The Role of Temporal Context in Change Blindness and Binding

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Abstract

The binding problem presents a significant challenge in our understanding of perception and the visual working memory. Using the conceptual network model of cognitive brain-processing, this study researches the role of temporal context in binding and change blindness, predicting that the reappearance of one or several objects from one trial to another has a significant effect on the sensitivity to change in an image-based change blindness task. Knowing the role of context is important to both our scientific understanding of perception as well as how we interpret situations vulnerable to change blindness, such as eyewitness accounts in court. Participants in our experiment were asked to perform a change-blindness task, tasked with spotting changes in objects belonging to sets of 6 images. The duration of the experiment was approximately 20 minutes. The results of the conducted RM-ANOVA showed no significant effect of context on change sensitivity or location accuracy.

The Role of Temporal Context on Change Blindness and Binding

Imagine standing in a field, staring at an apple tree, surrounded by fallen apples. You close your eyes for 10 seconds and hear a thud; another apple has fallen. You would most likely have great difficulty in identifying the most recently fallen apple if asked. This inability to track small, or in other cases large, changes is commonly referred to as change blindness (Simons and Levin, 1998). Change blindness is a popular phenomenon in, and outside the field of psychology. It's likely that most readers of this paper have seen one of many viral videos demonstrating the concept to some extent; they collectively have hundreds of millions of views on Youtube. While these videos may be entertaining, studying the concept of change blindness has another use; to increase our understanding of perception and cognition. Previous studies on change blindness show a surprisingly large flaw in our perception, and have led to interesting practical implications for a wide range of fields, including how it may raise questions about the validity of eyewitness accounts in court (Nelson et. al, 2011). A series of experiments by Simons and Levin (1997) demonstrated that the majority of participants did not notice when the actor in a short, silent film was replaced with another, even when the replaced actor appeared wearing a different hairstyle and clothing. Simons and Levin (1998) further demonstrated change blindness outside of laboratory conditions by conducting an experiment in New York in which an experimenter asked a non-complicit pedestrian for directions. The interaction was then briefly interrupted by two confederates walking between the two carrying a door. During this obstruction of the pedestrian's vision the confederate was replaced by a second experimenter. Only half of participants realised that the person they had been giving directions to had been replaced. Interestingly, the likelihood of realisation increased when the experimenter was in the same age-group as the pedestrian, suggesting that more VWM effort is expended when interacting with ingroup members (Simons & Levin, 1998). It has also been suggested that predatory big cats such as lions and tigers may take advantage of change blindness when hunting (Pastukhov & Carbon, 2021), creating a sort of natural change blindness task for their prey by moving forward slowly when the prey is looking in another direction. Participants in this study will not experience the same high stakes, however the concept investigated will be the same.

Change blindness is a result of the way we store information about what we perceive. When an object enters our field of vision, aspects of its nature are stored in our visual working memory (VWM) within 200-500ms (Luck & Vogel, 2013) such as location, colour, texture and shape (de Vries, 2004). This seems self-evident, but our vision is not limited to one object at once; we're exposed to countless numbers of objects and stimuli every time we open our eyes. Having a dedicated memory for each of the near-infinite combinations of these potential features is likely impossible and definitely inefficient. It then stands to reason that these different possible features of an object are represented separately and can become connected as necessary. This connection of each of an object's features and location is one form of binding. Without binding, a change in an object would simply result in the altered object being perceived as newly introduced, thus bindings must also form temporarily, be adaptive and differ based on context. So the question arises: how are new, seemingly arbitrary combinations of objects, colours, locations represented in the brain, with each location and feature corresponding to the correct object and position on the spatial map? This is known as the binding problem. This paper will explore the binding problem with an emphasis on the role of context, in particular how temporal context affects the strength and development of bindings.

The Problem with Binding

As previously mentioned, the binding problem is a key concept in this paper. On a functional level, i.e as the sum of its parts, binding is simple. Each aspect of the object is recognised and stored by the VWM in association to the aforementioned object and activated when the object is recalled. Examining the binding problem at the structural, neural level becomes more complicated, as the human brain has a limited cognitive capacity and efficient management of every possible combination of objects, their features and locations is not possible or even useful. The temporary nature of binding is important for the human brain's adaptability in updating locations and features of existing objects. Since each potential feature of an object must be represented separately, the problem then is how do bindings develop without having features and locations misattributed to one of multiple perceived objects at any given moment? One current theory offers a possible mechanism for binding. In de Vries' (2004) study, support was found for the theory that each cell assembly represents a memory trace of an object being attached to a location in the spatial map and activated within the same context. These objects are represented and activated in rapid series with a unique excitation loop per object rather than simultaneously. The existence of excitation loops both between involved cell assemblies, as well as between the cell assemblies and visual receptors are conditions for the formation of a connection between so called memory traces (de Vries, 2004). Further research is required, and increasing our understanding of the role of temporal context in the binding problem is one of the aims of this paper.

The Conceptual Network

This paper approaches the binding problem using the framework of previously mentioned memory traces, which will now be explained further, within a conceptual network. The conceptual network is a theoretical model of cognitive brain-processing, in which memory traces, or the collective identities of an object, are represented as cell assemblies in the larger network. Cell assemblies are formed following Hebb's (1949) learning rule; when multiple neuron clusters related to features or locations of objects are activated at once, the connection between them becomes stronger. This assembly of connected neuron clusters is known as a cell assembly. This means that when the representation of an object is activated, these cell assemblies become excited and all the associated neuron clusters start firing. The more often assemblies fire together, the stronger this memory trace becomes. Each neuron cluster requires a certain amount of activation, known as the critical threshold. When connections between neuron clusters are too weak and the critical threshold is not exceeded, the neuron will not fire. When a cell assembly is active at a level above the critical threshold, it can be considered, at the functional level, a stored memory of an object connected to a position on our spatial map to keep track of the object's location. After a period of prolonged activity levels below the critical threshold, these cell assemblies begin to passively decay to allow new assemblies to become active. In this manner, cell assemblies can be equated to a memory "slot" of the discrete slots theory, one of the two classes of theories regarding VWM, suggesting that memory has a finite number of slots after which no further objects are stored. The other being that the VWM is a continuous resource that can be spread thin, less information is stored about each object. Current empirical evidence suggests that the discrete slots theory is more supported (Luck & Vogel, 2013). De Vries (2004) suggests that the cell assembly and the location on the spatial map, or a second cell assembly representing a different object, must be excited simultaneously in order for binding to occur. Lamme's (2003) paper relates memory and attention to consciousness on the functional level, his results indicating that even aspects not able to be recalled are initially stored in the VWM, supporting the theory that consciousness precedes attention, meaning a retroactive cue should be effective in strengthening the connections between memory traces. This is because for a cell assembly to fire, a critical threshold must be reached, similar to the action potential in muscles. It is potentially this lack of firing from a cell assembly that causes details to be missed, resulting in the change blindness phenomenon.

In the previous study by Braam et al., (2021) categories of image pairs were used to avoid the possible confounding variable of familiarity and to avoid activation overlaps in developed cell assemblies, although Pashler's (1988) study using characters rather than images suggested familiarity may not have a significant effect. This study will continue in the same direction, using image pairs. De Vries (2004), like Pashler, used letters in their study, with results suggesting that objects close in nature should cause overlapping cell assemblies to fire when recollected (i.e a cell assembly associated with a crocodile should similarly fire when recalling an alligator).

The Current Study

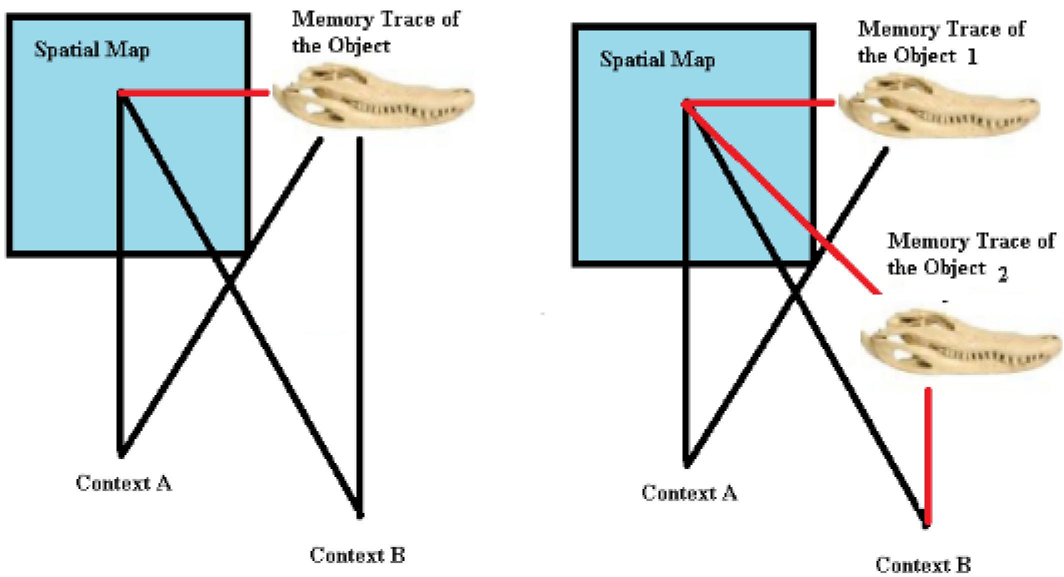
This paper aims to expand upon previous research by Braam et al. (2021) on change blindness through simple tasks, now with a focus on context, particularly temporal context. Fig.1 shows the role we expect context to have in binding and the strength of the memory trace over 2 trials, an interval of time being the change in context. The activation of the cell assembly should differ based on the familiarity of the context, meaning lower activity with fewer recurring objects. We predict then that sensitivity to change will be stronger if the memory trace of the changed target has already been activated in a previous context and in the spatial map as a recurring object from one trial to the next and especially so when displayed alongside objects from the first trial.

Additionally, it is part of a group of simultaneous bachelor thesis studies conducting the same experiment with differing experimental conditions with the shared hypothesis, that sensitivity to change as well as location accuracy and any interaction effect found to be occurring will correlate positively with the number of objects reappearing in the second trial of each pair and the target object being one of said reappearing objects.

Fig. 1

How Context affects Memory Traces in the Conceptual Network

Note: Red lines show temporary binding in VWM, black lines show permanent connections



Method

Participants

Our participants were recruited from two research services; Prolific (2023), a paid service, meaning participants received a small compensation of £2.50, and SONA; these participants were first year psychology students who are required to meet a quota of research participation and did not receive monetary compensation . A total of 47 participants took part in the experiment, 40 of which finished all 4 trial blocks. The ages ranged from 18 to 30, (M = 22.32, SD = 3.238). 28 participants were female with a mean age of 21.50 (SD = 3.168), 19 were male with a mean age of 23.53 (SD = 3.025). This experiment was approved by the Ethical Committee of the Department of Behavioural and Social Sciences of the University of Groningen.

Stimuli

The stimuli used for the study were 88 images obtained from https://konklab.fas.harvard.edu/ . These images of objects were pre-organised in pairs, with each pair consisting of a state change; for example one pair of images depicted an alligator skull, in the first with the jaw closed, the second with the jaw open (Fig. 2). The purpose of pairing these images is to create a detectable change for a depicted object, forming the foundation of our change blindness experiment. These pairs of images were then sorted into categories to protect against familiarity bias over several trials and to exclude the possibility of objects sharing similar identities and creating a confounding variable. The 11 image categories were : 'musical instruments', 'fruits and vegetables', 'athletic equipment', 'children's toys', 'portable storage/bags', 'household appliances', 'antiques', 'sweets', 'animals', 'household furniture' and 'stationary'. The number of 11 was chosen so as to always be able to introduce 5 non-recurring categories which, while only 3 were required in this experiment, was necessary for other researchers conducting experiments within the same study that had a condition in which 5 new objects were introduced per trial.

Fig. 2
Pair of images featuring a state change.

Design

In this study we used 3 binary factors for a 2x2x2 within subject experiment. Firstly, we controlled the number of objects (either 1 or 3) reappearing in the second trial of each pair of trials after also being present in the first. Secondly, whether or not the target in the second trial of each set was newly introduced or a recurring object from the first trial. Lastly, we controlled whether or not a change occurred in the target image between the pre- and post-change displays. This means there were 8 possible conditions for each set of trials.

Only the second trial of each set was used in the analysis, as we wanted to measure the change accuracy after the introduction of new objects to calculate the sensitivity and location accuracy for each condition.

The experiment aimed to measure the influence of these variables on the sensitivity to change, whether or not a change was correctly detected, as well as location accuracy, in the event of a change, whether the correct object was then also selected.

As an additional measure, we asked participants which strategy they used to approach the change blindness tasks, in order to determine if the participant had recognised the pair-based nature of the trials.

Procedure

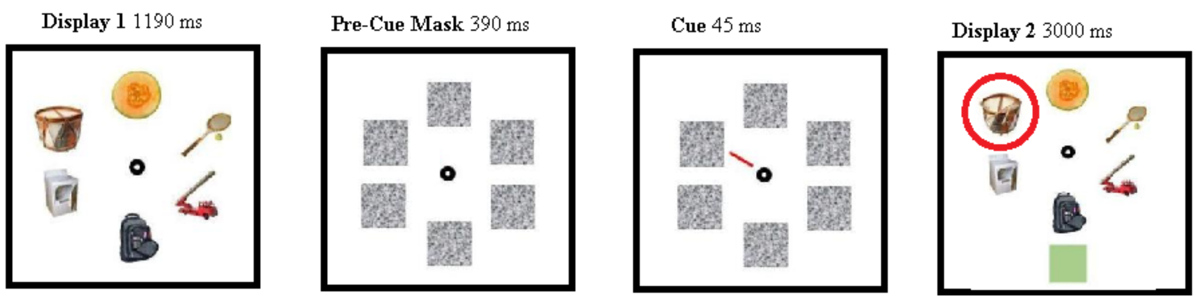
For this study, participants took part in the experiment remotely using a personal computer or laptop via the internet. Upon clicking the link to the experiment, they were taken to a Qualtrics (Qualtrics, 2023) webpage where they received instructions and expectations for the upcoming experiment, with a support email address provided in the case of questions. The nature of the experiment dictated that the instructions did not explain that our research focused on the role of temporal context. Afterwards, participants were requested to give their informed consent to have their data used in our analysis and, upon agreeing, could proceed to the experiment webpage.. The software used for the experiment itself was OSWeb (OSWeb, 2023). All participants in this study completed the experiment in English. Biographical data such as age, nationality and gender was provided by the service responsible for recruiting the participant, either Prolific or SONA.

After a prompt to begin, participants were given 2 practice blocks of 8 trials each in order to understand the process before beginning the trials used in our analysis. The data from these practice blocks were not used for the analysis, but were recorded. For only these practice blocks, feedback was given showing their success rate. Upon completion of the practice blocks, participants then completed 2 further blocks of 48 trials (6 per condition) each for 96 total..

At the beginning of each block, the participant was prompted to click a blue square to begin. 6 images positioned in a hexagon, equidistant (2cm distance on a 15” laptop screen) from a focus prompt in the centre of the screen, were then displayed for 1190 ms before being masked by noise-animated grey squares for 480 ms with a cue pointing towards the potentially changing target 90ms into the mask phase. Following the mask, the 6 images reappear, with the cued image changing depending on condition, the participant then had 3000ms to either click a green square below the display if there was no change, or select the changed object.. The second trial of each set follows the same procedure, but either 1 or 3 new objects are introduced, adjacent to one another. The new target of this second trial could either be one of the newly introduced images or one of the images reappearing from the first trial of the set. After completing the experiment, participants were asked to describe what strategy they used to identify changes.

Fig.3 Phase Durations

Note: Red circle in Display 2 shows the correct response, this was not visible to participants



Analysis

The analysis of our data was twofold, firstly to calculate sensitivity to change *d'*, we used signal detection theory (SDT) (Wickens, 2002). This is important, as changes are not simply identified correctly or incorrectly by participants, they are likely to have a tendency towards one option when unsure. There are four possible conditions for signal detections in this experiment: a change occurred and was detected, a change occurred and was not detected, no change occurred and no change was detected and lastly, no change occurred but the participant selected an object incorrectly. SDT allows us to correct for these participant biases, as we only examine trials in which a change did occur. *d'* values per condition per participant are then calculated by subtracting the z-scores of false positives from correct detections. To obtain the z-scores necessary to calculate the sensitivity *d we* corrected some participants' scores in extreme cases where they had either 0% or 100% scores in some conditions. We replaced 0.0 scores with 1/12 (= 0.5 * 1/Number of trials per condition) and 1.0 scores with 11/12 (= 1 - (0.5 * 1/Number of trials per condition). This simulates the participant having half a trial incorrect (or correct) and allows us to calculate z-scores without overly impacting the results. A repeated measures analysis of variance (RM-ANOVA) was then conducted on these d' values to determine if any differences between conditions are significant. A second RM-ANOVA was conducted to determine if these conditions had a significant effect on location accuracy; whether the participant selected the object that had changed.

Results

Two RM-ANOVAs were conducted for this study. For both RM-ANOVAs, all relevant assumptions were met and as such no corrections needed to be made. Small adjustments were made to participant scores in order to obtain the z-scores needed to calculate d' with signal detection theory.

Sensitivity

Based on our hypotheses, we expected the conditions with recurring targets and multiple recurring objects to return higher average means for sensitivity than new targets, with the recurring target amongst multiple reappearing objects scoring the highest. However, the descriptive statistics of d' (Table 1) seem to suggest a pattern of newly introduced objects alongside 1 recurring object being the highest scoring condition, contradictory to the expected pattern.

The results of the RM-ANOVA show that the number of recurring objects had no significant effect on sensitivity F (1, 39) = .268, p = .61. The same lack of significant effect was also found for whether the target was a recurring object or not F (1, 39) = .001, p = .98 as well as the interaction effect between the two F (1, 39) = .09, p = .773. These results contradict our hypotheses, as we predicted a positive relationship between a higher number of recurring objects and sensitivity as well as expecting a positive relationship between the target being a recurring object and sensitivity. The large overlap in confidence interval is visible in Fig. 3.

Table 1.

Descriptive Statistics of Sensitivity d' and Location Accuracy

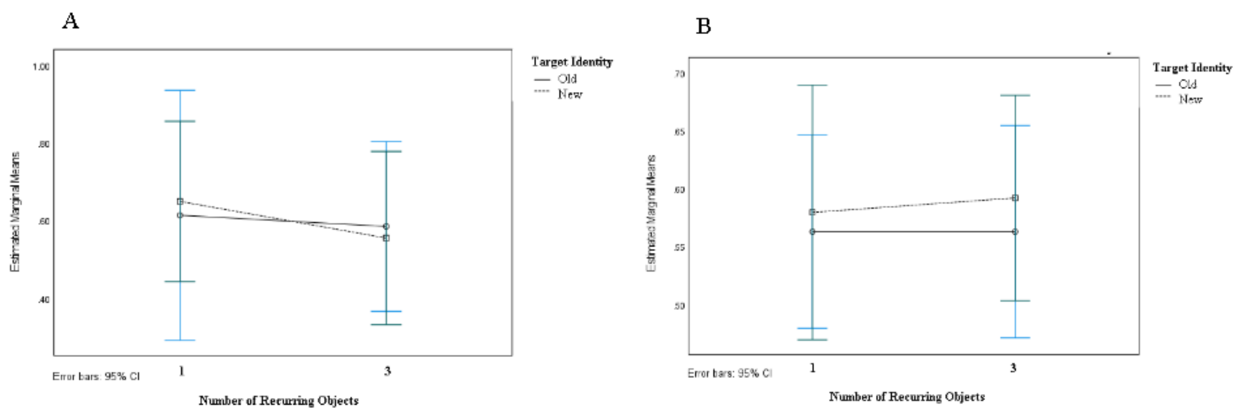
Condition	Mean	Std. Deviation	N
Sensitivity d'			
Recurring Target, 1 Recurring Object	.61	1.01	40
Recurring Target, 3 Recurring Objects	.58	.68	40
New Target, 1 Recurring Object	.65	.64	40
New Target, 3 Recurring Objects	.55	.69	40
Location Accuracy			
Recurring Target, 1 Recurring Object	.56	.26	40
Recurring Target, 3 Recurring Objects	.56	.29	40

New Target, 1 Recurring Object	.58	.34	40
New Target, 3 Recurring Objects	.59	.28	40

Fig. 3

A: Estimated Marginal Means of d' Sensitivity

B: Estimated Marginal Means of Location Accuracy



Location Accuracy

Our expectations for the location accuracy were the same as for sensitivity, and similarly to the descriptive statistics for sensitivity, the average score for location accuracy was higher in conditions in which the target was not a recurring object, contradicting our hypotheses. The pattern for the number of recurring objects is more in line with our expectations, but with a very small difference. The second RM-ANOVA resulted in a similarly insignificant set of results to the first. The number of recurring objects had an insignificant effect on location accuracy $F(1, 39) = .03$, $p = .86$. The target being a recurring object or not also had no significant effect $F(1, 39) = .12$, $p = .73$, as well as the interaction effect between the two independent variables F (1,

39) = .04, p = .85. Again, these results contradict the hypothesis we posed, that more recurring objects and a recurring target would correlate positively with location accuracy scores. Fig. 4 shows a similar overlap in confidence intervals to the previous graph relating to sensitivity, demonstrating the lack of significant effect.

Strategy Question

At the end of the experiment, participants were asked about the strategy they used to detect changes between displays. The reason for posing this strategy question was to see if any participants had realised that the trials were presented in consecutive pairs, with objects recurring from the first to the second, giving us some qualitative information about their results. Participants mainly mentioned focusing on the centre circle to keep an overview, no answers gave any indication that this pattern of trials was discovered or taken advantage of in any completed experiment.

Discussion

The aim of this study was to determine to what extent temporal context affects change blindness in the hopes of confirmation of hypotheses on a solution for the binding problem. In the introduction it was predicted that the temporal context, created by having objects repeated between pairs of trials, would give participants a subconscious advantage by strengthening the memory trace of the recurring object(s). It was expected that this stronger memory trace would facilitate the necessary activation required to recall an object more accurately and have a higher chance of forming a binding. The hypothesis presented was that the experiment would reveal a positive significant effect of both the controlled variables of number of recurring objects between trials and whether the target was one of these recurring objects upon the dependent variables of sensitivity to change and location accuracy in the selection of the correct object. Significant results of the conducted RM-ANOVA would have confirmed this hypothesis and supported the theory that temporal context has an impact on the binding of object information in the conceptual network model.

The results of the experiment did not support the hypothesis, no significant effect was found for any of the conditions on either sensitivity or location accuracy. The five sister studies conducted simultaneously using alternative experimental conditions; varying from 2-5 recurring objects and in part using exemplar image pairs, a green car and blue car being the pre- and post-change images for example, in place of state changed image pairs, as was the case in this experiment, revealed similarly insignificant results and lack of support for the hypotheses. The implications of these findings are that the effect of temporal context on binding may not be as strong as initially expected, or indeed not present at all. In fact, the descriptive statistics in Table 1 suggest a pattern in the opposite direction, that temporal context may even weaken sensitivity to change and to a lesser extent, location accuracy.

Limitations and Suggestions for Future Research

There are several possible causes for our experiment resulting in an insignificant result. Firstly, while the number of participants was quite large at over 240 for the study in its entirety, each participant took part in only one of six experimental conditions, with only 40 completing the experiment described in this paper. This limited sample size may have contributed to the lack of significance.

Possible limitations in the design of the experiment also exist; most participants scored only slightly above chance level, this could be an indication that the difficulty level of the experiment was too high and could be further tuned slightly to reduce guessing behaviour. Additionally regarding the design, the categorisation of the object pairs could be improved upon. The categories were not chosen with any scientific method, but by convenience from the images available in the database used, of which approximately one third of the image pairs were implemented in the experiment. The displayed objects also varied in colour; some were bright red and others a less eye-catching tan or beige in addition to being varied in real size, e.g a fire engine and a tennis racquet, and image quality, meaning changes may have been more recognizable in some objects than others.

Future research on this topic or a replication of this study would benefit from a larger participant sample size in addition to a more scientific, research-based approach to object selection and categorization, as previous research on the topic such as De Vries's paper on the effects of binding in object identification (2004) used black and white stimuli. The role of context in binding could be highly relevant in situations such as eye-witness accounts in court, in situations where context could play a larger role than in experimental conditions. An additional direction for research regarding the effect of temporal context on change blindness could include the level of temporal context as a controlled variable rather than both trials in a pair being consecutive.

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