The Role of Binding in the Change Detection of State-Changes: A Follow-up Study

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Abstract

Change blindness refers to the inability to detect changes during the visual perception. The current study focuses on the role of binding in the change detection of state-changes. Concerning the identity of the objects, we expected that when a target object shared its identity with another object on the screen the accuracy scores and confidence ratings would be higher. Concerning the distance we expected that placing the objects that share their identity adjacent would result in higher accuracy scores and confidence ratings. We therefore expected an interaction effect between identity and distance. The experiment had four different conditions; (i) The target object shares its identity with an object and are placed adjacent, (ii) The target object shares its identity with an object and are not placed adjacent, (iii) The identical objects do not share identity with the target object and are placed adjacent, and (iv) The identical objects do not share identity with the target object and are not placed adjacent. In the experiment, we used the identity cue to indicate next to which object a change would appear. In total, 42 participants took part in the change detection experiment. For both accuracy and confidence ratings the hypotheses on identity and distance were supported by the results. We also found an interaction effect for the dependent variable confidence ratings. No interaction effect was found for the accuracy scores, which opposes our hypothesis.

Keywords: Change blindness, binding, neural network, state-changes

The Role of Binding in the Change Detection of State-Changes

Change blindness is a widely studied phenomenon in cognitive psychology and related fields of research. This should not come as a surprise when you consider the fact that the world around us is constantly changing. Consequently, we are exposed to changes all the time. Being able to accurately detect change in daily life, would therefore be rather convenient. Considering the practical aspect of the ability to detect change, one may expect that we as humans are reasonably skilled. Nonetheless, research tells us otherwise. Change blindness implies that during the visual perception, a lot of changes are left unnoticed by the observer (Simsons & Levin, 1998). These changes could be in positions of objects, such as rotations, but also color and identity changes and even disappearing objects are left unnoticed (Lamme, 2003).

The current research is a follow-up study that builds upon the general knowledge in the field of change blindness, and most importantly, on the results that were obtained in the previous bachelor theses of Braam, Dzhurkov and Wazny (2021) and the master thesis of Manchev (2021). In these studies, they discussed the central role of binding within the change blindness process. During the binding process, the locations and identities of the objects become temporarily connected. These connections enable us to make accurate representations of our surroundings, which is essential for perception, action and decision making (De Vries, 2004). Without knowing the locations and identities of the objects, we would not be able to say if a change had happened, meaning that change blindness would occur.

When we are presented with multiple objects at once, a scanning mechanism becomes activated. This mechanism is necessary because we receive an overload of information from our surroundings. The working of this mechanism can be explained from a structural level. Structural models are used to explain the mechanisms behind certain processes. By means of this scanning mechanism, multiple objects are processed one by one. Despite this serial binding, the process takes place in such a quick manner, that we are still able to perceive our surroundings in one glance (De Vries, 2004).

At a structural level, binding is necessary for objects to receive the level of attention that is needed to enable us to detect change. Closely related to the mechanism behind this process, is the Hebbian learning rule (1949) which states that ‘cells that fire together, wire together’, meaning that when cells are repeatedly activated at the same time, they will become associated with one another (Keysers & Gazzola, 2014). Here, the concept of conceptual network becomes important. Within this network there are separate neural maps for the identity and the location of an object. In the spatial map, locations of objects are represented as excitation patterns. The object identities are represented as cell-assemblies, also referred to as memory traces at the functional level (De Vries, 2004). Given that a sufficient number of neurons becomes active, the excitation level of a certain cell-assembly of an object will autonomously rise to its maximum. Consequently, at the functional level, the activation of these memory traces will exceed the critical threshold, which will lead the location or identity of an object to receive attention and thus be in short-term memory (De Vries, 2004).

When discussing binding, we also need to consider the binding problem. When constructing a coherent perception of a single object, it is necessary to bind together the different properties of a certain object (e.g. object identity and its location). At the functional level, we know that this binding occurs, but at the structural level, we do not yet know exactly how the mechanism works (Manchev, 2021).

Instead of neural binding, many studies approach change blindness from the functional level. Here, the visual working memory (VWM) actively maintains representations of visual stimuli in our surroundings. The VWM holds representations of items so we do not lose this representation while participating in a proceeding task. This kind of memory enables us to fill in the temporal gaps and spatial shifts that are created by our eyes (Luck & Vogel, 2013).

Regarding the question of how many visual representations can be stored in the VWM, there are two different theories. Slot-based theories assume that only a limited number of items (Kmax) can be stored in the working memory for visual stimuli. When there is a larger number of visual stimuli than the VWM can hold in active maintenance, all information that exceeds the capacity of Kmax will not be stored. Resource-based theories, on the other hand, consider the capacity of the VWM to be flexible. Here, the resources are divided among all the items in the visual display. As a consequence of this division, there will be fewer resources available when the number of items in the visual display gets increasingly larger. In turn, this leads to a reduction in precision and accuracy in change detection (Luck & Vogel, 2013).

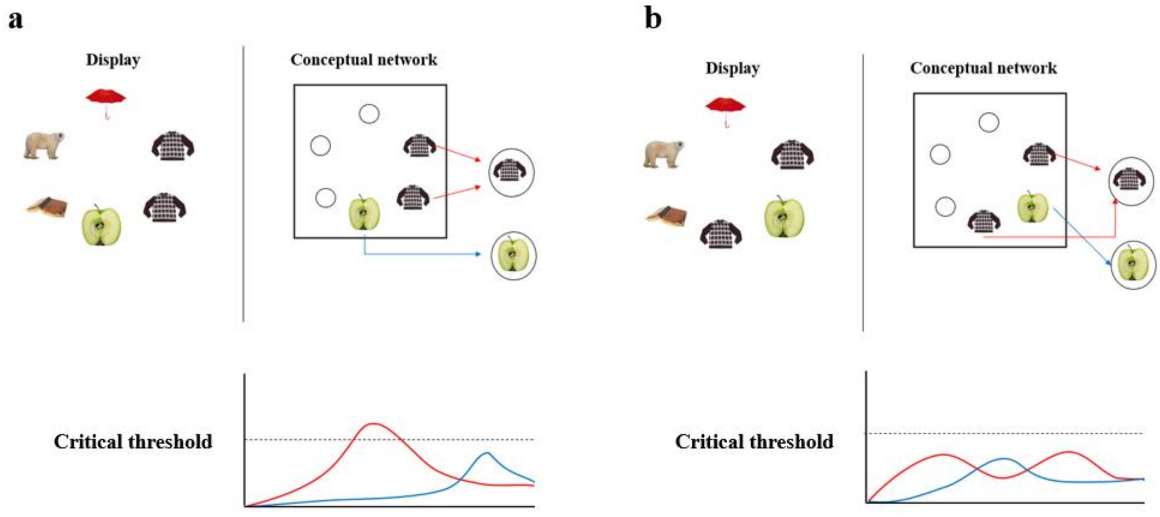
The previous bachelor theses concentrated on the role of binding in change blindness and were conducted as a further exploration of the role of VWM in change detection. To study the effects of binding on change blindness, they designed a change detection task in which the participants were required to indicate whether; (1) a change did or did not occur, and in the case that a change did occur, (2) if this change appeared on the right of the given cue, or (3) if this change appeared on the left of the given cue. In these tasks, different kinds of cues were used to indicate where the change would take place. Braam (2021) used an identity cue, which included an image that was shown in the middle of the screen, indicating the object location next to which a change would occur. The experiments of Dzhurkov (2021) and Wazny (2021) used a location cue. Here, a red arrow which pointed to the object location, next to a change in object would occur. The cues used in the experiments functioned as a reactivation of the memory trace of one of the objects in the pre-change display. Without cues, the experiment would be too complicated to perform.

There were two main expectations concerning shared identity of the objects and the distance between the identical objects. The idea is that when a cell-assembly is excited twice (the red lines in Figure 1), the excitation level of the cell-assembly of the object image reaches the critical threshold in a shorter amount of time, than when only one cell-assembly is activated (De Vries, 2004). Based on this idea, the first hypothesis stated that there would be a greater detection of change when the target object shared its identity with another object on the screen (Braam, 2021; Wazny, 2021). Findings suggest that the placement of the target object next to an identical object led to a simplification in a change detection task. This is confirmation for the binding hypothesis; images that are repeatedly presented together activate the same pathways, which leads the excitation levels of the cell-assemblies for these objects to faster reach their critical threshold. As stated earlier on, the exceeding of the critical threshold is believed to result in attention, and consequently to the detection of change in the stimuli.

The second hypothesis (Braam, 2021; Wazny, 2021) concerned the distance between the identical objects. When identical objects are placed adjacent to each other, the objects are bound right after each other (Figure 1a). As a result, it was expected that they will be more highly activated in our memory, which will lead the excitation level of the cell-assembly of an object image to faster reach the critical threshold. However, the results did not support this idea. There were also no supporting results found for an interaction effect between identity and distance; a combination of shared identity and adjacency did not lead to a higher accuracy scores. Dzhurkov's (2021), however, did find an interaction effect. Adjacency between the target object and its identical object resulted in the highest accuracy in change detection. The master thesis of Manchev (2021) also proposed the idea of an interaction effect between identity and distance. In addition to the identity cue and the location cue, which were used in the previous bachelor theses, Manchev introduced a third kind of cue, namely the extended identity cue. The extended identity is similar to the identity cue. The only difference is that the cue will remain visible while participants give their response. This addition was made after the different experiments of the study found mixed results for the state-changes. In accordance with the hypothesis, it was found that in shared identity and adjacency conditions, the accuracy of change detection was the highest. However, this was not found in all three experiments.

Figure 1

An example of a conceptual network where the target is placed next to its identical object (a) and where the identical objects are not placed next to the target (b) and the corresponding excitation patterns of the cell-assemblies and their critical thresholds. The arrows represent the temporary connections between the locations in the spatial map and the memory traces involved in the identities of the objects.



The previous bachelor theses found partial evidence for exemplar changes. For example, these kinds of changes can be illustrated with different breeds of dogs, as done by Manchev (2021). A Labradoodle and a Golden Retriever are two different exemplars, but they represent the same conceptual category ‘dog’. An example of a state-change is an open versus a closed book. The previous experiments, no evidence was found for the hypotheses when they concerned state-changes. Therefore, we will shift our full focus on state-changes. We will use the same three cues as were used before. Relative to the previous studies, we made some alterations to the experiments that will now be further described in detail.

In the first place, we incorporated the feedback that the previous experiments received. Some participants expressed their concern that the experiment was too difficult, because of the three answer options, as we described above; ‘Did a change occur? If yes, did it occur on the left or the right of the given cue?’ To make the current experiment less complicated, we reduced the response options from three to two. Participants now have to indicate whether; (1) a change occurred on the right of the cue, or (2) change occurred on the left of the cue. Therefore, each trial did contain a change.

The current research will use a different set of objects. We analyzed the objects that were used in the previous experiments to control for any unintended influences that could have had an effect on the results. We found that objects with different colors (i.e. a green train versus a red train) were easier to detect than objects that had little to no color changes. In the current object sets that are used in the experiments, we controlled for such color effects.

The last alteration is the inclusion of a confidence rating. After every trial, participants will need to express how confident they are in their choice. By doing so, we can take into account the effects of gambling by the participants on the results of our experiments. A participant that indicates low levels of confidence, could be guessing where the change occurred.

The central idea behind the current research is the same as in the previous studies, namely that a target object sharing its identity with an object in the pre-change display will facilitate greater change detection. We hypothesize that with an increasing distance between these identical stimuli, the strength of shared identity effect will decrease. In other words, placing the identical objects adjacent will lead to higher accuracy scores, due to the excitation level of a cell-assembly of an object reaching the critical threshold in a faster manner. In the current bachelor thesis the identity cue is used. The two other types of cueing are used in the other experiments of this larger study concerning change blindness (Garcia Martin, 2022; Griffiths, 2022; Houter, 2022; Piletti, 2022). It was assumed that the type of cueing would not affect the results of the experiments. The durations of the involved displays vary between the experiments due to the choices of the different researchers.

The current bachelor thesis will mostly extend on the results of the bachelor thesis of Braam (2021), since this experiment is most similar to the current one. Because our focus is on state-changes, we aim to test the effects of a shared object identity and the distance between the identical objects have in change detection of state-changes using an identity cue to indicate where the change took place. Our first hypothesis states that, similar as in exemplar changes, the change detection in state-changes will be more accurate when the target object also had its identical object present in the trial. Secondly, we expect that placing the identical objects adjacent will have a higher accuracy of change detection than when one object is in between. In the condition where the target object does not share its identity, we expect that the distance between the identical objects will not have an effect on the accuracy scores. These two hypotheses imply an interaction effect between identity and distance; a trial with shared identity and adjacency, would result in the highest accuracy scores. Regarding the confidence ratings, we propose the same hypotheses.

Method

Participants

The study was approved by the Ethics committee from the faculty of Behavioral and Social Sciences of the University of Groningen. Participants were recruited by means of announcements on the platforms Prolific and a participant pool of first-year psychology students at the University of Groningen. Volunteers from the social circles of the researchers were also allowed to participate in the experiment. The first-year students were provided with the corresponding credit points after participating in the experiment. Seven participants were removed from the data because they did not complete the experiment, which led us to a total of 42 participants. The sample included 33 females (78,6%) and nine males (21.4%). The age of the participants ranged from 18 to 56, with an average age of 20.89 (*SD* = 4.99). The average age for females was 20.95 (*SD* = 5.53) and for males 20.75 (*SD* = 2.41). The first-year psychology students' group (in total 37 participants) consisted of 29 females (*M* = 20.95, *SD* = 5.58) and eight males (*M* = 20.75, *SD* = 2.41). Among the five volunteers were four females (*M* = 21.63, *SD* = 7.45) and one 20-year-old male.

Stimuli

The object images that we used in the experiments were required via the website of the Harvard University Konklab (http://konklab.fas.harvard.edu/#). We first grouped the object images into pairs which included two different states of a particular object, for example a polar bear standing up and a polar bear laying down (Figure 2). We made two different sets of images, each containing six categories. Each category contained four pairs of objects. The object set used in the current experiment contained the following six categories: fruit, antiques, kitchen, tools, animal, and clothing/wearable. In each trial, one category was represented twice, so we could test the shared identity hypothesis. The six different categories enabled us to select significantly different objects for each trial. To test the shared identity hypothesis, we needed to ensure that the other objects presented in a trial were significantly different from the target object and its identical image. As mentioned before, we found that change detection was easier when the objects changed color. To ensure that we were measuring the identity of the changed objects, we controlled for any color changes that could have had an influence on the results of the previous studies (Braam, 2021; Dzhurkov, 2021; Manchev, 2021; Wazny, 2021).

Figure 2

Example of a state-change.

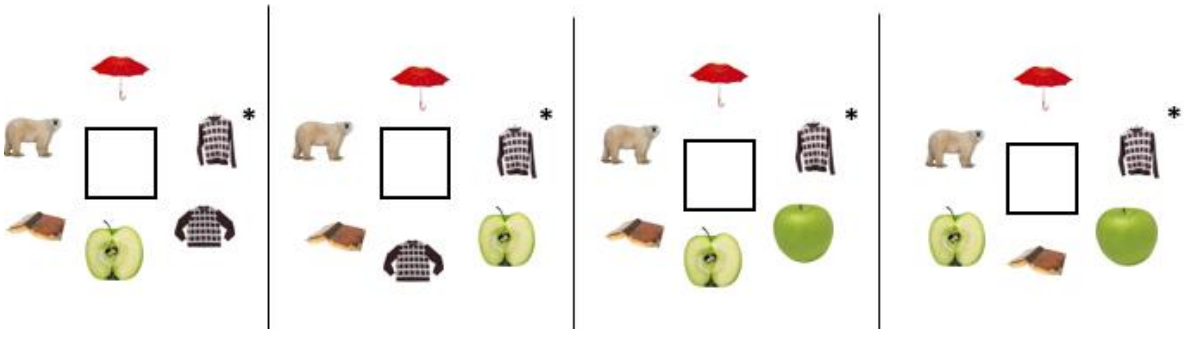
Design

The experiment focused on two independent variables, namely the shared identity between the target object and an identical object and the distance between two identical objects. Each of the independent variables had two levels. The identity of the target object could either be unique or the target shared its identity with an object in the trial. The identical objects could either be placed adjacent or nonadjacent. A combination of the different levels of the independent variables results in four different conditions (Figure 3).

The experiment had two dependent variables, namely the accuracy scores on each condition and the corresponding confidence ratings. The accuracy scores were based on the average scores for each condition and were indicated by a number between zero and one. The confidence ratings were presented in the experiment by five different green squares (see

Figure 3

Examples of the four conditions.



Note. The target object is indicated with a '*'. From left to right; the target object shares its identity with an object and are placed adjacent. The target object shares its identity with an object and are not placed adjacent. The identical objects do not share identity with the target object and are placed adjacent. The identical objects do not share identity with the target object and are not placed adjacent.

Figure 4a screen 4) which were later labeled with the numbers one to five. Again, we used the average scores for convenience.

Procedure

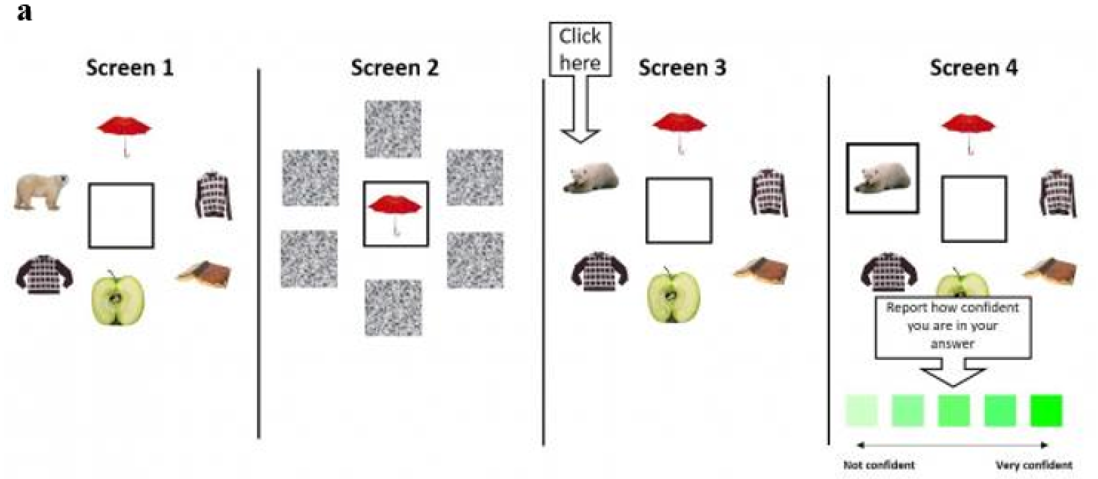
The experiment was conducted online. Volunteers from the social circles of the researchers received a URL-link, which provided excess to the experiment. Prior to the experiment the participants were given preliminary information, ethical formalities, and an informed consent via the online survey software Qualtrics Survey Solutions (www.qualtrics.com). After the information about the procedure and the purpose of the study, the participants could agree or disagree with the participation in the experiment. When they agreed, we first collected some bio data (age and gender) from the participants before they were led to the online experiment, where they were provided with instructions on how to correctly perform the experiment (see Appendix A). Participants could perform the experiment on a computer or laptop via OSWeb (Mathôt & March, in press). Starting the experiment, the participants first got two practice blocks, which each contained eight trials. This was provided with the aim to get familiar with the object images and the speed of experiment. In these practice trials, the participants got visual feedback on if they correctly identified the change or not. The square in the middle of the screen (Figure 4a), would turn green for a correct answer, and red for an incorrect answer after the third screen. After this, the real experiment took place, which did not contain this feedback and consisted of four experimental blocks with 24 trials. The participants could start each trial when they felt ready by clicking on the blue square in the middle of the screen. Each trial was made out of four screens (Figure 4a). The first screen, called the pre-change display, contained six objects which were displayed in a circle. The second screen contained a mask consisting of six grey squares which blocked the objects from visual interpretation. By doing this, we ensured that the change detection depended on the working memory instead of the sensory memory. The identity cue was placed in the middle of this second screen and indicated next to which an object image would change in the third screen. Participants had to identify the target object by clicking on it. The last screen contained a confidence rating that consisted of five green squares. The square most on the left indicated that the participant was not very confident in the response or that the participant was guessing where the change took place. Consequently, by clicking on the square that was most to the right, participants indicated that they were very confident in perceiving a change. On average, participants took 18 minutes and 39 seconds to complete the experiment.

At the end of the experiment, the participants were provided with their personal data and a brief explanation of their results. A bar graph was presented that corresponded with their accuracy of change detection in the task. The graph displayed the accuracy scores for the four different conditions (Figure 3).

Figure 4

Instructions provided to the participants (a) and the durations of the screens in ms (b).

a



b

Pre-trial screen (blue square)	Until response
Blank screen	500
Reference screen (circle or square)	100
Pre-change display (screen 1)	1200
Interval before retro cue	400
Duration Retro Cue (screen 2)	250
Interval after retro cue	750
Post-change display (screen 3)	Until response

Statistical analysis

After the data collection, the outcomes from the change blindness task were presented in an Excel file. We aggregated and restructured the data in SPSS following the method of Lacroix & Giguère (2006) to make sure the data would have the right format for our analyses. After restructuring the raw data, each participant was presented by the mean accuracy of the change detection and the mean confidence rating for each condition. The three assumptions for a repeated measure ANOVA were met. To investigate the interaction effect between identity, distance, and the accuracy scores, we first performed a repeated measures ANOVA. After this, we performed two one-way ANOVAs to further investigate the interaction effect. For the confidence ratings, we performed the same analyses.

Results

Our hypotheses were similar to those in the previous bachelor theses. Our first hypothesis was based on identity; we expected that the change detection in state-changes would be more accurate when the target object shared its identity with another object on the screen. The second hypothesis was based on the distance between the identical objects; we expected adjacency would lead to higher accuracy of change detection than when one object was in between the identical objects. The overall assumption was that participants would have better scores on the change detection task when the target object shared its identity with another object in the trial and were placed next to each other. This implies an interaction effect between identity and distance. Regarding the confidence ratings, the hypotheses are similar to those for accuracy; first, we hypothesize that there would be an interaction effect between distance and identity. Besides that, we expected that participants would be more confident in their responses when the target object shared its identity. Lastly, we expect that the confidence ratings would be higher when the identical objects were placed adjacent to each other. Before conducting the analyses, we checked if the three assumptions for a repeated measure ANOVA were met. Each observation was independent, there were no outliers and the sphericity assumption was determined by the Mauchly's tests.

Accuracy

The descriptive statistics of the four conditions for the independent variables identity and distance are displayed in Figure 5a. A repeated measures ANOVA was conducted to investigate whether an interaction effect exists between the two independent variables. The multivariate tests showed a non-significant interaction effect ($F(1, 41) = 0.12$, $p = 0.73$, partial $\eta 2 = 0.00$) between identity and distance. This result opposes our interaction hypothesis.

To investigate the absence of an interaction effect, two separate one-way ANOVAs were conducted. We controlled for the variable identity, so we could examine whether identical objects that are placed next to each other have higher accuracy scores than identical objects that are not placed next to each other. In the no shared identity condition, the multivariate test showed no statistically significant difference in the accuracy scores of the participants based on the distance ($F(1, 41) = 2.82$, $p = 0.10$, partial $\eta 2 = .06$). As indicated by the 95% confidence interval ($M = 0.03$, $SE = 0.02$, 95% CI [-0.01, 0.07]) provided in by the pairwise comparisons, adjacency ($M = 0.53$, $SE = 0.03$, 95% CI [0.47, 0.59]) did not lead to higher accuracy scores than non-adjacent objects ($M = 0.49$, $SE = 0.03$, 95% CI [0.43, 0.56]), as this confidence interval does include zero. These results are in line with our expectations; we expected that adjacency would not influence the accuracy outcomes when the target object did not share its identity with another object. In the one-way ANOVA for the shared identity condition, we did find a significant difference in accuracy scores ($F(1, 41) = 7.28$, $p = 0.01$, partial $\eta 2 = .15$). Looking at the pairwise comparisons, the 95% confidence interval ($M = 0.04$, $SE = 0.02$, 95% CI [0.01, 0.07]) does not include zero, which indicates that the accuracy scores are significantly higher when the identical objects are placed adjacent ($M = 0.75$, $SE = 0.03$, 95% CI [0.70, 0.81]) than when they are not placed adjacent ($M = 0.71$, $SE = 0.02$, 95%

CI [0.66, 0.76]). These results support our hypothesis that participants have higher accuracy responses in the change blindness task when the identical objects are placed next to each other. However, since the overall interaction effect is not significant, the variable distance does not have an additional effect on the shared identity in the accuracy of change detection.

The main effect for identity was found to be statistically significant ($F(1, 41) = 94.45$, $p < 0.00$, partial $\eta 2 = .70$). The confidence interval ($M = 0.22$, $SE = 0.02$, 95% CI [0.18, 0.27]) provided by the pairwise comparisons indicates that shared identity ($M = 0.73$, $SE = 0.03$, 95% CI [0.68, 0.78]) has significantly higher accuracy scores than the no shared identity condition ($M = 0.51$, $SE = 0.03$, 95% CI [0.45, 0.57]). These results support our identity hypothesis. The main effect for distance was also found to be statistically significant ($F(1, 41) = 9.03$, $p = 0.01$, partial $\eta 2 = .18$). The confidence interval provided by the pairwise comparisons ($M = 0.04$, $SE = 0.01$, 95% CI [0.01, 0.06]) indicates that the accuracy scores were higher when the objects were placed adjacent ($M = 0.64$, $SE = 0.03$, 95% CI [0.59, 0.69]) than when they were placed non-adjacent ($M = 0.60$, $SE = 0.03$, 95% CI [0.55, 0.65]). These results are in line with the hypothesis on distance.

Confidence ratings

To investigate the effects of distance and identity on the confidence that the participants had in their responses, we performed similar analyses as we did above for the accuracy of change detection. The descriptive statistics are presented in Figure 5b. First, a repeated measures ANOVA was conducted to evaluate a possible interaction effect. An interaction effect was found ($F(1, 41) = 5.55$, $p = 0.02$, partial $\eta 2 = 0.12$) determined by the multivariate test, which supports our interaction hypothesis.

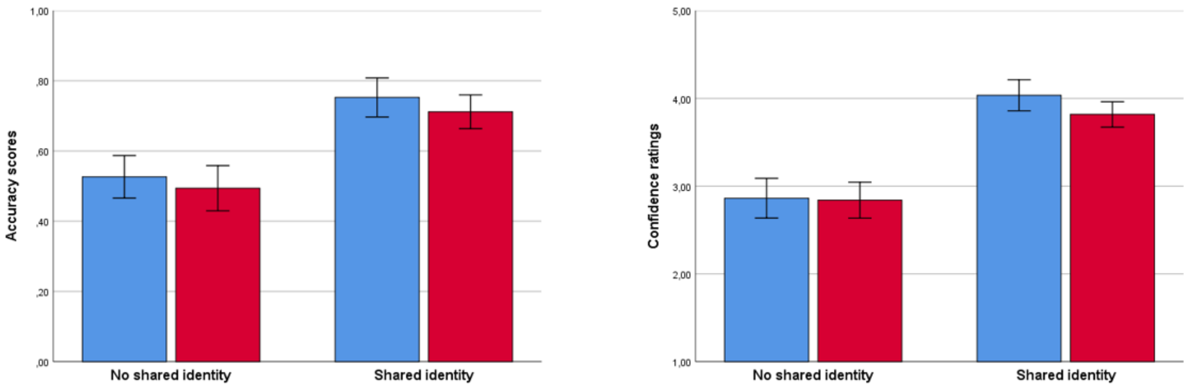
Two one-ways ANOVAs were performed to investigate this interaction effect. In the first analysis, there was no statistically significant difference in the confidence ratings based on distance in the no shared identity condition ($F(1, 41) = 0.15$, $p = 0.70$, partial $\eta 2 = 0.00$), which we predicted. According to the pairwise comparisons, placing the objects adjacent (*M* = 2.86, *SE* = 0.11, 95% CI [2.64, 3.09]) did not lead to significantly higher confidence ratings compared to when the objects were not placed adjacent (*M* = 2.84, *SE* = 0.10, 95% CI [2.64, 3.05]) in the condition where the target object did not share its identity. This was indicated by the 95% confidence interval (*M* = 0.02, *SE* = 0.06, 95% CI [-0.09, 0.14]). The second one-way ANOVA was performed to examine the effect of distance on the confidence ratings in the shared identity condition. Here, a statistically significant difference was determined by the multivariate tests ($F(1, 41) = 15.81$, $p < 0.00$, partial $\eta 2 = 0.28$). The pairwise comparisons showed that placing the objects adjacent (*M* = 4.04, *SE* = 0.09, 95% CI [3.86, 4.21]) led to higher confidence ratings than when there was one object in between (*M* = 3.82, *SE* = 0.07, 95% CI [3.67, 3.96]). The 95% confidence interval (*M* = 0.22, *SE* = 0.06, 95% CI [0.11, 0.33]) does not include zero, confirming that this difference is statistically significant. These results support our hypothesis; we expected that placing objects next to each other would result in higher confidence ratings from the participants.

Looking at the main effect for identity, we found a statistically significant effect ($F(1, 41) = 126.62$, $p < 0.00$, partial $\eta 2 = .76$). The pairwise comparisons provide us with an 95% confidence interval (*M* = 1.07, *SE* = 0.10, 95% CI [0.88, 1.27]) that does not include the value zero, indicating that shared identity (*M* = 3.93, *SE* = 0.08, 95% CI [3.77, 4.08]) has significantly higher scores on confidence ratings that when the target did not share its identity with another object (*M* = 2.85, *SE* = 0.10, 95% CI [2.64, 3.06]). The main effect for distance was also found to be statistically significant ($F(1, 41) = 10.49$, $p = 0.00$, partial $\eta 2 = .20$). The confidence interval provided by the pairwise comparisons (*M* = 0.12, *SE* = 0.04, 95% CI [0.05, 0.20]) indicates that the confidence ratings were higher when the objects were placed next to each other (*M* = 3.45, *SE* = 0.08, 95% CI [3.29, 3.61]) than when they were not (*M* = 3.33, *SE* = 0.08, 95% CI [3.17, 3.48]). These results support our hypotheses.

Figure 5

Bar graphs displaying the effects of identity and distance on accuracy scores (a) and confidence ratings (b). The blue bars represent adjacency of the identical objects. The red bars represent that the objects were not placed adjacent. Error bars: 95% CI.

a **b**



Discussion

The purpose of this study was to investigate the previous findings (Braam, 2021; Dzhurkov, 2021; Manchev, 2021; Wazny, 2021) for state-changes. We expected an interaction between shared identity and adjacency; a combination between the target object sharing its identity with another object on the screen and placing the objects adjacent would lead to the highest accuracy scores. The results, however, did not support this hypothesis. This could mean that a combination of shared identity and adjacency does not have an additional effect on the accuracy scores.

The second hypothesis was based on identity; we predicted higher accuracy scores when the target shared its identity with another object in the trial. The results support this hypothesis. These results can be explained by looking back at Figure 1. When objects are repeatedly presented together (Figure 1a), which is the case in the shared identity condition, they will activate the same pathway, which will consequently lead the excitation levels of a certain cell-assembly of an object to reach its critical threshold in a faster manner. As stated before, if the critical threshold is exceeded, an object will be in short-term memory. The temporal excitation pattern of a cell-assembly of a unique object does not exceed the critical threshold (Figure 1b), meaning change blindness is likely to occur.

The last hypothesis regarding the accuracy was based on distance. We found support for our hypothesis; when the target and its identical object are placed adjacent, the accuracy scores were higher. As displayed in Figure 1a, two identical objects that are placed adjacent to each other become bound right after each other, which leads to the excitation level of a cell-assembly of an object to reach the critical threshold faster. We observed a slight difference in the accuracy of change detection in the no shared identity condition (Figure 5a). This could mean that, even though the target did not share its identity with an object on the screen, two identical objects placed adjacent in the trial could make the change detection slightly easier for participants.

Regarding the confidence ratings, we found similar results. Participants reported higher confidence ratings for the conditions when the target shared its identity with another object on the screen. They also reported higher confidence scores when the target object and its identical object were placed adjacent. The only difference in comparison with the accuracy results is that we did find an interaction effect for the confidence ratings. This could mean that even though participants felt more confident in their responses in conditions with shared identity and adjacency, their accuracy scores were not significantly higher. This overestimation in confidence could be due to the participants (unconsciously) using a ‘rule’ when they saw two identical objects presented, and therefore feeling more confident in their response.

Compared to the other experiments of this larger study (Garcia Martin, 2022; Griffiths, 2022; Houter, 2022; Piletti, 2022), most of the results were consistent with each other. All studies found that adjacency had no influence in the no shared identity condition. In addition, all experiments found confirmation for the shared identity hypothesis. Regarding the confidence ratings, all experiments found a significant interaction effect between identity and distance. Similar as in the current study, Houter (2022) found an interaction effect between identity and distance for the confidence ratings, but not for the accuracy scores. The similarity in results could be due to the fact that the used cues are similar. As stated before, the only difference between the identity cue and the extended identity cue is how long the cue will remain on the screen.

Some findings in the larger studies that were not consistent with the current study. Both Garcia Martin (2022) and Griffiths (2022) used the location cue and found an interaction effect between identity and distance on the accuracy scores of the change blindness experiment, which may imply that the type of cueing does matter. A possible explanation for these results is that participants found it easier to remember an object location than yet another object identity to indicate next to where the change took place, as is the case in the identity cue. Piletti (2022) did not find a significant effect for the variable distance in the accuracy scores of the experiment. The difference in findings could be due to the different presentation times for the pre-change screens. The current experiment used a relatively longer pre-change display. We expect that longer presentation of the objects has a positive effect on the accuracy of change detection.

To a great extent, the results are consistent with the results of the previous studies (Braam, 2021; Dzhurkov, 2021; Manchev 2021; Wazny, 2021). Similar to these studies, we found significant effects of identity on the accuracy scores. Braam (2021) did not find a significant effect of distance, whereas the current experiment did. In their thesis they stated that the absence of this effect could be due to the number of objects and the presentation time of the display. Just like Braam's experiment, the current study did not find an interaction effect of identity and distance in the accuracy scores of the experiment. Dzhurkov (2021), however, did find a significant interaction effect. This discrepancy in results could be due to the difference in the detection of exemplar and state-changes. The exemplar changes are more explicit than the change in the state of an object. This could mean that two different occurrences of state-changes activate the same cell-assembly of an object less strongly than exemplar changes, which makes it more difficult to detect the change.

De Vries (2004) already illustrated the results of these studies by focusing on letters. Here, it was concluded that when the target letter was present multiple times in the display, the responses were faster and more accurate. In line with this, we found that the display of shared identity leads to a simplification of the change detection task. The presence of identical objects means that participants need to remember less different objects than when all the objects in the trial were different, which leads to a simplification of the task. The current study can add a practical aspect to the findings of De Vries; the effects of changing objects are more similar to real world experiences than the changing of letters.

Since the experiments using the location cue (Garcia Martin, 2022; Griffiths, 2022) exclusively found a significant interaction effect between identity and distance on the accuracy scores, future research should investigate whether the type of cueing in a change blindness experiment affects the accuracy of change detection. Future research should also investigate the discrepancy between the actual accuracy scores of the participants and their confidence ratings that we found in the experiments (Houter, 2022; Piletti, 2022).

The study has a few limitations. We used a relatively small sample. For the most part, the sample consisted of first-year psychology students, which means that the sample is not representative for the general population. Because of the online experiment, we could not control the environment in which the experiment took place. We also could not answer any questions that the participants might have had.

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Appendix A

Instructions for the experiment

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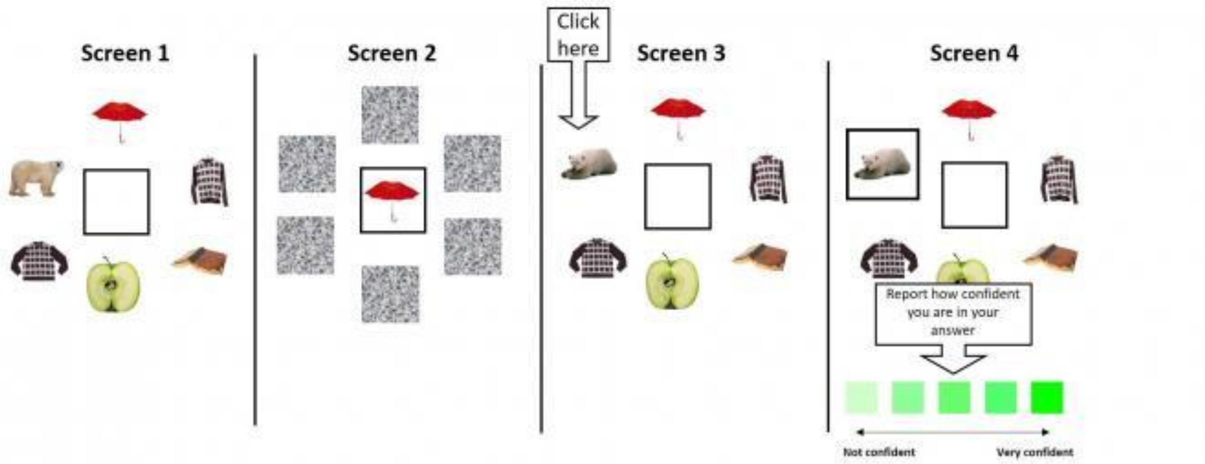
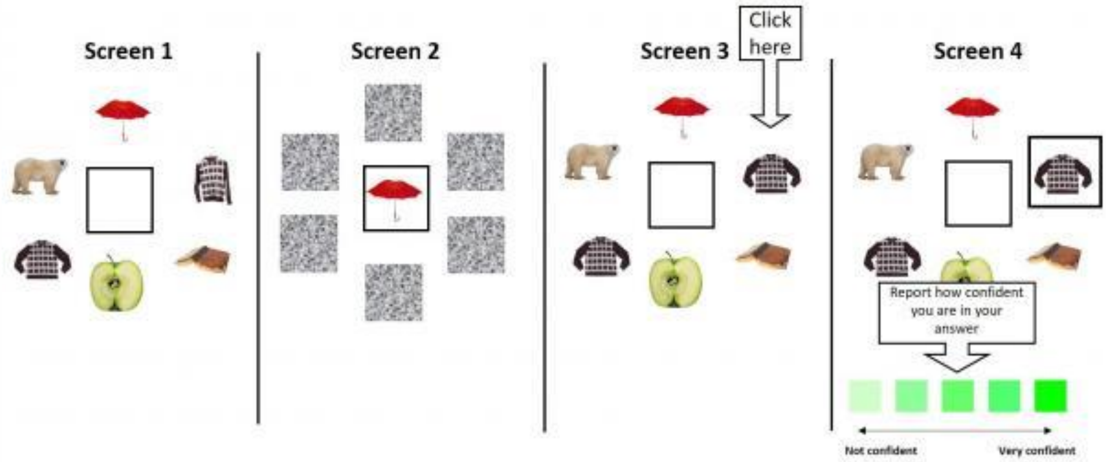
The experiment contains several trials. Each trial consists of 4 screens that are displayed one after the other. Your task is to remember the objects in Screen 1 because after they have been masked by Screen 2, you have to decide in Screen 3 which one of the previously displayed objects has changed. Since Screen 1 is presented only briefly, Screen 2 contains a cue to help you. In Screen 2, the object in the square is the cue and it is always identical to exactly one of the objects on the circle. This object on the circle is the cued object. In each trial, a single object, either to the left or to the right of the cue, will change. Below you see an example of a trial where the object to the left of the cue has undergone a change. You must click on the object that changed.



Once you have selected the object you believe underwent a change from Screen 1 to Screen 3, you will need to report how confident you are in your choice. To do so, a row of five green squares varying in brightness will appear in Screen 4. The five squares reflect five degrees of confidence, varying from ‘not confident’ for the left most square to ‘very confident’ for the right most square. Click on the square that indicates the confidence that you have in your choice.

Alternatively, if the object to the right of the cued object has changed, you click on that one, as shown in the example below.
Screen 1 will always show six objects and only one of them will change. They all have the same chance for a change. In all trials, two of the displayed objects are similar to each other whereas the other four are unique.



Afterwards, you again need to rate how confident you are that you saw the change, just as in the previous example. Please, choose the square that best represents how confident you are in your answer. If you did not notice a change and are guessing, please select the response that represents having the least confidence. The speed at which you respond will not be measured, as this is not a reaction time task. However, it is a memory task, meaning taking excessively long will increase risk of forgetting the correct response. Please complete the task at the speed in which you are most able to notice, and report the correct object

Is everything clear? If necessary, you can go back to consult the previous instruction pages.
We will proceed with two small practice blocks of eight trials. You can start each trial by clicking on a blue square. In different trials the changed object can occur at each of the six locations but in each trial only one object can change, not more. After a correct response to a practice trial, the square in the center of the screen will turn from black into green. After an incorrect response, it will turn red. In the trials of the experiment itself, this feedback will no longer occur
Please, be as accurate as possible. Good luck!