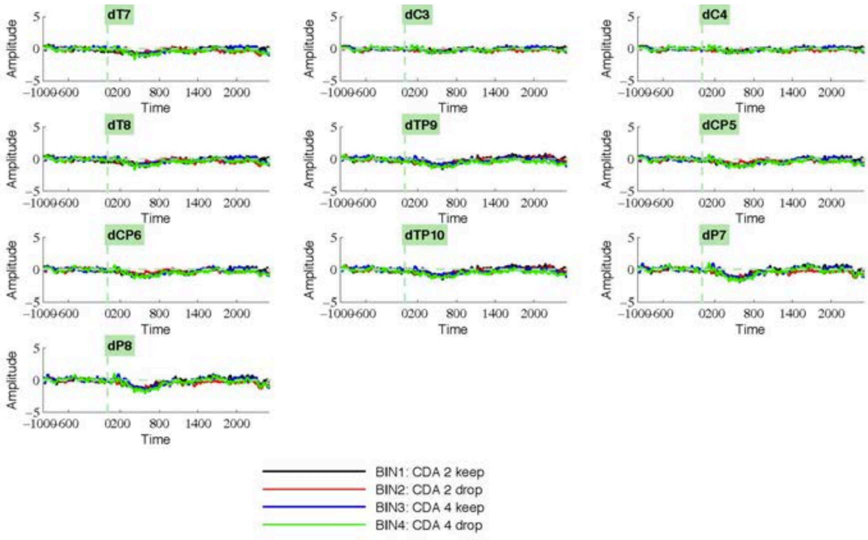

Figure 15. Waveforms from parietal electrode sites for all conditions.

The target onset was at 0ms and target presentation lasted for 200ms. CDA signal started around 200ms after the target onset as it was suggested by the literature. [2], [12], [15], [19] CDA was observed more clearly on the occipital electrode sites.

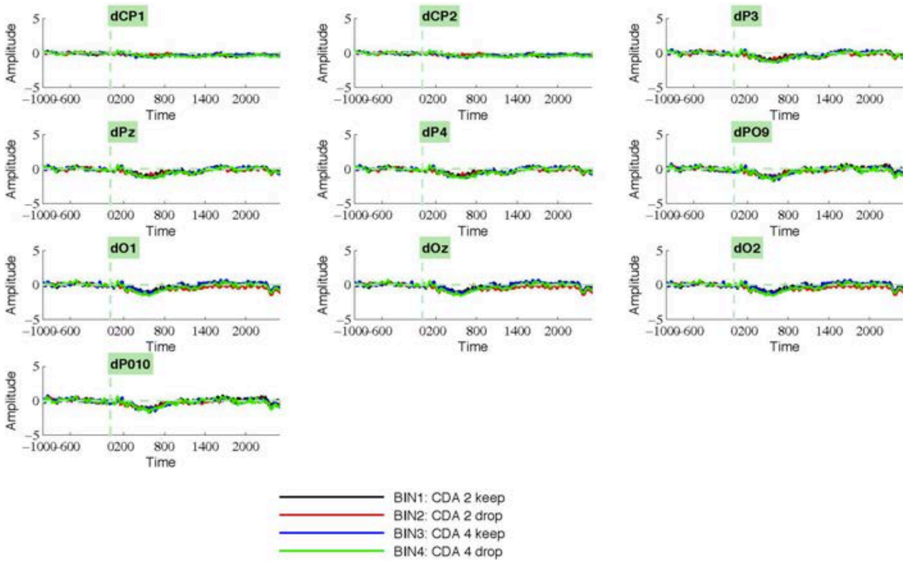

Figure 16. Waveforms from occipital electrode sites for all conditions.

A two-way ANOVA with factors task and load was performed on mean amplitudes (of electrodes of parietal and occipital electrode sites on which CDA was observed (T7 - T8, CP5 - CP6, TP9 - TP10, P3 - P4, P7 - P8, O1 - O2, PO9 - P010)) for 200-800ms time window in order to make sure that participants did not guess the task beforehand and to see if the memory load had effect on their performance.

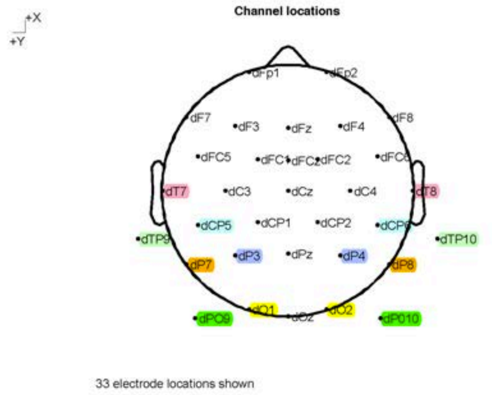

Figure 17. Topography that shows the electrode pairs on which the CDA amplitude is observed.

The results of ANOVA analysis on mean amplitudes of electrodes on which CDA was observed indicated no statistically significant effect on the factor load [F(1-16) = 1.81; p = .2] for the time period between target onset and the second cue, meaning the CDA amplitudes were not significantly higher at the load of four compared to the amplitudes at the load of two. As it was expected, the task did not have a statistically significant effect on the mean amplitudes of electrodes on which CDA was observed [F(1-16) = 1.49; p = .24] at this period.

Second cue onset was at 800ms; presentation of second cue lasted for 600ms and was followed by another 600ms maintenance period. The previously observed negativity decreased after 800ms though it continued until 1400ms and disappeared around 1400ms. A big decrease in CDA amplitude was observed after 800ms time point. However, another two-way ANOVA with factors task and load (on mean amplitudes of electrodes of parietal and occipital electrode sites on which CDA was observed T7 - T8, CP5 - CP6, TP9 - TP10, P3 - P4, P7 - P8, O1 - O2, PO9 - P010)) showed that task factor did not have a significant effect on those mean amplitude values [F(1-16) = 2.62; p= .13] during the period between the second cue and the probe screen onset. CDA amplitude does not significantly differ for load for mean amplitudes of CDA observed electrodes [F(1,16) = .14; p= .72] for this time window either.

Although a difference between CDA amplitudes for “keep” and “drop” conditions could be visually observed on the scalp maps that were generated based on ERPs, this pattern for CDA amplitudes could not be seen throughout the maintenance period for the second cue. The ERP signal was mapped after ipsilateral signal was subtracted from contralateral signal. Blue color indicated computed negativity (the darker shade of the color got, the more negativity increased).

The waveforms presented before showed that the CDA amplitude started to occur around 200ms; however, it reached maximum negativity at around 700ms. The negativity started to decrease around 800ms. The CDA amplitude after second cue onset was considerably less then before onset period but it reached its peak point at 1200ms. However, CDA signals for “keep” conditions did not significantly differ from the signals for “drop” conditions. As it could be also derived from the results of two-way ANOVA that was conducted on mean amplitudes at 1200ms with factors task and load on the mean amplitude values of electrodes on which CDA was observed [task: F(1,16) = .34, p = .57; load: F(1,16) = 3.04, p = .1].

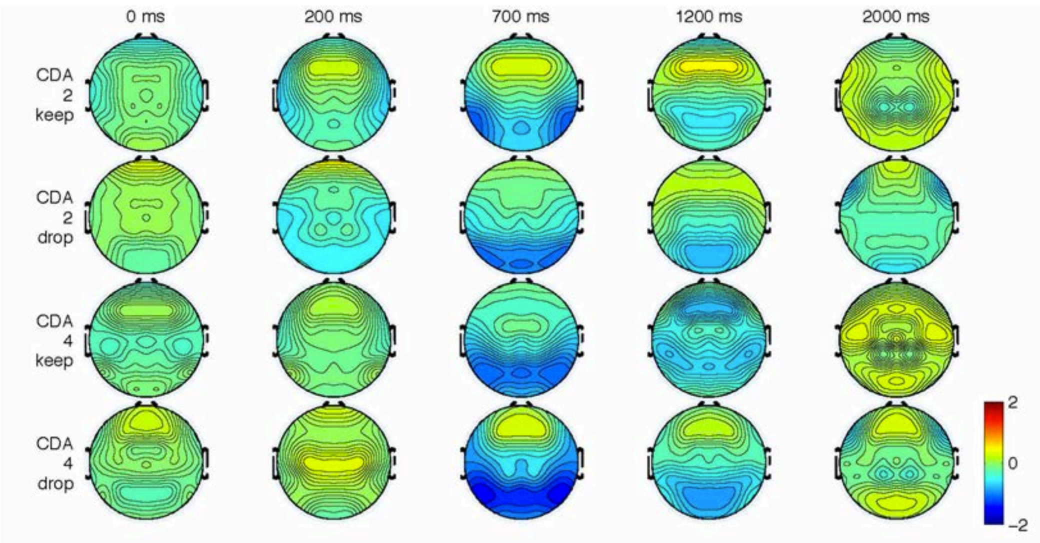

Figure 18. Scalp maps for peak CDA amplitudes on 0ms, 200ms, 700ms, 1200ms and 2000ms.

On waveform and scalp maps, a drop in CDA amplitude after second cue onset could be visually observed. However, ANOVA analysis results for the factors load and task did not show any statistically significant difference on mean amplitude values computed over all electrodes or over electrodes on which the CDA negativity could be observed.

Discussion

The hypothesis that the ability to drop objects from WM is related to the general WM capacity was proposed in line with the findings of Vogel et al.'s earlier study (2005)[3]. In that study, they divided their participants into low WM capacity and high WM capacity groups. They calculated people's WM capacity with a formula that gives a value that shows WM capacity in average number of items in WM. In line with Vogel et al. study [3], the WM capacity of the subjects were also calculated in terms of k values.

The accuracy rates and k values that were obtained from the current study were lower than what was stated in the literature [1], [2], [3], [15], [20]. The accuracy rates being lower than the ones reported in earlier studies [1], [2], [15] (M = 71%, highest accuracy rate = 80%) and k values being lower than the average WM capacity stated in the literature for young adults [2], [3], [20] point to the possibility that the task in general was too hard for the participants.

Figure 14 showed that the task was significantly more difficult for the load of four in all conditions, for mean accuracy rates are significantly affected at the load of four compared to the load of two. The graph also indicated that "drop" condition was significantly more difficult than "keep" condition since there was also a statistically significant effect of task in accuracy rates.

The analysis of behavioral data showed us a linear relationship between "keep" and "drop" condition accuracy rates at the load of four (see figure 12). This means that in four-object condition if a person has a low WM capacity, their WM capacity is low in "drop" condition as well, and if their general WM capacity is higher, their accuracy is also higher in "drop" condition. This may lead to the possibility that people with low WM capacity are also bad at being able to drop objects from their WM, while people with high WM capacity have better ability to drop objects from WM.

However, this relationship could not be seen at the load of two objects between "drop" and "keep" conditions. One explanation for the lack of relationship between general WM capacity and ability to drop objects from WM at the load of two objects is that the task was too easy for participants at the load of two. However, this may not be the case for the task "drop", since accuracy rates are relatively low for two-object load in general.

On the other hand, false alarm rates were significantly higher in "drop" condition than in "keep" condition. This supports the interpretation that people had difficulty in dropping objects from WM. This possibility was also supported by ANOVA analysis with factors distractor and load.

Decrease of accuracy rates in "drop" condition can be interpreted as follows: People could not manage to drop objects from their WM or they could not distinguish between target and distractor when they were responding, since mean accuracy rate decreased below chance level in "drop" task for change in distractor conditions when target did not change.

In addition to this, the average WM capacity for "keep" condition – i.e. general WM task- was also lower then two objects. These results may signify that the experiment itself was a hard task for the participants. Hence, as expected by the hypothesis, people's ability to drop objects from WM was low because general WM capacity was low. This is not a conclusive claim though, since the reason may be simply because people cannot drop objects from WM. ERP analysis will help understand the situation more clearly.

The behavioral and ERP analysis suggested that the task was too difficult for the set of participants. K values for each subject, which indicate the general WM capacity of a person were lower than what was stated in literature [2], [3], [20] in general. Only three subjects had a k value of more than two items in a four-item memory array. The rest of the subjects' memory capacity was less than two items for a four-item memory array.

This was also shown by CDA waveforms and the results of two-way ANOVA for the period after the second cue onset. The CDA waveforms dropped considerably for every condition and ANOVA that is performed on mean amplitudes between 800ms-2000ms latencies showed no significant effect of load or task difference on those amplitudes.

One of the possible arguments that explain this condition is that the task became too complex for the participants after the second cue onset hence the memory capacity of the participants for all condition and all loads considerably dropped. Since the task was too complex for them, other cognitive processes interfered with WM and they could not drop objects in any condition and they also could not maintain some of the objects that were presented to them. This resulted in waveforms with similar amplitudes for every condition.

Another explanation for not having a clear cut distinction between “keep” and “drop” conditions although there is CDA drop after second cue onset is that the number of trials in the experiment was too little. This resulted in EEG signal being too noisy and this affected the ERP data. As a result, CDA signals would not be as accurate and that would affect the observed differences in conditions.

The considerable drop in CDA after first maintenance period and second cue offset can lead to another interpretation of the results when it is taken into account with the lower accuracy rates of the participants. The total maintenance period for the target memory array may be too long so that all items cannot be kept in Visual WM for the time course of the trial until probe onset.

All things considered, the results point to the difficulty of the task for the participants; therefore the hypothesis cannot be proven by the current results. The current behavioral and ERP data cannot justify the hypothesis. The research should be developed further for clearer decision on the hypothesis.

Future Research

The most significant difficulty for the interpretation of ERP data was the noise in EEG signal. An important cause for this noise was that the number of trials for each condition per participant was too small. The number of trials in the experiment should be increased to lower the effect of the noise.

However, the duration of the experiment was one hour and participants' subjective opinion pointed out that they experienced concentration problems towards the end of the experiment although there were no statistically significant difference between first and second halves of the experiment. The average k value and accuracy rate also point out to the fact that the task was too hard for the participants. The experiment can be divided into two days and participants can complete the experiment in two days to overcome this problem.

There may be two reasons for this issue: The total maintenance period for the target items to be memorized could be too long for the participants coupled with the task they have to perform. The presentation duration of the second cue should be shortened to get rid of this possibility.

The second possible cause is that the color discrimination task may be too hard for them. The literature also states that color based selection is very ineffective. [3], [21]. Therefore, an additional experiment on basis of location of target stimuli could be added to make sure that the task difficulty is not caused by color selection task in second cue.

Another remark that was made by the participants was that the suppression task caused them to lose concentration on the actual task very frequently. This was pointed out as the biggest problem on concentration by many participants. The experiment design was modified once due to this concentration problem. It should be reviewed again to get rid of this problem.

All in all, although a drop in CDA signal is observed after the second cue onset in the experiment, this amplitude decrease was observed in all conditions for all loads. This result points to the idea that the task that was indicated by the second cue was too hard for the participants. There are several possible reasons for this issue. The experiment should be repeated with more trials and a few developments in the experiment design to reach a more definite conclusion on the hypothesis.

Conclusion

In this thesis, we investigated the research question whether people could drop objects from their WM and whether there is a relationship between their general WM capacity and ability to drop objects from their WM.

The first hypothesis to research the first part of the question was if people could drop objects from their WM, their CDA amplitudes, which is shown to be correlated with the number of objects held in WM (i.e. WM capacity) [1], [2], would drop in half when they were instructed to drop half of the objects that they maintained in their WM beforehand. This observation should also be supported by the behavioral analysis results.

The second hypothesis to investigate the second half of the question was if people with high WM capacity were better at dropping objects from their WM than people with low WM capacity, the CDA amplitudes of people with high WM capacity when they have to drop half of the objects would be half of their CDA amplitudes when they have to keep all of them while CDA amplitudes of low capacity individuals would not show significant change between both conditions.

To test this hypothesis, we designed a study in which people were instructed to maintain two or four items in their WM at the first step. After 600ms of maintenance period, they were either instructed to drop half of the objects from WM or they were instructed to keep maintaining all of them. They also had to perform a verbal suppression task in order to prevent them from verbally encoding the stimuli.

The analysis of behavioral and ERP results showed that participants had difficulty not only in the dropping objects from their WM, but also in the whole task regardless of them having to drop objects or keep maintaining them.

In addition, behavioral analyses of WM capacity, accuracy rates in presence of a distractor change and false alarm rates in keep and drop conditions supports the possibility that people could not drop items from their WM.

When these behavioral analyses were considered with ERP result analyses for the study, the results may be interpreted so that in the drop condition the subjects were not able to perform the task — they were not able to either drop or disregard the distractors when presented with the probe display.

A possible reason for their inability to perform could be that the task was too complicated for people and their WM capacities were all low as a result of an interference with other cognitive processes.

Another possible reason for not observing a significant difference between CDA amplitudes for “keep” and “drop” conditions were thought to be few number of trials for each condition per subject. The proposal in this thesis was that study should be repeated with more trials in order to get rid of the noise in the signal more. However, the duration of the experiment and level of concentration of subjects should also be considered and participants should be tested in two separate sessions.

The subjective reports of the participants revealed that they considered verbal suppression task a big distractor. A revision in the experiment design had been done due to this problem previously. Another revision suggestion was proposed in the thesis.

To sum up, the analysis of current behavioral data rejects the hypothesis that people can drop objects from their WM. ERP data, on the other hand, is noisy and the experiment should be repeated with some improvements in order to get clearer ERP results.

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Appendix

English Abstract

Introduction

The studies show that a healthy young adult can successfully maintain 3-4 objects in Visual working memory (Visual WM) in average. Ikkai, McCollough and Vogel [1] have further shown that in a lateralized change detection Visual WM task, it is possible to observe a negative deflection in EEG over parietal cortex, which is stronger on the side contralateral to the hemifield in which items to be remembered were shown. The difference between the amplitude measured over ipsilateral and contralateral hemisphere—termed Contralateral Delay Activity (CDA)—is assumed to reflect the current working memory load. Further experiments have shown that the magnitude of CDA is closely related to individual's Visual WM capacity. [2] As it tracks Visual WM load, it has been successfully used to study the ability to filter unrelated information from Visual WM. [3] Analogue to observing active filtering of items from Visual WM, the current study aims to investigate, whether people can drop objects from Visual WM during the maintenance period.

Methods

25 healthy young adults participated in the study. Each participant performed 288 trials of a change detection task. Participants were instructed to memorize 2 or 4 objects and later either keep all of the objects in their Visual WM or drop half of them. Event-related potentials from 32 channel locations were recorded during the performance of the task.

Results & Discussion

Similar to the earlier studies, we expected to find a positive correlation between Visual WM capacity and the ability to drop objects from working memory. Behavioral data confirmed the correlation at the load of 4, but not at the load of 2 items, possibly reflecting the ease of performing the task at the Visual WM load of 2 items. However, the further analysis of behavioral data resulted in the rejection of the hypothesis that people can drop objects from their WM.

ERP data were too noisy and this led to some difficulties in interpreting ERP analysis. The experiment should be repeated with some improvements to obtain clearer ERP data.

German Abstract

Einleitung

Studien zeigen, dass ein durchschnittlicher, gesunder Mensch drei bis vier Objekte im visuellen Arbeitsgedächtnis (vA) halten kann. Ikkai, McCollough und Vogel [1] zeigen außerdem, dass es in einem lateralisierten change-detection-vA-Task möglich ist, im EEG-Signal eine negative Ablenkung über dem Parietallappen zu beobachten. Diese ist auf jener Seite stärker ausgeprägt, die sich kontralateral zum Halbfeld befindet, in dem die zu merkenden Objekte gezeigt werden. Der Unterschied zwischen den Amplituden, die über der kontralateralen und der ipsilateralen Gehirnhälfte gemessen werden, wird Contralateral Delay Activity (CDA) genannt. Es wird angenommen, dass CDA die aktuelle Auslastung des Arbeitsgedächtnises widerspiegelt. Weitere Experimente haben gezeigt, dass die Ausprägung der CDA eng verbunden ist mit der individuellen Kapazität des vA. [2] Da CDA die Auslastung des vA wiedergibt, wurde es erfolgreich eingesetzt um die Fähigkeit zu untersuchen, irrelevante Informationen aus dem vA zu filtern. [3] In Hinblick auf die Beobachtung dieses aktiven Filterns von Elementen aus dem vA, zielt die hier vorliegende Studie darauf ab festzustellen, ob es Menschen möglich ist, auch während des Aufrechterhaltens des vA Informationen zu löschen.

Methoden

25 gesunde, junge Erwachsene nahmen an der Studie teil. Jeder Teilnehmende durchlief 288 Trials eines Change-Detection-Tasks. Die Teilnehmenden wurden instruiert sich entweder zwei oder vier Objekte zu merken und später entweder keines oder zwei dieser Objekte aus dem vA zu löschen. 32 Kanäle wurden verwendet um während des Experiments ereigniskorrelierte Potentiale (EKP) aufzuzeichnen.

Ergebnisse

In Übereinstimmung mit früheren Studien, erwarteten wir eine positive Korrelation von Aufnahmefähigkeit des vA und dem Vermögen Objekte aus dem Arbeitsgedächtnis zu löschen. Behaviorale Daten bestätigen die Hypothese im Falle von vier Objekten, jedoch nicht im Falle von zwei Objekten. Dies zeigt möglicherweise, wie einfach der Task im Falle von

nur zwei Elementen durchgeführt werden konnte. Die weitere Analyse der behavioralen Daten hat allerdings dazu geführt, die Hypothese zurückzuweisen, dass Menschen Objekte aus dem Arbeitsgedächtnis löschen können.

Das relativ schlechte Signal-Rausch-Verhältnis in den EKP Daten hat zu einigen Schwierigkeiten in der Analyse geführt. Um ein besseres Verhältnis zu bekommen, sollte das Experiment mit einigen Verbesserungen noch einmal durchgeführt werden.

Academic CV

Surname(s) / First name(s)	**ULUÇ IŞIL**
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Education

Dates	20 September 2012 – Present
Title of qualification awarded	Master of Science
Name and type of organisation providing education and training	University of Vienna, Middle European Interdisciplinary Master Programme in Cognitive Science
Master of Science Thesis Title	Can People Drop Objects from Their Working Memory
Master of Arts Thesis Supervisor	Assoc. Prof. Dr. Grega Repovs
Dates	15 September 2004 – 30 June 2007
Title of qualification awarded	Master of Arts
Name and type of organisation providing education and training	Bogazici University, Graduate School of Social Sciences & Humanities, Department of Philosophy
Master of Arts Thesis Title	The Immediate Object of Visual Perception
Master of Arts Thesis Supervisor	Prof. Dr. Stephen H. Voss
Master of Arts Thesis Date	June 2007
Dates	15 September 1999 – 02 July 2004
Title of qualification awarded	Bachelor of Arts
Name and type of organisation providing education and training	Bogazici University, Faculty of Arts, Department of Philosophy
Dates	September 1999 – June 1999
Title of qualification awarded	High School
Name and type of organisation providing education and training	Korfez Oruc Reis Anadolu Lisesi

Research experience

Dates	16 October 2013 – Present
Occupation or position held	Main Experimenter, Mind and Brain Lab, University of Ljubljana

Main activities and responsibilities	Conducting an Experiment on CDA measurement for Visual Working Memory (EEG experiment) • Conducting power analysis of the experiment, • Programming the experiment, • Conducting EEG data collection, • Data analysis
Dates	15 April 2013 – 15 June 2013
Occupation or position held	Co-Experimenter, University of Vienna
Main activities and responsibilities	Assisting an Experiment on Visuo-Spatial Cueing for Unconscious Peripheral Vision (behavioral study with eye-tracker) • Measuring Luminance values, • Helping with experiment design, • Conducting data collection

Conferences:

Mei:CogSci Conference 2014 Krakow –Presentation: Can People Drop Objects from Their Working Memory 12-14/06/2014

Mei:CogSci Conference 2013 Budapest – Poster Presentation: A Visuo-Spatial Cueing Experiment for Unconscious Peripheral Vision 18-21/06/2013

2013 Dubrovnik Conference for Cognitive Science (DuCog) – Poster Presentation: The Role of Negative Emotion Regulation in a Cognitive Theory of Nightmares 16-19/05/2013

Publications

Uluc, I., Slana, A., Repovs, G., "Can People Drop Objects from Their Working Memory" (2014), *MEi:CogSci Conference Proceedings.*

Uluc, I. & Schöberl, T., "A Visuo-Spatial Cueing Experiment for Unconscious Peripheral Vision" (2013), *MEi:CogSci Conference Proceedings*.

Uluc, I. "The Role of Negative Emotion Regulation in a Cognitive Theory of Nightmares" (2013), *DuCog Proceedings*

Uluc, I. & Voss, S., "The Immediate Object of Visual Perception" (2007), *Thesis*, Istanbul: Bogazici University Publications

Scholarships and Awards:

- Bogazici University Honours Degree (2004)
- TEV Undergraduate Scholarship (1999 - 2004)
- TEV Outstanding Success Award (2002 - 2004)
- Prime Ministry Scholarship (1999 - 2004)
- Bogazici University Scholarship (1999 - Earthquake Support/Allowance)

Work experience

Dates	15 April 2007 – 01 July 2007
Occupation or position held	Student Assistant
Main activities and responsibilities	Help Editing the Philosophical Journal *Felsefe Tartismalari* for Publication
Name and address of employer	Bogazici University, Istanbul, Turkey

Languages

Mother tongue **Turkish**

Other languages

European level (*)	Understanding				Speaking				Writing	
	Listening		Reading		Spoken interaction		Spoken production			
English	C2	Proficient user	C2	Proficient user	C2	Proficient user	C2	Proficient user	C2	Proficient user
French	A2	Basic User	A2	Basic User	A2	Basic User	A2	Basic User	A2	Basic User

(*) Common European Framework of Reference for Languages

Toefl IBT: 17 December 2011, Istanbul Language Center, Turkey, TOEFL IBT Score: 103