Spring 2018

Contextually Cued Visual Sequences of Attention

William Narhi

CONTEXTUALLY CUED VISUAL SEQUENCES OF ATTENTION

by

William Narhi

A thesis submitted in partial fulfillment of the requirements
for graduation with Honors in the Psychology

Andrew Hollingworth
Thesis Mentor

Spring 2018

All requirements for graduation with Honors in the
Psychology have been completed.

J. Toby Mordkoff
Psychology Honors Advisor

CONTEXTUALLY CUED VISUAL SEQUENCES OF ATTENTION

by

William Narhi

A thesis submitted in partial fulfillment of the requirements
for graduation with Honors in Psychology

Andrew Hollingworth
Thesis Advisor

Spring, 2018

All requirements for graduation with Honors in Psychology have been completed.

J. Toby Mordkoff
Psychology Honors Advisor

Abstract

Repeated exposure to a context has the ability to guide attention toward task-relevant locations, often without awareness. Previous research on contextual cuing typically uses only one relevant location for each context. Thus, in the present study, we aimed to measure whether multiple locations could be contextually cued for each context. Moreover, each trial required a sequence of eye movements as each location had to be fixated in a specific order. A second experiment sought to observe the automaticity of these sequential eye movements with the implementation of a transfer task. Results for the first experiment and the training phase of the second experiment showed significant improvement in performance for repeated versus novel contexts. Surprisingly, in Experiment 2, the learned sequence of eye movements did not transfer to a novel task in the same context. In addition, exit questions suggested higher levels of context repetition awareness than in most previous contextual cuing studies.

Introduction

When approaching a four-way intersection, a conscientious driver will check multiple areas in their visual field to decide as quickly as possible when it is safe for them to proceed. The driver may check for crossing pedestrians and the color of the traffic light for their lane (Groeger, 2001). This task requires the intelligent use of visual attention. One well studied aspect of visual attention is what determines where gaze is first directed upon exposure to a scene. A study by Neider and Zelinsky (2006) found that search was facilitated for targets which were scene-constrained, with more initial eye movements being directed towards consistent target locations in repeated scenes. In the present study, we ought to extend past what may attract our initial attention, and instead investigate what can influence where our second or third saccades are directed in a scene. When confronted with a familiar scene and a familiar task which requires fixated multiple objects, such as proceeding safely through a four-way intersection, do we instantiate a similar behavioral pattern each time?

To investigate this issue, we used a modified contextual cueing task. Contextual cueing refers to the ability for a consistent arrangement of stimuli to direct attention to task-relevant locations (Chung & Jiang, 1998: see Chun, 2000, for a review). Interestingly, participants were unable to recognize the repeated arrays during follow-up questioning. A later study by Olson and Chun (2001) found that temporally patterned events could also be used to contextually cue target locations. In the present study, we attempted to extend the contextual cuing phenomena to multiple relevant locations that were required to be fixated in order.to complete the task. Specifically, participants spelled a word with their eye movements by sequentially fixating each letter individually. To our knowledge, no previous study has attempted to examine the effects of contextual cuing when multiple targets are present in a single array. As such, our novel design which mandates fixating multiple targets in a specific pattern in order to complete each trial is the first to use multiple targets and sequence learning in a contextual cuing paradigm.

Due to our task requiring the learning of multiple relevant locations and a specific sequence for them, there was a possibility that attempting to learn both of these types of information at once would have impeded one another due to competition for cognitive resources. However, a study by Jiménez and Vázquez (2011) concluded that implicit sequence learning and contextual cuing could be learned at the same time without a corresponding cost. Their series of experiments demonstrated that both a complex response sequence and contextual cues could be used to facilitate search, suggesting that these two types of learning processes do not utilize the same cognitive resources. Based on these results, we anticipated that our sequence of target locations that were indicated by their context would similarly not be hindered by competition for central cognitive resources. Importantly, however, as with most of the research done in the sequential learning field, Jiménez and Vázquez’s sequence consisted of a pattern of target identities over a series of trials, which also translated into a response pattern. Our study differs from this methodology by used a pattern of visuospatial locations contained within a single array, which call for a specific sequence of eye movements to complete each trial.

Although our main goal in the present investigation concerned the extent to which a contextually cued sequence of eye movements could be learned, we were also interested in the automaticity of this learning. Previous experiments in the statistical learning literature have demonstrated that effects similar to contextual cueing typically do not transfer. For example, Jiang et al. 2015 divided arbitrary search/foraging arrays into four quadrants and biased targets to appear more often in one of the quadrants during training, which was labeled the “rich region”. Their results showed that, over time, participants became more efficient at finding the target when it appeared in the rich region compared to non-rich regions. Interestingly, participants were not aware of which region was rich, a finding consistent with past research in probability cuing. More importantly, they included a testing phase designed to assess whether the successful probability cuing would transfer to a distinct task (standard search task versus foraging-like task). Their results showed no transfer effects were present when trained on either of the two tasks and testing on the other, suggesting that the type of statistical learning used in their study does not transfer across tasks. In Experiment 2, we examined whether the contextual cuing of multiple targets in a sequence transferred to a novel search task in order to assess the automaticity of the eye movement sequence. We expected that this sequence of eye movements might transfer because if a distinct context proves itself to be a strong enough cue to direct multiple eye movements, we believed that this behavior may become automatic enough to continue so long as the context remains the same, even when presented with a new task.

In sum, in the present experiments we sought to be able to show whether or not repeated contexts would be able to cue for a sequence of multiple targets, thereby improving performance over time and when compared to novel contexts. We then attempted to observe the transferability of this effect to a new task, in addition to increasing the number of learnable contexts. Exit questions after each experiment were designed to test how apparent the repetition of certain arrays was, as well as the ability of participants to recognize these contexts.

Experiment 1

Experiment 1 examined whether a correct sequence of relevant locations could be learned when presented in a reoccurring context. To do this, arrays of six empty rings were used as contexts. Inside each ring was an alphanumeric character that appeared only when fixated. The task was to spell a three-letter word, ‘ANT’, in the correct order and without interruption, which ensured that the desired sequence of specific eye movements had to be conducted in every array and was always the last three eye movements on any trial.

Method

Participants

Twelve participants (eight female) from the University of Iowa completed the experiment for course credit. Each reported to have normal or corrected-to-normal vision.

Apparatus

Stimuli were viewed on an LCD monitor (resolution: 1280 x 960 pixels) with a 100 Hz refresh rate at a distance of 77 cm. A chin and forehead rest were used in order to maintain this distance as well as the head position of the participants, in order for their right eye to be monitored by a SR Research Eyelink 1000 eyetracker, sampling at 1000 Hz. A standard keyboard was used to record the responses to the exit questions. The experiment was controlled with E-prime software.

Stimuli

Six identical white rings on a black background appeared on every trial, each with an inner diameter of 2.3° of visual angle and a width of .10°, along with a central grayscale fixation cross subtending 0.61° x 0.61° (Figure 1). These rings would appear at randomly generated locations in novel arrays, and in consistent arrangements in repeated arrays that were randomly determined for each participant at the start of the experiment. Rings would change to green (RGB: 0,255,0) when a relevant interest area was being viewed in the correct order of progression for each trial, and back to white if a mistake was made.

Each ring contained one of the following: the letter “A”, “N”, or “T”, or “#”, each located in the center and subtending .67°x.67°. These stimuli would appear to the participant when the eyetracker recorded 12 consecutive samples within a range of 1.57° from the center of each ring and would disappear immediately a sample was detected outside this range.

Procedure

After providing consent, participants were given both oral and written instructions. One participant was conducted at a time with an experimenter present to calibrate the eyetracker and ensure that the center of the screen was being fixated before manually starting each trial. The task was to spell the word ‘ANT’ with their eyes, one letter at a time, in that order and without interruption. Each trial began with the eyes at central fixation. After a 500 ms delay, six empty white rings would appear simultaneously. In order to find the three relevant letters were on each trial, the participants needed to move their eyes and fixate a ring. The revealed stimuli would

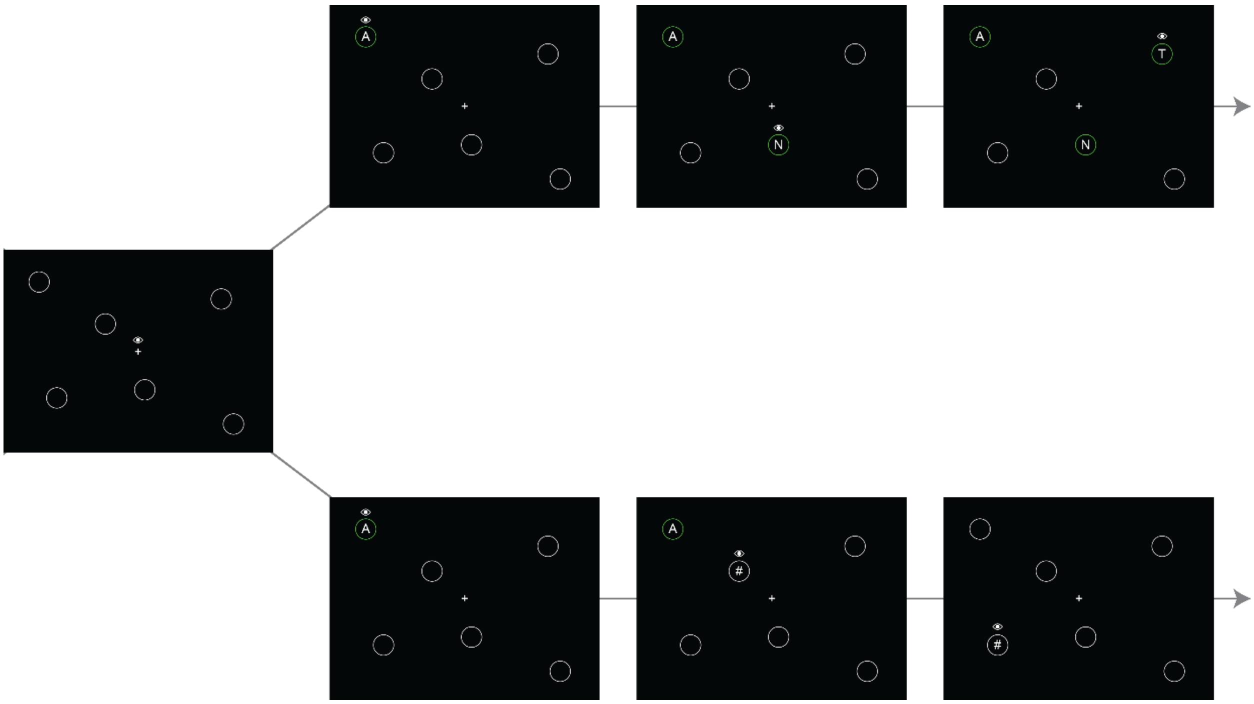

Figure 1. Participants were instructed to spell the word ‘ANT’ with their eye movements by fixating rings in order to reveal the hidden characters. The two paths indicate two possible scenarios for how this example trial could have progressed. The top path represents three eye movements to only the target locations and in the correct order, efficiently completing the trial. This was more likely to occur once the participant learned the relevant locations and order of locations, if this was a repeated sequence condition. The bottom path represents a more likely occurrence when the relevant locations for this repeated array were still unknown, or if it was a novel trial. After finding the initial letter, an eye movement is made to a distractor location, resetting their progress.

remain visible as long as fixation was maintained within its area. If the participant began fixating the locations of the relevant letters in the correct order (any form of progression going from ‘A’ to ‘N’ to ‘T’ only), the letters within the rings would remain visible even after the participant looked away, and the ring around the letter would change to green. If one of the three ‘#’ sign locations were fixated, or if the relevant letters were fixated out of order, the stimuli within the ring, as well as any letters that had remained visible, would then disappear immediately after the eyes had moved away from the current interest area, and any rings that had changed to green would return to white. For example, the first time the ring containing ‘A’ was fixated, that ring would turn from white to green. If the ring containing ‘N’ was fixated next, then the ‘A’ would remain visible within its green ring and the ring around the ‘N’ would turn green as well. However, if the ring containing ‘T’ or one of the three ‘#’ was instead fixated after the ‘A’, the ring around the ‘A’ would return to white and the ‘A’ would disappear. Once all three letters had been fixated in the correct order, the array would remain visible showing the correct rings in green and the white letters inside of them for 400 ms before an inter-trial interval of 500 ms.

The experiment consisted of 10 practice trials and 320 experimental trials, split into 2 blocks of 160 trials each. Half of the trials consisted of novel arrays of rings and stimuli locations, while the remaining trials were evenly split between four different repeated arrays in which the rings and stimuli locations within those rings remained constant throughout the experiment. The mixture of these trials was randomly determined. At the conclusion of the 330 trials, participants were asked if they had recognized any repeated arrangements of rings during the experiment and selected ‘Y’ or ‘N’ on the keyboard. Regardless of their response to the previous question, they were then shown four pairs of arrays. One array was shown at a time, and each pair consisted of one of the repeated arrays and one randomly generated array. After each pair of arrays was shown, participants were asked whether they recognized the first or the second array just shown and responded by either selecting the ‘1’ or ‘2’ key on the keyboard. It was randomly determined whether the repeated array would appear first or second in each pair. Participants were then thanked and any of their questions were answered by the experimenter.

Results

Trials were removed from the analysis if search time was recorded as greater than 2.5 standard deviations from the participants’ individual means, or if no fixations were recorded within any of the three target interest areas. This process resulted in removing 25% of trials.

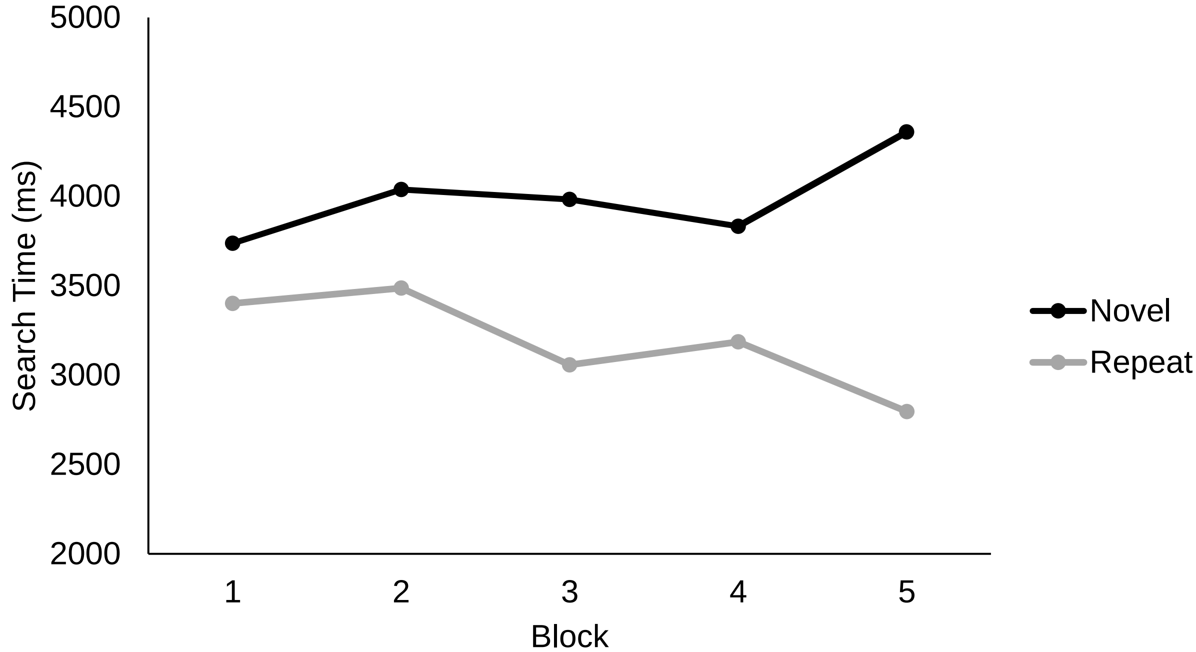

Figure 2. Mean trial completion ST across all participants over time by array type (novel vs. repeated) for Experiment 1.

Search Time. Search time (ST) was measured as the time from the onset of the array to the completion of fixating all three relevant targets in the correct order. A main effect of repetition on ST was observed between novel (mean = 3990 ms) and repeated (mean = 3185 ms) arrays, as the repeated arrays produced significantly faster ST: $F(1,11) = 19.011$, $p = .001$, $\eta_p^2 = .633$. There was no significant effect of block (Block 1: 3568 ms, Block 2: 3762 ms, Block 3: 3520 ms, Block 4: 3509 ms, Block 5: 3578 ms) on ST: $F(4,44) = 1.451$, $p = .233$, $\eta_p^2 = .117$. However, as is evident in Figure 2, because performance improved for repeated arrays, but remained relatively constant for novel ones, a significant interaction was present for ST between repetition and block: $F(4,44) = 5.852$, $p = .001$, $\eta_p^2 = .347$. In sum, these ST data indicate that, over the course of the experiment, participants became quicker at completing repeat trials and were faster at completing trials when shown a repeat versus a novel context.

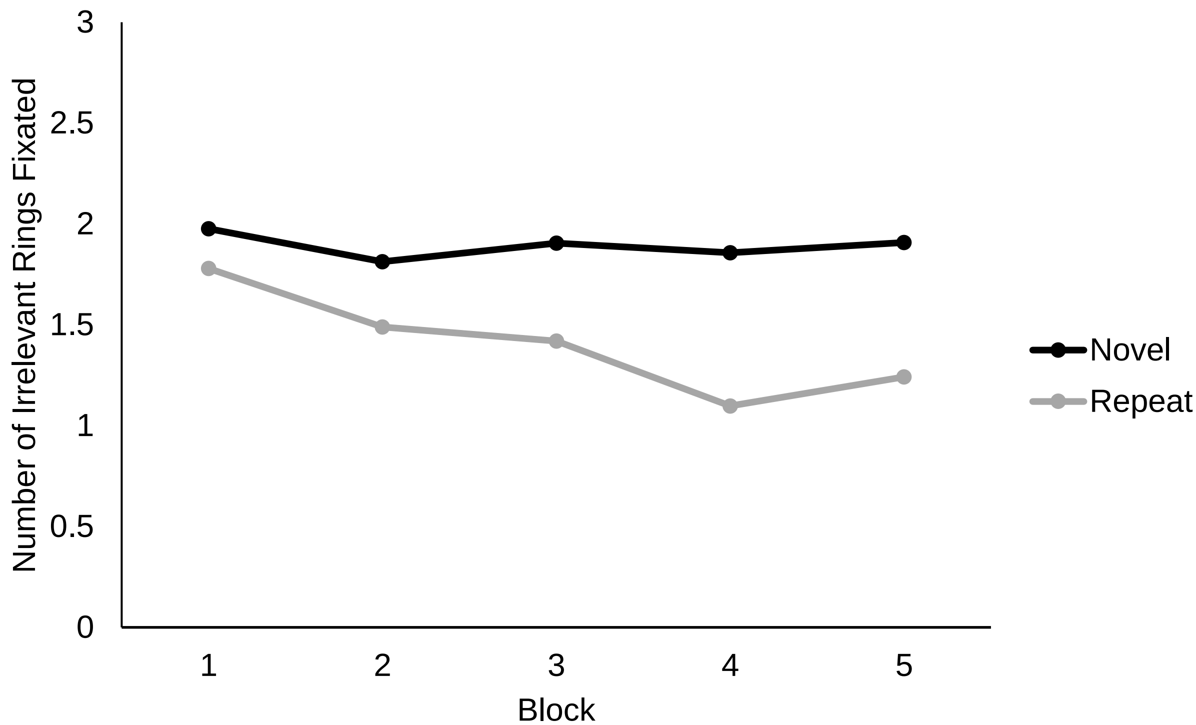

Figure 3. Mean number of distractors fixated per trial across all participants over time by array type (novel vs. repeated) for Experiment 1.

Index of Selectivity. Our index of selectivity was measured by the average number of distractors that were fixated on any given trial. This index tells us how many ‘mistakes’ participants were likely to make. That is, a smaller number indicates they had learned where the target rings were likely to be located, regardless of whether the correct order had been learned. A main effect of repetition on selectivity was observed between novel (mean = 1.89 distractors fixated) and repeated (mean = 1.41 distractors fixated) arrays, as the repeated arrays produced significantly more efficient selectivity: $F(1,11) = 33.834$, $p < .001$, $\eta_p^2 = .755$. There was also a significant main effect of block (Block 1: 1.88 distractors fixated, Block 2: 1.65 distractors fixated, Block 3: 1.66 distractors fixated, Block 4: 1.48 distractors fixated, Block 5: 1.58 distractors fixated) on selectivity: $F(4,44) = 9.256$, $p < .001$, $\eta_p^2 = .457$. In addition, as is evident in Figure 3, because selectivity improved for repeated arrays, but remained relatively level for novel arrays, a significant interaction was present for selectivity between repetition and block: $F(4,44) = 10.158$, $p < .001$, $\eta_p^2 = .480$. These selectivity results suggest that, when shown a repeated context, participants attended to fewer distractor locations and reduced erroneous fixations more over time in comparison to when they saw a novel context.

Index of Sequential Learning. To measure the level at which the correct order of target locations was learned we calculated the respective mean probabilities by repetition for fixating the first location (‘A’) in the sequence first, the second location (‘N’) in the sequence second, and the third location (‘T’) in the sequence third (Figure 4). For these analyses, we were only interested in fixations made inside one of the six rings on any given trial. Participants were significantly more likely to fixate the ‘A’ location first in repeat (mean = .30) versus novel (mean = .19) arrays: $t(11) = 3.38$, $p = .006$. For all the trials in which ‘A’ was fixated first, participants were more likely to subsequently fixate the ‘N’ location in repeat (mean = .40) versus novel (mean = .23) arrays: $t(11) = 2.59$, $p = .03$. For all the trials in which ‘A’ was fixated first and ‘N’ was fixated second, participants were also more likely to fixate the ‘T’ location in repeat (mean = .86) versus novel (mean = .19) arrays: $t(11) = 8.76$, $p < .001$. Additionally, we analyzed the probability that after ‘A’ was fixated for the first time (regardless of whether it was the first interest area fixated or not) how likely participants were to subsequently direct their attention to the ‘N’ location, given that ‘N’ had not previously been fixated. Once again, there was a significantly higher probability of this occurrence for repeated (mean = .48) versus novel (mean = .35) arrays: $t(11) = 2.98$, $p = .01$. These results strongly suggest that participants were much more likely to instantiate the correct sequence of eye movements when confronted with a familiar context.

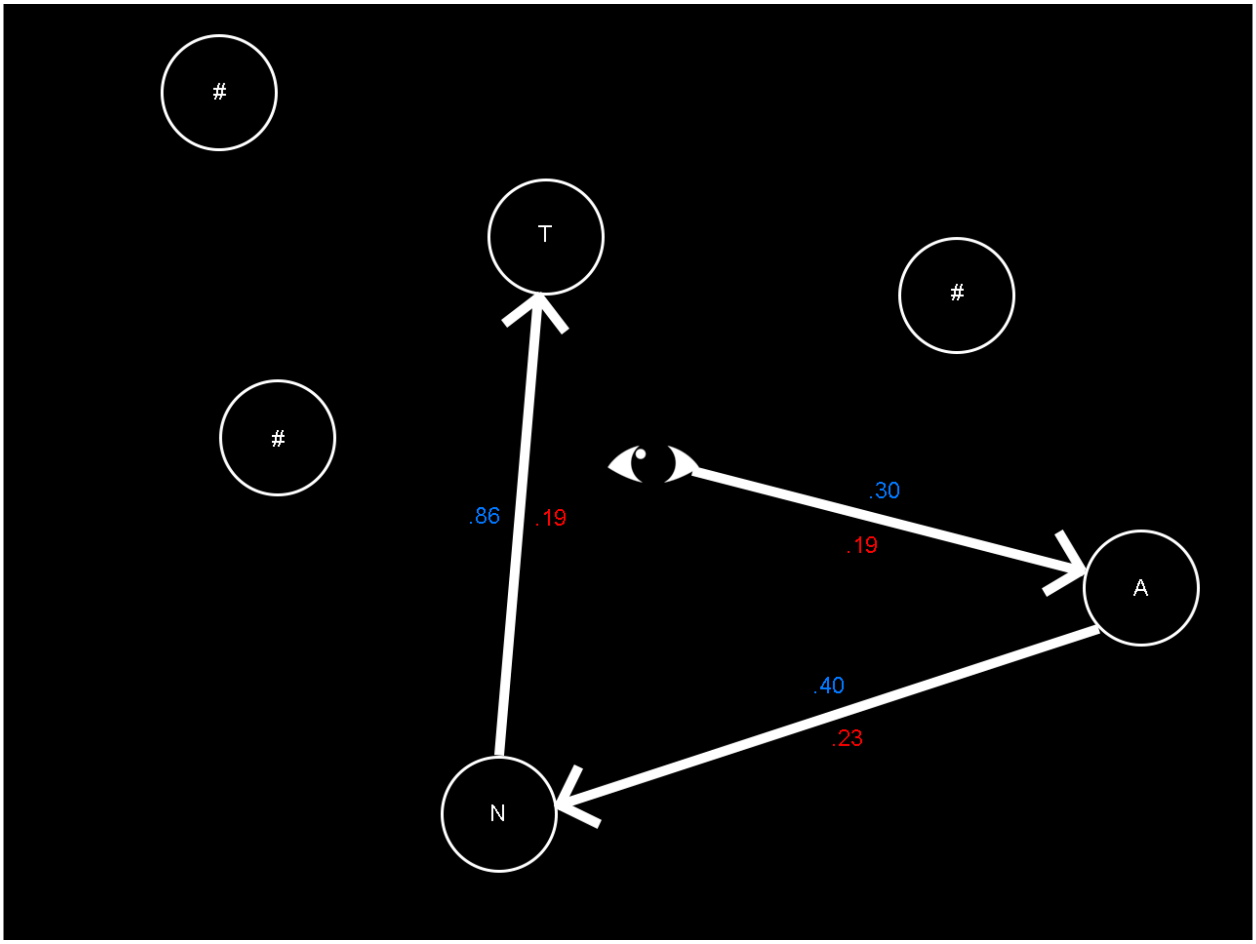

Figure 4. Probabilities for fixating only the targets in the correct sequence by repetition in Experiment 1. The first arrow from the central eye indicates the likelihood that the first fixation in an interest area on a given trial was recorded in the 'A' location. The second arrow indicates the likelihood that, for all trials in which the first interest area fixated was 'A', the second fixation in an interest area was recorded in the 'N' location. The third arrow indicates the likelihood that, for all trials in which the first two interest areas fixated were 'A' and 'N', respectively, the third and final fixation in an interest area was recorded in the 'T' location, also representing a 'flawless' trial. Blue numbers indicate mean probabilities for repeat arrays and red numbers indicate mean probabilities for novel arrays.

Exit Questions. The exit questions were designed to test participant awareness of the repeated arrays viewed throughout the experiment. 100% of participants answered 'Yes' to our yes-or-no question concerning whether or not they noticed any repeated arrays during the experiment. However, when asked to recognize repeated versus novel, accuracy only reached an insignificant 65% versus chance at 50%: $t(11) = 1.74$, $p = .11$. These results show a higher awareness of the presence of recurring contexts compared to previous studies of contextual cuing in arbitrary arrays. However, the overall failure to significantly surpass chance accuracy suggests explicit knowledge of the repeated arrangements remained quite low.

Collectively, these results provide strong evidence that the multiple target locations and their sequence in repeated arrays were successfully cued by their context. Relatively to randomly generated arrays, repeated arrays generated quicker search times, fewer distractor locations fixated, and a higher likelihood of following the correct order of targets. It was clear that the faster search times and fewer distractors fixated for repeated arrays also continued to improve over time, suggesting that more exposure only led to increased learning and performance. Overall, we were able to conclude that four consistent arrays interspersed amongst novel arrays were able to contextually cue three specific eye movements upon exposure to the repeated arrays. However, due to the results from our exit questions, we cannot be certain whether this contextual cuing was driven by implicit or explicit awareness of the repeated ring arrangements.

Experiment 2

In Experiment 2, the number of repeated arrays was increased in order to see if the same effect would remain with a higher number of learnable contexts, in addition to try and reduce awareness of the repetition of some arrays. A transfer phase was also added in an attempt to measure the automaticity of the pattern of eye movements learned during the (now) training phase when given a particular context when given a new task. The main goal of including the transfer phase was to observe whether the same sequence of eye movements would be performed in a learned context, even when the new task only involves one target. In other words, after having repeatedly followed a certain pattern of eye movements when confronted with a distinct context, would one simply follow that same pattern in the same context during a new search task when that learned sequence of eye movements is now irrelevant? If so, this would suggest a high level of automaticity and durability of this method of contextual cuing.

Method

Participants

Twenty-four participants (16 female) from the University of Iowa completed the experiment for course credit. Each reported normal or corrected-to-normal vision.

Apparatus

The apparatus was the same as in Experiment 1, with only the addition of a response pad which was used during the transfer phase.

Stimuli

The training phase stimuli was the same as in Experiment 1. During the testing phase, Landolt Cs subtending .31°x.31° of varying up-down-left-right orientations were used as the stimuli inside each of the six rings (same rings as in the training).

Procedure

Informed consent and eyetracking procedure was conducted in the same as Experiment 1. The training phase was also the same as in Experiment 1, with the only difference being that six repeated arrays of white rings now appeared throughout the experiment, 14 samples were required to reveal the internal character, and the total amount of trials was reduced to 288 for time. In addition, the 288 trials consisted of 24 blocks, each block containing 12 trials; one of each repeated array along with six novel arrays, randomly mixed.

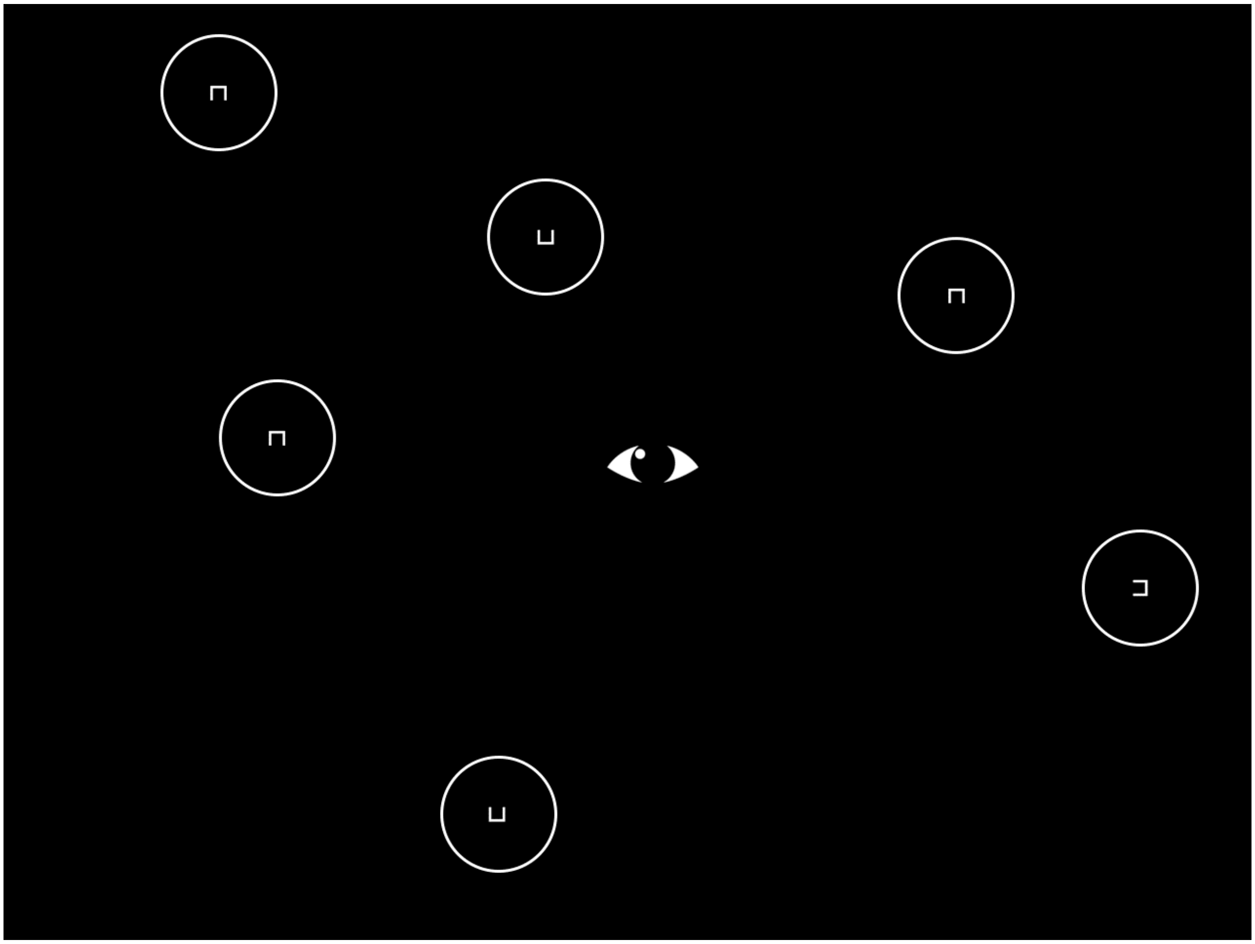

Figure 5. Representation of a typical transfer phase array for Experiment 2. The task is to find the one character with a gap on the left or the right side, amongst five distractors with gaps either on the top or bottom. In this example the correct response would be pressing the left button, because there is a shape with a gap on the left side present.

Before the transfer phase began, participants were instructed on their new task. They were told to search for the one ‘C’ shaped object with its gap either on its left or right side, among five other ‘C’ shaped objects with gaps facing up or down. Once they identified their target, they were to respond to its orientation using the two corresponding buttons on a response pad (that is, left response button for the target having a gap on the left side, and right response button for the target having a gap on the right side). The rings in the transfer phase were the same as in the transfer phase and Experiment 1, with the six repeated arrays appearing evenly among half of the total trials, with the rest of the intermixed trials containing randomly generated arrangements of rings. The ‘C’ shaped targets orientated either up, down, left, or right were always present within their respective rings and appeared simultaneously with the rest of the array after a fixation cross was shown for 500 ms. The target was placed in a randomly chosen location for each trial. The trial ended immediately after a response was made, and no feedback was given. Exit questions followed that were the same as in Experiment 1, only now extended to test all of the six repeated arrays in this experiment. The first twelve participants completed 48 trials of the transfer task, while the latter twelve participants had their transfer task increased to 96 trials in order for more fine-grained analyses to be done concerning target location in the repeated contexts.

Results

Training Phase

Seven percent of trials were excluded from analyses if search time was recorded as greater than 2.5 standard deviations from the participants’ individual means, or if no fixations were recorded within any of the three target interest areas. All training phase data were analyzed in the same way as in Experiment 1.

Search Time. As in Experiment 1, a main effect of repetition on ST was observed during the training phase between novel (mean = 3295 ms) and repeated (mean = 2850 ms) arrays, as the repeated arrays produced significantly faster ST: $F(1,23) = 37.471$, $p < .001$, $\eta_p^2 = .620$. As can be seen in Figure 6, both novel and repeat conditions show a downward trend over time, and this resulted in a significant effect of block (Block 1: 3285 ms, Block 2: 3271 ms, Block 3: 3230 ms, Block 4: 3097 ms, Block 5: 3073 ms, Block 6: 3088 ms, Block 7: 2964 ms, Block 8: 3040

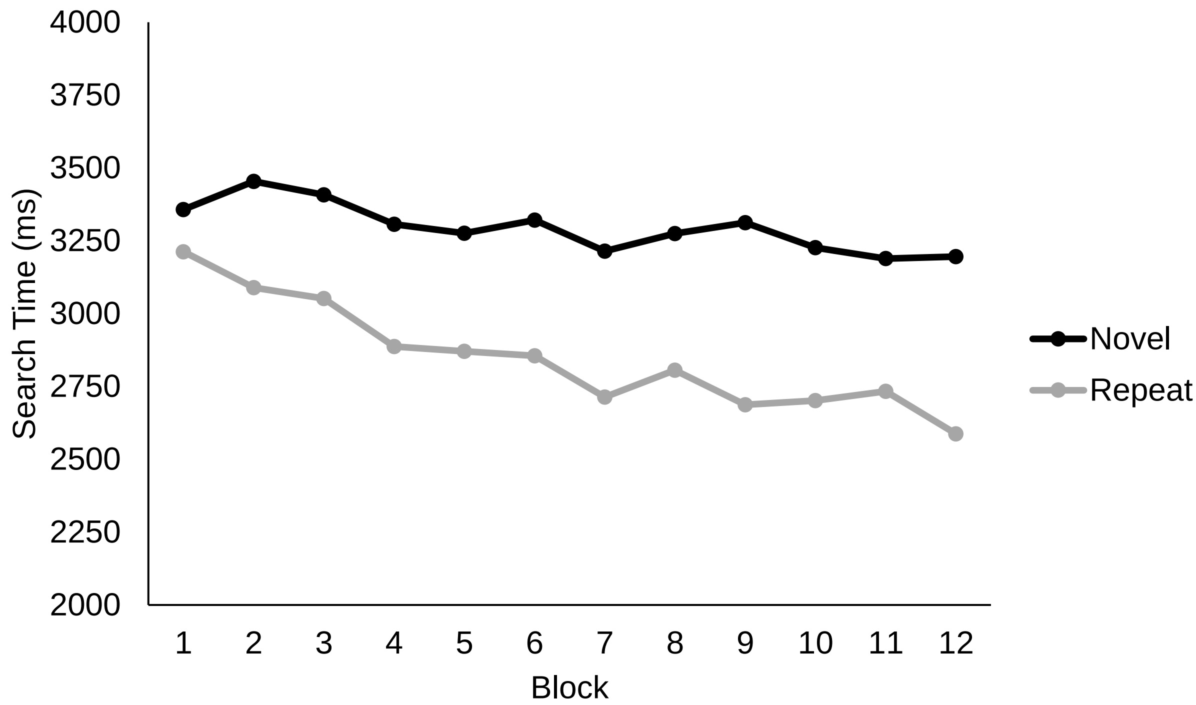

Figure 6. Mean trial completion ST across all participants over time by array type (novel vs. repeated) for Experiment 2.

ms, Block 9: 3000 ms, Block 10: 2964 ms, Block 11: 2961 ms, Block 12: 2892 ms) on ST: F(11,253) = 2.629, p = .003, η_p^2 = .103. However, no interaction was present: F(11,253) = 1.150, p = .323, η_p^2 = .048. Together, these results show a clear advantage in search time for repeated versus novel arrays, meaning participants were quicker at making the correct sequence of eye movements when confronted with a familiar context.

Index of Selectivity. For our index of selectivity during the training phase, a main effect of repetition on selectivity was observed between novel (mean = 2.05 distractors fixated) and repeated (mean = 1.72 distractors fixated) arrays, as the repeated arrays produced significantly more efficient selectivity: F(1,23) = 12.681, p = .002, η_p^2 = .355. There was also significant a

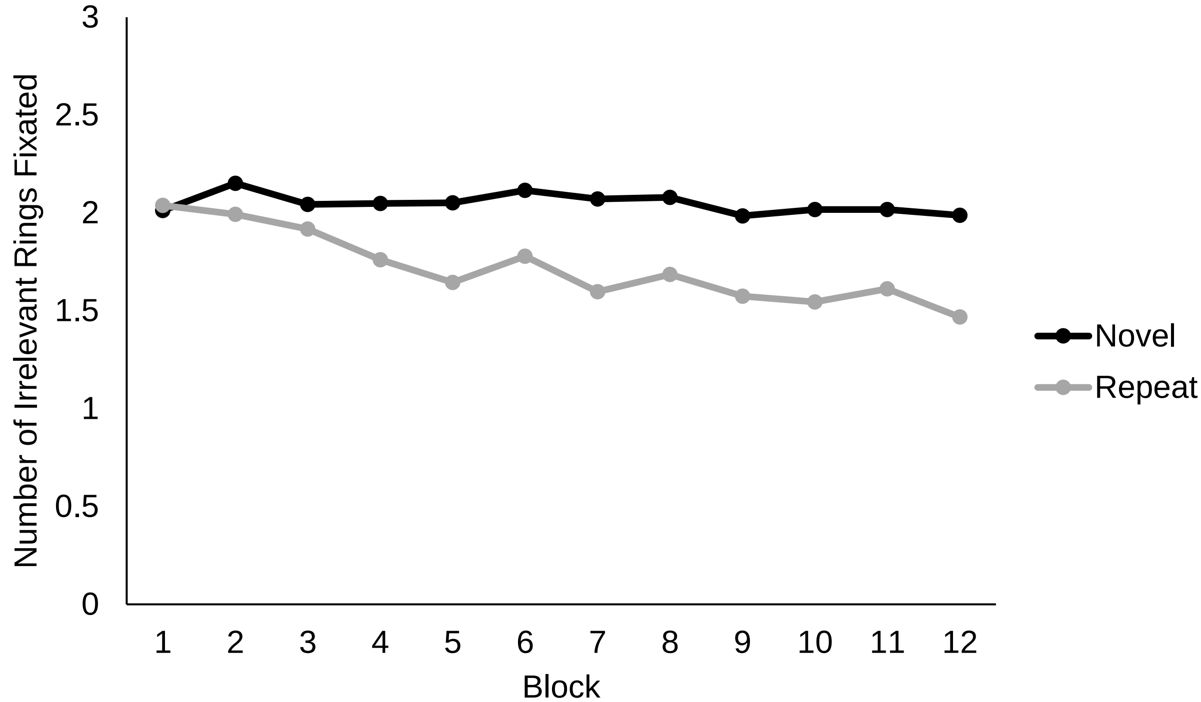

Figure 7. Mean number of distractors fixated per trial across all participants over time by array type (novel vs. repeated) for Experiment 2.

main effect of block (Block 1: 2.03 distractors fixated, Block 2: 2.07 distractors fixated, Block 3: 1.98 distractors fixated, Block 4: 1.90 distractors fixated, Block 5: 1.85 distractors fixated, Block 6: 1.95 distractors fixated, Block 7: 1.83 distractors fixated, Block 8: 1.88 distractors fixated, Block 9: 1.78 distractors fixated, Block 10: 1.78 distractors fixated, Block 11: 1.81 distractors fixated, Block 12: 1.73 distractors fixated) on selectivity: $F(11,253) = 4.370$, $p < .001$, $\eta_p^2 = .160$. A significant interaction was also present: $F(11,253) = 3.326$, $p < .001$, $\eta_p^2 = .126$. As in Experiment 1, these results again suggest that the three relevant locations containing the targets were more likely to be fixated than the irrelevant distractor locations in repeat versus novel arrays.

Index of Sequence Learning. As represented in Figure 8, during the training phase in Experiment 2 participants were significantly more likely to fixate the ‘A’ location first in repeat (mean = .27) versus novel (mean = .17) arrays: $t(23) = 3.10$, $p = .005$. For all the trials in which ‘A’ was fixated first, participants were more likely to subsequently fixate the ‘N’ location in repeat (mean = .33) versus novel (mean = .17) arrays: $t(23) = 3.06$, $p = .006$. For all the trials in which ‘A’ was fixated first and ‘N’ was fixated second, participants were also more likely to fixate the ‘T’ location in repeat (mean = .46) versus novel (mean = .21) arrays: $t(19) = 2.56$, $p = .02$. An important note to make is that four participants failed to ever perform a ‘flawless’ trial,

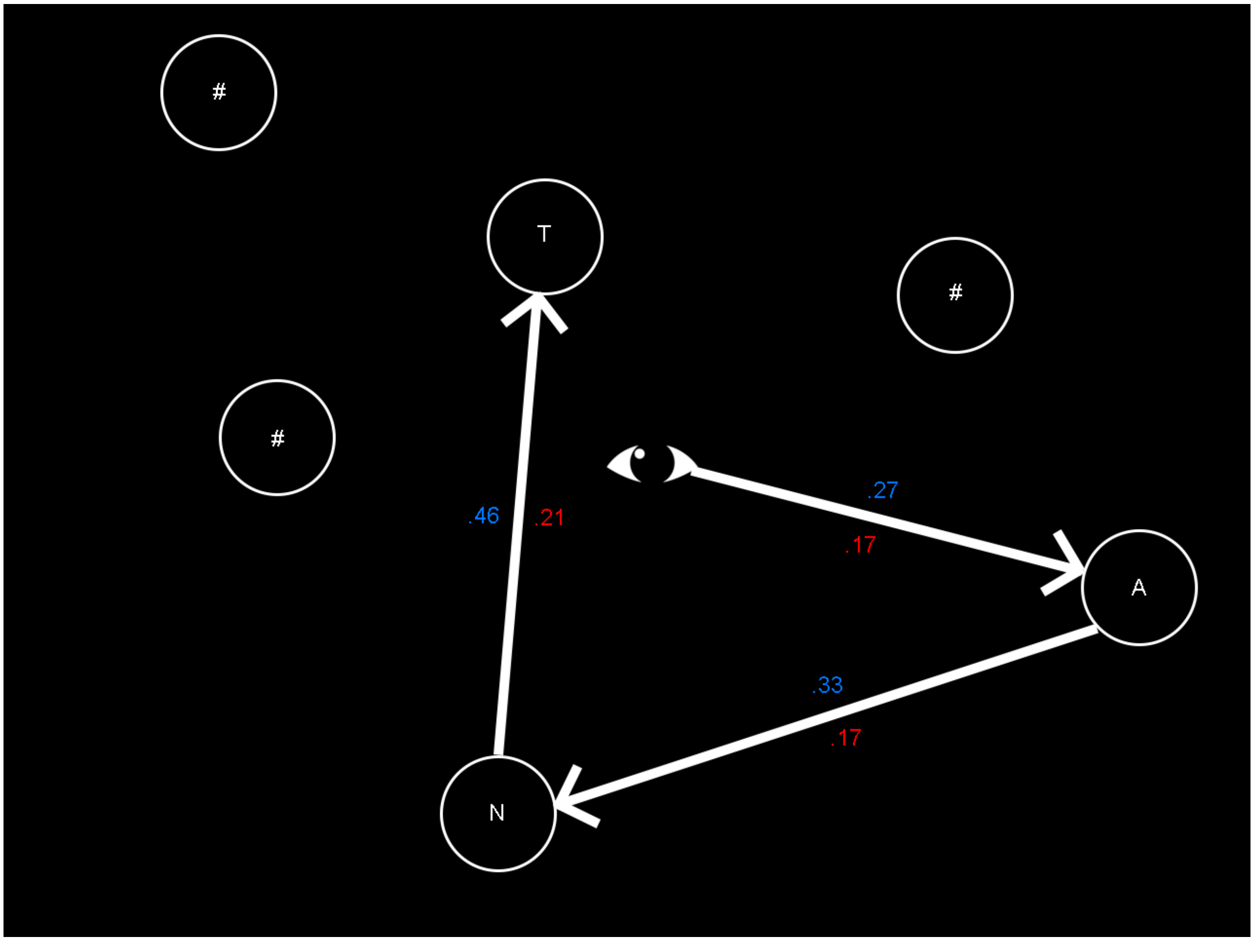

Figure 8. Probabilities for fixating only the targets in the correct sequence by repetition in Experiment 2 training. The first arrow from the central eye indicates the likelihood that the first fixation in an interest area on a given trial was recorded in the ‘A’ location. The second arrow indicates the likelihood that, for all trials in which the first interest area fixated was ‘A’, the second fixation in an interest area was recorded in the ‘N’ location. The third arrow indicates the likelihood that, for all trials in which the first two interest areas fixated were ‘A’ and ‘N’, respectively, the third and final fixation in an interest area was recorded in the ‘T’ location, also representing a ‘flawless’ trial. Blue numbers indicate mean probabilities for repeat arrays and red numbers indicate mean probabilities for novel arrays.

which is the reason for the decrease in the degrees of freedom for the paired samples *t*-test reported for the probability of fixating 'T' on the third fixation. Additionally, there was an insignificant difference found in the probability of fixating the 'N' location first in repeat (mean = .15) versus novel (mean = .17) arrays: $t(23) = 1.02$, $p = .320$, as well as fixating the 'T' location first in repeat (mean = .16) versus novel (mean = .18) arrays: $t(23) = .74$, $p = .467$. Finally, we analyzed the probability that after 'A' was fixated for the first time, regardless of whether it was the first interest area fixated or not, how likely were participants to subsequently direct their attention to the 'N' location, as long as 'N' had not been fixated beforehand. Unlike in Experiment 1, however, there was no significant probability of this occurrence being more likely in repeated (mean = .39) versus novel (mean = .32) arrays: $t(23) = 1.56$, $p = .134$.

Considering the vast similarity in our results between the training phase of Experiment 2 and the whole of Experiment 1, we concluded that using six repeated arrays was just as efficacious as the four used in Experiment 1. The additional difficulty of learning two additional contexts, with less exposure to each individual arrangement, did not impair performance, and the comparable results in trial completion time, selectivity, and sequential target attendance suggest that contextual cuing of the multiple target locations and their specific identities was achieved successfully in this training phase.

Transfer Phase

For the data collected from the transfer phase of Experiment 2, trials were trimmed from analyses if search time was recorded as greater than 2.5 standard deviations from each individual participant's mean. This resulted in 1.4% of trials being excluded from analyses.

Our first measure of the level of automaticity of the contextually cued sequence of eye movements was to calculate whether a faster ST would result from the target being placed in the location where the ‘A’ would have been in the repeated arrays, versus an observed chance value from the novel arrays. Although a clear numerical difference can be seen for this measure between the novel (mean = 1394 ms) and repeat (mean = 1299 ms) arrays, this difference proved to be statistically insignificant: $t(23) = 1.52$, $p = .143$. We then examined the probability that the former location of the ‘A’ target would be the first location fixated during the transfer phase. This measure trended towards significance in favor of a higher likelihood in fixating where the first target location had been during training for repeat arrays (mean = .20) versus observed chance in novel arrays (mean = .15): $t(23) = 1.83$, $p = .08$.

Finally, consistent with the analyses conducted in Experiment 1 and the training phase, we calculated the frequency in which, for repeat arrays, the former ‘N’ location was fixated after the former ‘A’ location was fixated for the first time in a trial. For this measure we examined trials regardless of when the former ‘A’ location had been first fixated relative in comparison to the other locations, and only excluded trials in which the former ‘N’ location was fixated before the former ‘A’ location. As with the training phase, however, the likelihood of this occurrence was not significantly different for the repeated arrays (mean = .27) versus observed chance in novel arrays (mean = .20): $t(23) = 1.36$, $p = .188$.

Taking all these results into consideration, we must infer that our successful contextual cuing of eye movements did not convincingly transfer to the search task. None of our transfer measures resulted in significance, making an argument for the transferability of our training task difficult. However, because of a couple of compelling numerical and nearly significant differences, we are unable to make a confident conclusion as to the transferability of the contextual cuing phenomenon as a whole.

Exit Questions

Every participant excluding one (96%) answered 'Yes' to having seen any repeated arrangements of rings over the entirety of the experiment. For the recognition task between pairs of a repeat and novel arrays, although the overall accuracy was the exact same observed for Experiment 1 (65% correct performance for identifying repeat arrays), this result came out as significantly greater than chance (50% accuracy) for Experiment 2: $t(23) = 3.98$, $p < .001$. This suggests, paradoxically, that participants in Experiment 2 were statistically able to more easily recognize six repeated arrays than participants in Experiment 1 were able to recognize their four repeated arrays.

General Discussion

The present experiments sought to investigate the question of whether a sequence of multiple targets could be contextually cued and, if so, whether this sequence of eye movements would transfer to a new task in which only one target was present. In Experiment 1, participants successfully learned the relevant locations in repeated arrays. This was demonstrated by the following results. First, STs were faster on repeated compared with novel arrays. Second, he number of distractors fixated per trial, our index of selectivity, was significantly lower for repeated arrays. Finally, participants were significantly more likely to follow the correct order of the targets when viewing repeated arrays. Unlike in many of the previous studies in contextual cuing, however, the results from our exit questions suggested that participants were aware of certain arrangements being repeated throughout the experiment, although overall recognition of their four repeated arrays remained below chance.

Experiment 2 had two objectives: one, to observe whether the same improvement in performance would be seen with an increase to six repeated arrays and two, to measure the level of automaticity of our contextual cuing in a transfer task. We were able to successfully reproduce the improvement in ST, number of distractors fixated, and likelihood to follow the sequence order in the training phase with six repeated arrays. However, our measures during the transfer phase failed to reach significance, a finding that is consistent with Jiang et al.'s 2015 study on probability cuing, which is another type of statistical learning. Despite the statistical results, a few compelling numerical differences appeared and some of these seemed to trend towards significance. Due to this, we were unable to conclude decisively that no transfer was present, and this topic remains to be more closely studied before a confident conclusion can be made. Surprisingly, participants did perform significantly better than chance overall on the final recognition questions, suggesting their awareness of the repeated arrays was explicit. The results from our exit questions could be explained by our relatively sparse arrays compared to previous contextual cuing experiments. Only six stimuli (six rings with their respective characters) appeared on every trial, and in Experiment 1 and the training for Experiment 2, participants were required to fixate at least half of all the stimuli present. The relatively low number of distractors along with the high number of targets, and the high amount of time required to search these arrays may have led participants to deliberately process each trial more than participants in prior contextual cuing experiments with one target and many more distractors.

A study by Zellin, Conci, von Mühlenen, and Müller (2011) argued that only one target location out of a possible two or three could be reliably cued by context in order to facilitate search. Our results appear to refute that conclusion, as participants were able to both direct attention to the three relevant locations efficiently in repeated arrangements as well as have some knowledge of the targets' identities as they were more likely to attend to them in the correct order in repeated versus novel arrays. Our results would therefore suggest that multiple target locations can be successfully contextually cued, at least when all the targets are present in each array. A major difference between our study and that by Zellin et al. (2011) is that they, like all other previous studies in contextual cuing, only ever had one target present on each trial, while still attempting to cue the multiple locations. Using this methodology, they found that one location would gain dominance over the others in terms of attracting attention when a repeated array was shown. Although it is possible in our study that the first item in the sequence of targets benefited the most from the contextual cuing, our results do show that participants were significantly more likely to follow the sequence of targets without interruption in repeated arrays, which suggests that all the target locations benefited at least somewhat from the contextual cues. In addition, Zellin et al. (2011) reported much lower performance results in the recognition exit questions, which allowed them to claim that their subjects were largely unaware of the repeated contexts. This differs from the present study in which our exit questions suggest a higher level of explicit knowledge about the repeated contexts than most contextual cuing studies observe.

In conclusion, we demonstrated that the contextual cuing phenomenon can be expanded to a sequence of multiple targets and effectively guiding eye movements. Our results suggest that based on context alone, participants were able to show significant improvement in efficiency at completing the task in our paradigm when shown a familiar array versus a novel one. These findings have implications for any work environment which requires the viewing of familiar scenes which much be searched, such as the X-rays seen by TSA bag screeners of suitcases or CAT scans examined by radiologists. In these types of work, much of the images being searched look much the same as every other one previously viewed, and hopefully the employees in these positions are making more than one fixation on each image that comes before them. However, if you are asked to search through hundreds, or possibly thousands, of images that look much the same as each other (such as carry-on suitcases) you may begin searching one in a consistent manner, especially if you are asked to do so as quickly as you can (perhaps because a line of passengers in a hurry are waiting for you). It may be possible that searching through copious repeated contexts may eventually lead to repeated behavior while viewing them. This, however, would be an undesirable search strategy should a target be located at a position not included in the pattern of eye movements that you have started to initiate when confronted with these familiar contexts. Should this hypothesis be true, we would seek to design training techniques or interfaces that would interrupt this repetitive behavior every so often.

The current study has shown that a sequence of eye movements is possible to effectively cue by a familiar context. Subsequent research should seek to examine methodology changes to make the learning more implicit and observe whether the same effects reported here can still be found. Investigations into the limits of the number of sequential targets that can be contextually cued or the impacts of larger distractor set sizes could also be done. Being that a number of our transfer measures appeared to trend towards significance, future studies into the transferability of contextual cuing to distinct tasks would also be of value.

Acknowledgements

The author would like to thank Brett Bahle for whom without which this project would not have been possible and Andrew Hollingworth for supporting this research and providing expert advice.

References

Brockmole, J. R., Castelhano, M. S., & Henderson, J. M. (2006). Contextual cueing in naturalistic scenes: Global and local contexts. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*(4), 699.

Chun, M. M., & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive psychology*, *36*(1), 28-71.

Conci, M., & Müller, H. J. (2012). Contextual learning of multiple target locations in visual search. *Visual Cognition*, *20*(7), 746-770.

Groeger, J. A. (2013). *Understanding driving: Applying cognitive psychology to a complex everyday task*. London: Routledge.

Jiang, Y. V., Swallow, K. M., Won, B. Y., Cistera, J. D., & Rosenbaum, G. M. (2015). Task specificity of attention training: the case of probability cuing. *Attention, Perception, & Psychophysics*, *77*(1), 50-66.

Jiménez, L., & Vázquez, G. A. (2011). Implicit sequence learning and contextual cueing do not compete for central cognitive resources. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(1), 222.

Neider, M. B., & Zelinsky, G. J. (2006). Scene context guides eye movements during visual search. *Vision research*, *46*(5), 614-621.

Olson, I. R., & Chun, M. M. (2001). Temporal contextual cuing of visual attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*(5), 1299.

Zellin, M., Conci, M., von Mühlenen, A., & Müller, H. J. (2011). Two (or three) is one too many: testing the flexibility of contextual cueing with multiple target locations. *Attention, Perception, & Psychophysics*, *73*(7), 2065.