Work Memories Reflecting Change Detection

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ABSTRACT: *The capacity of working memory to maintain visual information is highly limited and varies significantly across individuals. An important research effort is to understand the mechanisms of its limitation, one being the efficient selection of the relevant items from the immediate external environment to encode and maintain in working memory stores, while preventing the irrelevant items to occupy it's capacity. Recently, a series of EEG studies using lateralized change detection task, in which the participants only have to maintain items presented on one visual hemifield, while irrelevant items are also presented on the opposite hemifield, identified a neurophysiological correlate of storage capacity in the form of contralateral delay activity (CDA) wave. Moreover, studies revealed that low-capacity participants maintain irrelevant items along the target items, when both are presented in the same visual hemifield, indicating a reduced ability to filter irrelevant stimuli from visual working memory. These studies, however, do not consider the possibility that participants might also maintain the irrelevant items presented to the opposite visual hemifield. To address this concern, we designed an experiment in which we directly manipulated the presence of distractors in the irrelevant visual hemifield to estimate and control for their effect. Twenty-eight participants took part in a visual working memory experiment in which they were asked to maintain orientation of items presented to the left or right visual hemifield, while the distracting items were either present or absent in the opposite visual hemifield. The results revealed significantly lower estimates of the capacity in the presence vs. absence of distractors, suggesting that participants were not able to ignore the distracting items presented to the opposite visual hemifield, challenging the validity of the estimates of visual working memory capacity in CDA and other studies employing lateralized change detection task.*

Keywords: Change Detection Task, Capacity, Contralateral Delay Activity, Distractors, Visual Working Memory

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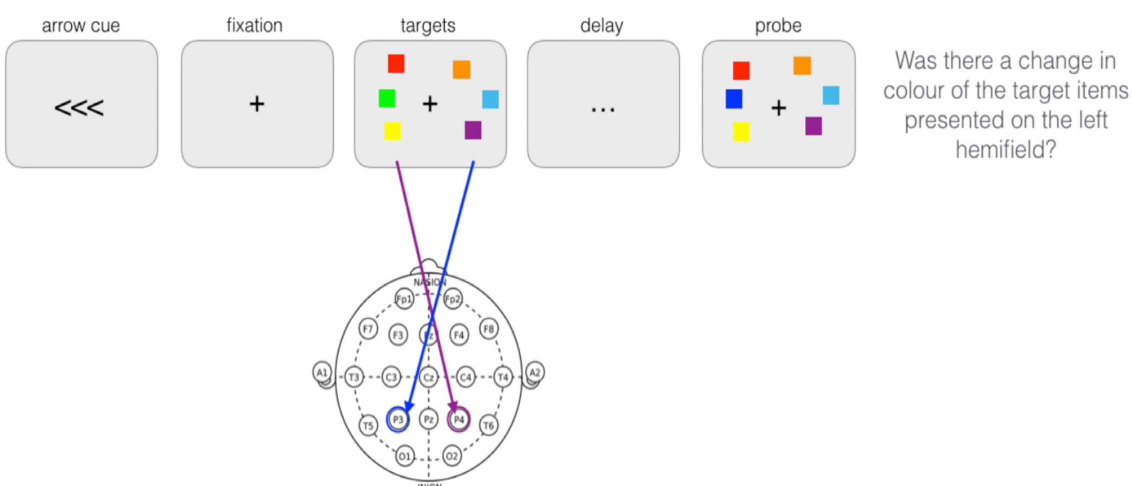
1. Introduction

In everyday life, access to immediate external environment obtained through different sensory systems is crucial not only to respond to the sources of threat, being one of the basic functions of sensory systems, but also to guide complex mental tasks needed to carry out goal directed behavior. For example, when driving a car, one must have access to the visual environment at all times, in order to follow the driving rules and avoid potential obstacles, such as pedestrians and other vehicles in the traffic. Frequently, however, sensory input from the relevant visual information is either interrupted by short events, such as eyeblinks or saccades, or redirected to irrelevant visual stimuli, such as a phone screen when receiving a call. In such cases, a temporary memory buffer known as visual working memory (VWM) [1], which allows us to actively maintain and integrate relevant visual information in the absence of the external environment, is needed to carry out the tasks at hand.

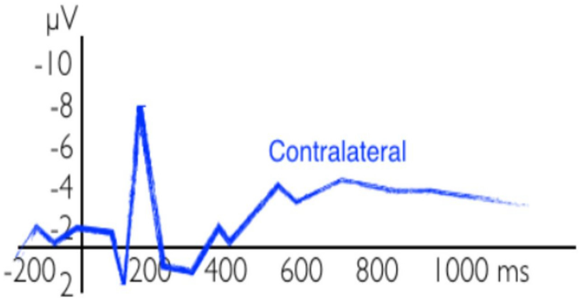
An important effort of VWM research is to understand the reasons for the highly limited capacity to maintain visual representations, which spans from 3 to 5 meaningful items in young adults, varies significantly across individuals and declines in healthy aging [2]. Recently, a series of EEG studies [5, 3] focused on the neural substrates of VWM processes and identified a neurophysiological index of storage capacity in the form of the slow negative ERP difference wave, known as contralateral delay activity (CDA). Studies have shown that CDA is sensitive to the number of objects maintained in VWM [3]—its amplitude increases as the number of objects maintained in VWM increases, but reaches an asymptote at around 3-4 items (Figure 1F), depending on each individual's memory capacity. Interestingly, the extent of the increase in amplitude in CDA when working memory load is increased from two to four items was found to strongly correlate with individual's VWM capacity and is therefore considered a neurophysiological index of VWM capacity [5]. Moreover, studies have shown [3] that low-capacity participants find it hard to ignore irrelevant distractors when presented either concurrently with or successively to the target items [6]. The authors suggested that irrelevant items burden the limited VWM capacity, leading to lower working memory performance.

A typical paradigm used to study CDA is lateralized change detection task [5] (Figure 1A), in which participants are presented with a number of items on both sides of the screen, but only have to focus on the side that was previously indicated with a cue (usually an arrow pointing either left or right), encode and maintain the relevant item information (e.g. colors or orientations), while keeping their eye-gaze focused at the fixation point in the middle of the screen. Such tasks evoke an increase in electrical activity above the parietal-occipital cortex of the hemisphere contralateral to the visual hemifield in which the target items were presented (Figure 1C). CDA is computed as the difference in EEG activity between contralateral and ipsilateral hemispheres (Figure 1E). In this way, any nonspecific, task-general bilateral activity such as perceptual responses (Figure 1D), is removed and the remaining signal should be solely related to working memory processes [3].

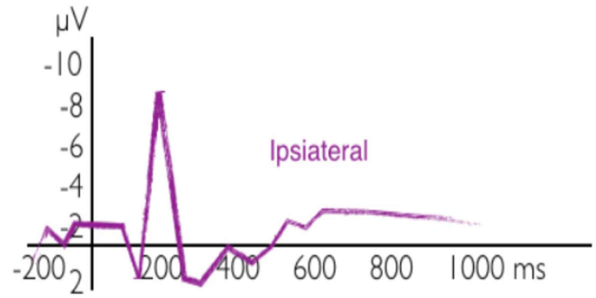
While this logic seems well reasoned for eliminating taskirrelevant activity, we have identified a potential issue in the experimental design that could lead to false conclusions. When testing VWM capacity, researchers usually don't consider the possibility



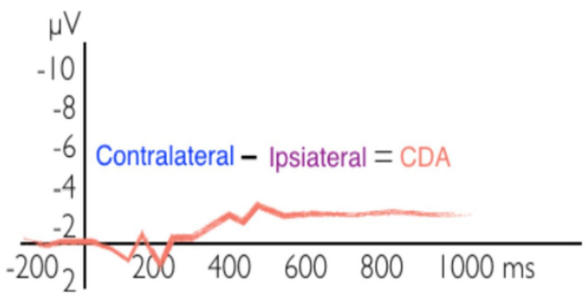
A) Lateralized change detection task B) EEG recording of the signal



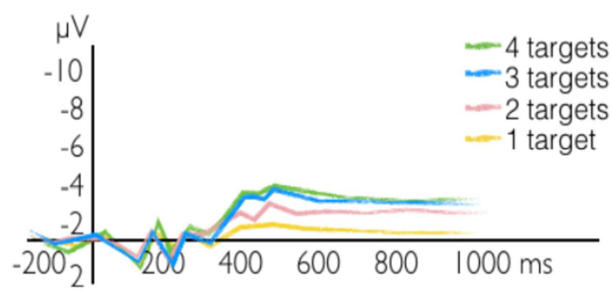
C) EEG response in contralateral hemisphere



D) EEG response in ipsilateral hemisphere



E) Contralateral delay activity (CDA)



F) CDA as a function of memory load

Figure 1. Contralateral delay activity as included by a change detection task. A) Lateralized change detection task. B) EEG recording of the signal obtained while a participant is performing the task. C) EEG response to the target items in the Contralateral hemisphere. D) EEG response in the ipsilateral hemisphere. E) Contralateral delay activity (CDA), computed as the difference in EEG signal between contralateral and ipsilateral hemisphere. F) CDA increases as a function of memory load and reaches an asymptote around participant's working memory capacity. Adopted from [3, 5]

that participants might be either distracted by or also encode and maintain the items presented to the irrelevant hemifield. Encoding and maintenance of irrelevant distractors was demonstrated in previous studies [6, 3], however, in these studies the irrelevant distractors were present in the same visual hemifield interspersed between relevant targets. In this study we considered the possibility that the distractors significantly affect VWM performance even when presented to the irrelevant visual hemifield. In this case, the participants might try to encode items from both hemifields, spreading the VWM resources across both relevant and irrelevant items and reducing the ability to maintain the items from the relevant visual hemifield. If that is the case, in such studies the results would underestimate the VWM capacity for the relevant hemisphere.

To address this concern, we designed an experiment in which we directly manipulated the presence of distractors in the irrelevant visual hemifield, which enabled us to estimate and control for their effect.

2. Method

2.1 Participants

Twenty-eight students (22 females) aged between 19 and 25 (M = 20.5, SD = 1.6) signed an informed consent to participate in an 1.5-hour experimental session. Five participants were excluded from the analysis due to inadequate performance in the VWM task (accuracy was lower than chance in one of the task conditions).

2.2 Task and Procedure

Participants completed multiple trials of the VWM task (Figure 2). On each trial they were shown a brief array of black rectangles of different orientations (*targets*) presented either on one or both sides of the screen and were asked to remember the items presented in either left or right hemifield only, as indicated with an arrow (*initial cue*). Following a brief delay a *second cue*, which matched the initial cue and reminded the participants which objects they will need to base their response on, was presented. After another delay, the *probe* items were shown on both sides of the screen and the participants had to indicate by a button-press, whether there was a change in the orientation of any of the rectangles on the relevant, previously indicated side of the screen, ignoring a possible change on the other side of the screen.

Two main factors were manipulated: *side*, which corresponded to the side of the screen from which the participants had to remember orientation of the presented items (*left, right*) and *distractors,* corresponding to whether the items were presented to both or the relevant visual hemifield only (*distractor* and *nodistractor condition*). Overall we tested 4 experimental conditions: 4 target items presented to the left (L4N) or right (R4N) visual hemifield with no distractors on the opposite hemifield; and 4

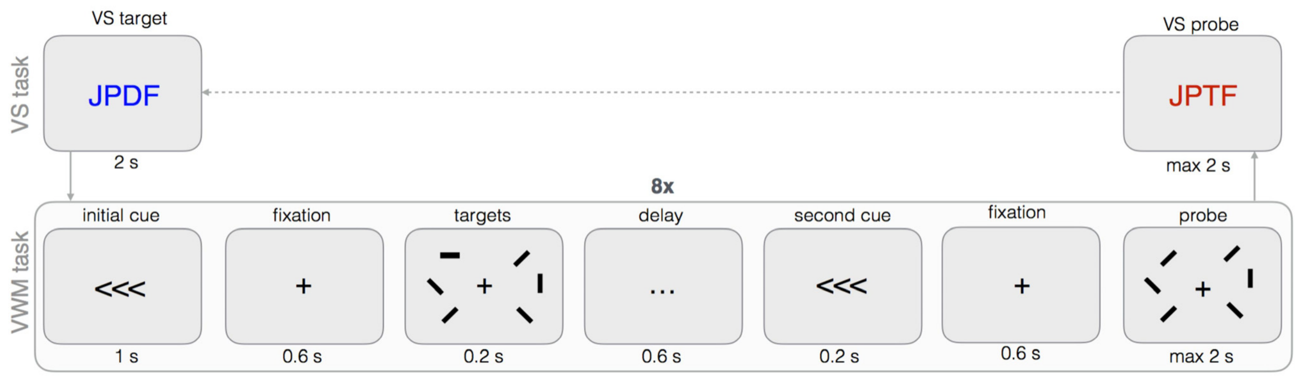


Figure 2. Task progression and trail structure. See main text for full descripion

target items presented to the left (L4D) or right (R4D) visual hemifield, with distractors present.

In order to hinder verbal recoding of the visually presented stimuli, in addition to the VWM task, participants also performed a concurrent verbal suppression (VS) task, which was embedded between the trials of the main VWM task (Figure 2). Before the start of the VWM task, a suppression stimulus (VS target) consisting of blue-colored letters was presented for 2 s. Participants were instructed to maintain the letter sequence while performing the VWM task. After every eight VWM trials a VS probe was presented in red and the participants had to indicate by pressing the appropriate key, whether the probe was the same or different from the target.

Data were collected in a sound-isolated room, allowing participants to attend to the task without any interruption. To control for eye-movements, we used an EyeLink 1000 system.

2.3 Data Analysis

Statistical analyses are based on estimates of working memory capacity (K). The capacity estimates were computed with Pashler's formula [4]:

$$K = N \frac{h - f}{1 - f}$$

where *h* and *f* are the observed *hit* and *false alarm* rates and *N* is the number of to-be-remembered items.

3. Results

The goal of this study was to assess the effect of distractors in lateralized change detection task on the VWM capacity. A repeated measures ANOVA with within-subject factors *side* (left vs. right) and *distractor* (distractors vs. no-distractors) revealed a main effect of distractor, $F(1, 22) = 19.7$, $p < .001$, $\cdot 2 = .06$, reflecting lower capacities in the presence of distractors (see Figure 3). Neither the effect of side, $F(1, 22) = 0.754$, $p = .394$, nor its interaction with distractor, $F(1, 22) = 1.36$, $p = .254$, were significant.

4. Discussion

The aim of this experiment was to identify a potential shortcoming of lateralized change detection tasks used in the CDA studies

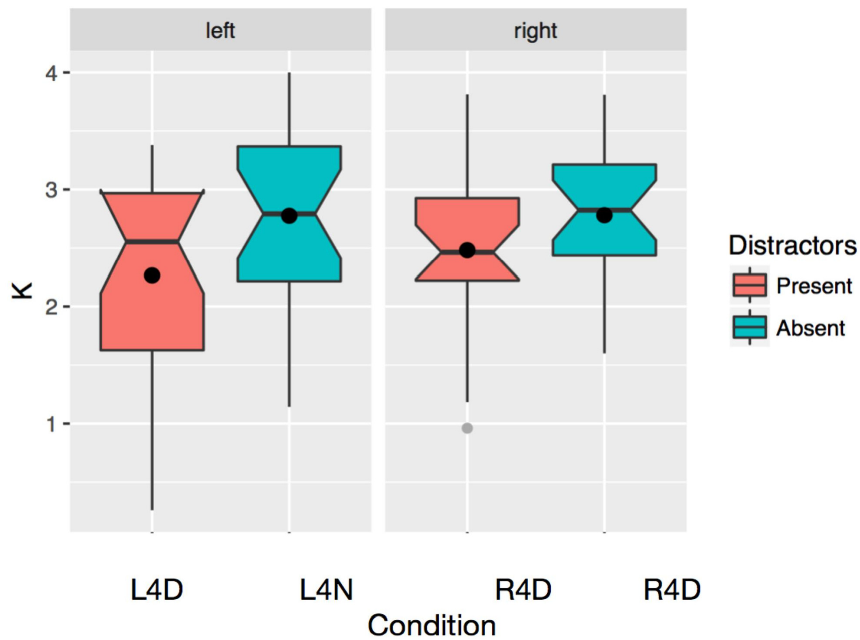


Figure 3. Estimated number of successfully maintained items (K) in the four experimental conditions. L4D: four targets presented to left visual hemifield with distractors present in the right hemifield, R4D: four targets presented to the right visual hemifield with distractors present in the left visual hemifield, L4N and R4N, four targets presented to the left and right visual hemifield, respectively, with no distractors shown in the contralateral visual hemifield. Box plot: The bottom and top of the box plot are Q1 and Q3, the line between them is the median. The lower whisker is Q1 + 1.5*IQR. The upper whisker: Q3 +1.5*IQR. The black circle is the mean

in assessing VWM capacity, by manipulating the presence of distractors in the irrelevant visual hemifield. Specifically, our concern was, that the presence of distractors could result in reduced estimates of VWM capacity, when defined as the number of remembered target items.

Whereas the estimated VWM capacity did not differ between left and right hemispheres, the results indeed revealed significantly lower estimates of VWM capacity in the presence vs. absence of distractors. This suggests that participants were not able to ignore the distracting items in the irrelevant contralateral visual hemifield, which resulted in lower estimate of successfully remembered items (K) in the distractor present conditions. These results are in line with prior studies using CDA [3], which have shown that participants find it hard to ignore irrelevant distractors when presented along the target items [6]. These studies, however, assessed the effect of distractors presented in the same visual hemifield, while not taking into consideration the possibility that the distractors can significantly affect working memory performance even when presented to the irrelevant visual hemifield.

The effect of the distractors could be explained either by a reduced ability to encode the target items, or—as suggested by previous research [3]—by leading the participants to encode and maintain also irrelevant distractors, thereby reducing the effective capacity for encoding of the relevant items.

Though confirming the negative effect of the distractors, the results do not enable unequivocal explanation of the mechanism underlying their effect. One possibility is that, similar to the observations of the CDA studies [3], participants fail to ignore the irrelevant stimuli and maintain them along the relevant items occupying limited working memory resources and leaving less of them available to successfully encode and maintain target items. The second possibility is that distractors do not occupy the limited capacity working memory store, but rather disrupt the initial encoding of the relevant items, so that the active maintenance system fails to successfully engage and then sustain the activity of the representations in the first place.

Whereas our experiment does not provide sufficient information to distinguish between these two possibilities, future studies tracking the magnitude of the CDA in the presence and absence of distractors in the contralateral visual hemifield, could help resolve the dilemma.

Acknowledgements

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