

SEQUENTIALLY GUIDED ATTENTION

**An Attentional Serial Reaction Time Task**

Undergraduate Research Thesis

Presented in partial fulfillment of the requirements for graduation with *honors research distinction* in Psychology in the undergraduate colleges of The Ohio State University.

by

Margaret Duffy

The Ohio State University

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Project Advisor: Dr. David Osher, Department of Psychology

### **Abstract**

The brain has the ability to filter and prioritize a cacophony of often extraneous visual stimuli via a mechanism called attention. Traditionally, attention is thought to be guided by either a goal-driven mechanism (top-down, supported by fronto-parietal brain networks) or a stimulus-driven mechanism (bottom-up, supported by visual networks). However, recent work has highlighted a type of attention that does not fit within this dichotomy: one driven by prior experience (i.e., selection history) that can be characterized as a habit, inflexible, insensitive to outcome devaluation, and automatic. Serial reaction time studies have demonstrated these properties; however, this type of task relies largely on motor learning. Contextual cueing studies have also displayed the learning of associations between responses and contexts, however these fail to display the effect on an individual level. For the present study, we developed a behavioral task with spatial-temporal demands to probe habit-like attention. Participants were tasked with making decisions about stimuli that appeared in blocks alternating between learned and novel locations. We implemented an altered version of the sequence to test the perseveration of the attentional habit in which participants completed a shorter version of the main task, but the last location of the learned sequence was changed. Finally, we assessed participants' knowledge of the learned sequence with a short post-test that asked them to predict the next location of the image in the sequence. Our results indicated strong significant reaction time and accuracy effects for the learned compared to the random sequence, supporting the idea of sequentially guided attention. Participants appeared to possess explicit knowledge of the learned sequence, challenging the inclusion of implicitness as a criterion for attentional habits. The altered sequence demonstrated a significant difference in reaction time between critical and non-critical

trials. However, this was not the case for accuracy. Future directions include the implementation of the task using a more complex learned sequence and a more highly powered reversal task.

### **Introduction**

In our world, we are constantly being presented with an abundance of visual stimuli, of which we must find a way to narrow down the most important and filter out what is irrelevant to us. The mechanism our brain uses to do this is known as attention. It is agreed upon in the field of psychology that we use two models of attentional control: “top-down” and “bottom-up.” Top-down processing is determined by willful plans and current goals, considered voluntary attentional control, while bottom-up processing is determined by physical salience and features of stimuli (e.g a brightly colored target), and considered automatic attentional control (Jonides, 1981). This distinction has remained dominant to the present, however, some research has shown that there may be another mechanism we use to modulate our attention, one driven by memory, which this dichotomy fails to account for (Awh et al, 2012). It has been established that goal-driven selection is enhanced when resources are focused on one dimension instead of two, as demonstrated by Wolfe et al. (1989) with a task that compared performance between blocks in which the target defining feature (color and orientation) varied versus pure blocks where the target defining feature was the same. However, this phenomenon could also be explained by the priming of recent selection of the same feature value. Maljkovic and Nakayama (1994) revealed that the search for a target with a defining feature was more efficient in subsequent trials of search for the same feature. We have also seen evidence for attention driven by memory in selection bias toward items that have previously yielded reward. For example, it has been demonstrated that equally salient stimuli can capture attention even when contradicting current selection goals due to previous yielding of reward (Hickey et al., 2010). We have even seen

evidence of learned reward value involuntarily biasing selection on a neural level as in Luque et al. (2017), where recordings of event-related potentials during reinforcement learning tasks have shown resistance to outcome devaluation. All this proposes a modified taxonomy in attentional control: one where in addition to current goals and physical salience, selection history also modulates our attention.

### **Serial Reaction Time**

One way to study attention guided by prior experience is the serial reaction time motor learning paradigm (Nissen & Bullemer, 1987). This paradigm is demonstrated by a task known as the serial reaction time task. In this study, a light appeared in one of four locations, and participants were instructed to press one of four keys directly under the light that flashed. The task alternated between blocks of random and repeating sequences. It was demonstrated that participants in the condition with the repeating sequence had significantly faster reaction times, reflecting the learning of the specific sequence. By giving the task to patients with memory impairments who were still able to learn the repeating sequence despite their lack of awareness, Nissen and Bullemer also demonstrated that this learning may be implicit. This type of learned motor sequence can be seen in many aspects of our lives. For example, when you type in your ATM pin, the behavior becomes so automatic you do not even have to think about it, and you may not even be able to verbally report what the actual numbers of the code are despite being able to type it in. This ability to learn a repeating sequence supports the suggestion that selection history works to modulate our attention.

### **Probabilistic Cueing**

Attention guided by memory can also be seen in people's ability to extract and utilize environmental regularities in a search. In the laboratory, probabilistic cueing tasks have explored

this phenomenon. In this type of task, participants search for a visual target among a configuration of distractors, in which the target is more frequently located in one area of the display, though participants are not explicitly aware of this regularity. Many implications of these tasks have demonstrated faster response times for the location in which the target appears more often. When asked to indicate where the target appeared most frequently participants perform at chance level, suggesting that this attentional bias is implicit (Jiang et al., 2018).

### **Contextual Cueing**

Contextual cueing is another example of enduring attention driven by prior experience (Chun & Jiang, 1998). In contextual cueing tasks, repeating configurations of distractors lead to faster detection of a target in comparison to random configurations. The repeating configurations are rigid—all the distractors and targets are in the same spatial layout and orientations—and thus provide an implicit cue to the location of the target. For example, in a T among L search task, participants are faster to locate the T when the search display is the same as in previous trials in comparison to when the Ls are arranged in a random configuration. The repeated contexts (often many per experiment) are learned incidentally, gradually, and most often implicitly. This effect persists over a long period of time—the faster acquisition of a target in a repeated/learned versus a new context is preserved for over a week after the initial testing (Chun & Jiang, 2003). Despite these findings, effect sizes for this type of task are small, especially for individual subjects.

### **Habit-like Attention**

Some researchers have begun to term the repeated attentional biases demonstrated by these tasks as attentional habits. So, how do we define habits? Habits have been conceptualized in many ways among both everyday people and in the literature. The discrepancies in the definition of habit have led to challenges in empirically establishing certain behaviors as

“habitual” (De Houwer, 2019). Wood and Runger (2016) characterize habits as repeating the same response in a given context. Habits serve as an efficient default mode of response and are insensitive to changes in the contingency of response outcomes. Graybiel (2008) conceptualizes habits as gradually learned, inflexible, and unconscious. Based on these definitions, researchers have begun to suggest that recurring shifts in attention driven by selection history behave like a habit; they are automatic, implicit, insensitive to changes in value, and inflexible. Jiang and Sisk (2019) review examples of enduring changes of attention in tasks such as probabilistic cueing and contextual cueing and argue that their demonstration of gradual, implicit, inflexible learning is analogous to habit formation.

### **Implicated Brain Regions**

Attentional control has previously been seen as a frontal-parietal mechanism (Katsuki & Constantinidis, 2014); however, sequence learning has shown activation in the basal ganglia, specifically the mid and anterior caudate and putamen, and in the globus pallidus (Janacek et al, 2020). This type of learning is different than fast, declarative, hippocampal learning (Jiang & Sisk, 2019). Notably, the basal ganglia have also been demonstrated as necessary for habit maintenance and formation (Yin & Knowlton, 2006). This suggests the existence of a separate system for attentional modulation in the brain that involves habit learning. The habit system in the brain has previously been seen as primarily motor; however, there is evidence that it is also involved in cognition (Graybiel, 2008). For example, as you are driving through a city, you effortlessly attend to specific locations, but not necessarily due to the physical salience or goal relevance of the stimuli. This suggests that attention driven by selection history could be essential for freeing up cognitive resources for routine tasks.

### **The Present Study**

The present study aimed to develop a task to behaviorally probe attention modulated by selection history and investigate the extent to which this type of attention resembles habit. In order to do this, we created a modified version of the SRT that demands spatial-temporal attention rather than primarily relying on motor learning. Participants were asked to make a decision about stimuli that appeared in 1 of 4 locations. Blocks alternated between learned and novel sequences of image locations. We expected faster reaction times and higher accuracy for the learned condition, which would suggest learning of the sequence. We also aimed to quantify this learning effect for individual subjects. Previously, there has been little evidence of individual differences in implicit learning (such as with contextual cueing), however, (Kalra et al, 2019) demonstrated stable individual differences in this type of learning among individuals in serial response tasks, so we aimed to develop a task that would produce similar effects. We also aimed to study the inflexibility and implicitness of the learned effect, as would be characteristic of an attentional habit. In order to do this, an altered version of the learned sequence and an awareness test were implemented. We predicted that if the learned sequence was changed, participants would be slower and less accurate with their responses. We also hypothesized that participants would be able to accurately predict a future location of the learned sequence even if they reported no knowledge of a pattern, indicating that the learning occurred implicitly.

The development of a taxonomy for selection history effects will have many implications in the field of psychology. This potential system for attentional modulation, which has seldom been studied, could control activity in the visual system in much the same way as other attentional mechanisms. However, it will account for the things we attend to that are neither top-down nor bottom-up, presenting further disruption to the canonical top-down/bottom-up

dichotomy of attention, motivating a re-evaluation of attentional control mechanisms across the field.

## **Method**

### **Participants**

Participants were recruited from the student population at the Ohio State University. Participants either received introductory psychology course credit or \$10 per hour for their participation. All participants gave informed consent and had normal or corrected to normal vision. The methods of this experiment were approved by the institutional review board at the Ohio State University.

### **Materials**

The experiment was coded using MATLAB and Psychtoolbox. The stimuli were presented on a 24-inch monitor with a Dell OptiPlex 7000 desktop computer.

### **Procedure**

Participants scheduled sessions according to their availability and the times we had posted on Ohio State's Research Experience Program website. Each session of the experiment lasted approximately one hour. All participants gave informed consent. Written instructions were displayed on the screen, and verbal instructions were given. Participants were instructed to report the direction of the tilt of a grating (either 2° left or right) that appeared in one of four squares on the screen, using a left or right button press. They were asked to respond as quickly and accurately as possible. They were told there would be breaks built in throughout the experiment and were instructed to press the space bar when ready to move on to the next block.

After the instructions, participants began the main experiment. Participants completed 108 blocks of 16 trials, with four targets in each quadrant per block. The direction of the tilt of



the image was randomized. The blocks alternated between learned and novel locations of the target. The learned sequence of target locations moved in a clockwise direction and formed a circular pattern, and the background was green (Figure 1). The target's location was randomized for the novel sequence and was set against a blue background (Figure 2). The stimuli were presented for 250 milliseconds. After a decision was made about the target's orientation, the participant was presented with feedback (correct/incorrect), and the subsequent trial began. This portion of the experiment lasted for approximately 50 minutes depending on how long participants took during the scheduled breaks.

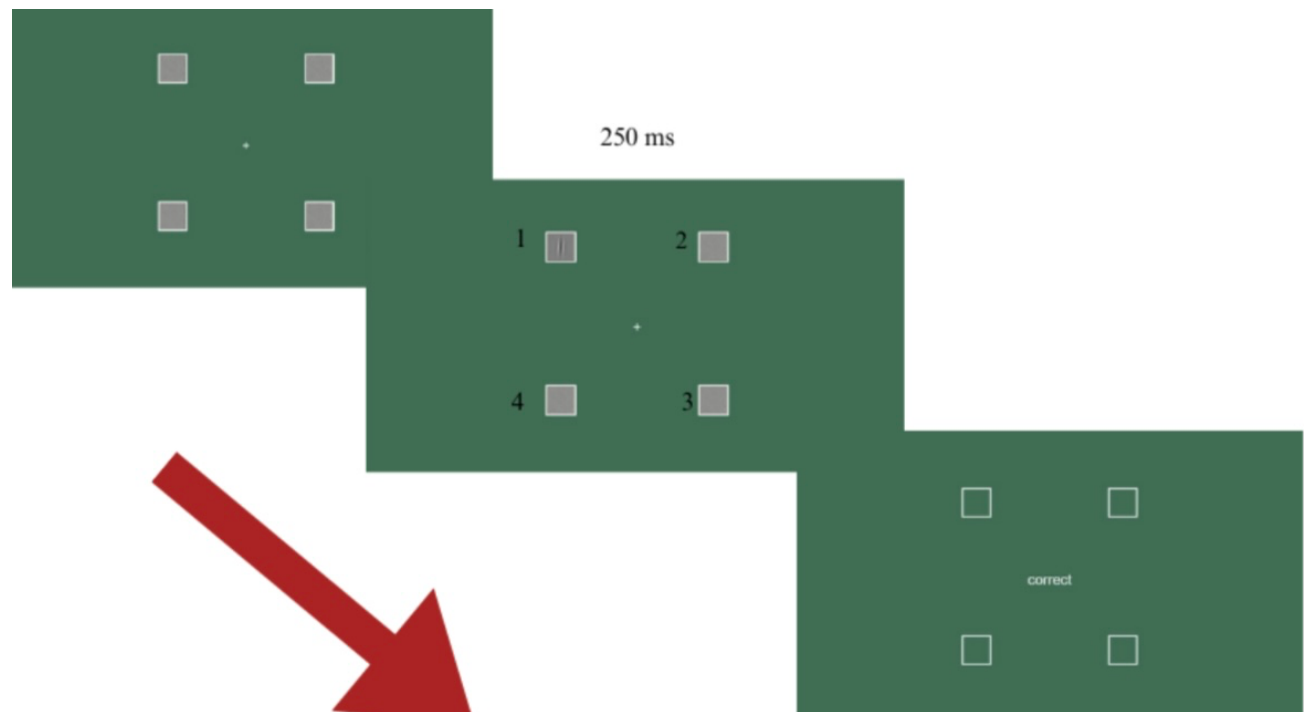
Following the main task, participants completed a task with an altered version of the learned sequence to test for perseveration. They were given the same instructions as in the main experiment but were told that this task would be much shorter (approximately 5 minutes). Following these instructions, participants completed three blocks of 16 trials with four targets in each quadrant per block. All three blocks were the changed version of the learned sequence of locations. The first 3 locations of the images followed the clockwise circular pattern, but the last image location in the learned sequence appeared in a random location each time. The stimuli were presented for 250 milliseconds. After a decision was made about the target's orientation, the participant was presented with feedback (correct/incorrect), and the next trial began.

After the altered sequence, participants were asked to complete a short post-task. Participants were told they would be presented with the same four squares as in the main task, in which the same images would appear, but this time, after the image had appeared twice, they had to predict the future location of the image using the mouse rather than indicating the direction of the tilt of the image. After these instructions, participants completed ten trials of this alternating between both the novel and learned sequences. At the end, they were prompted with the

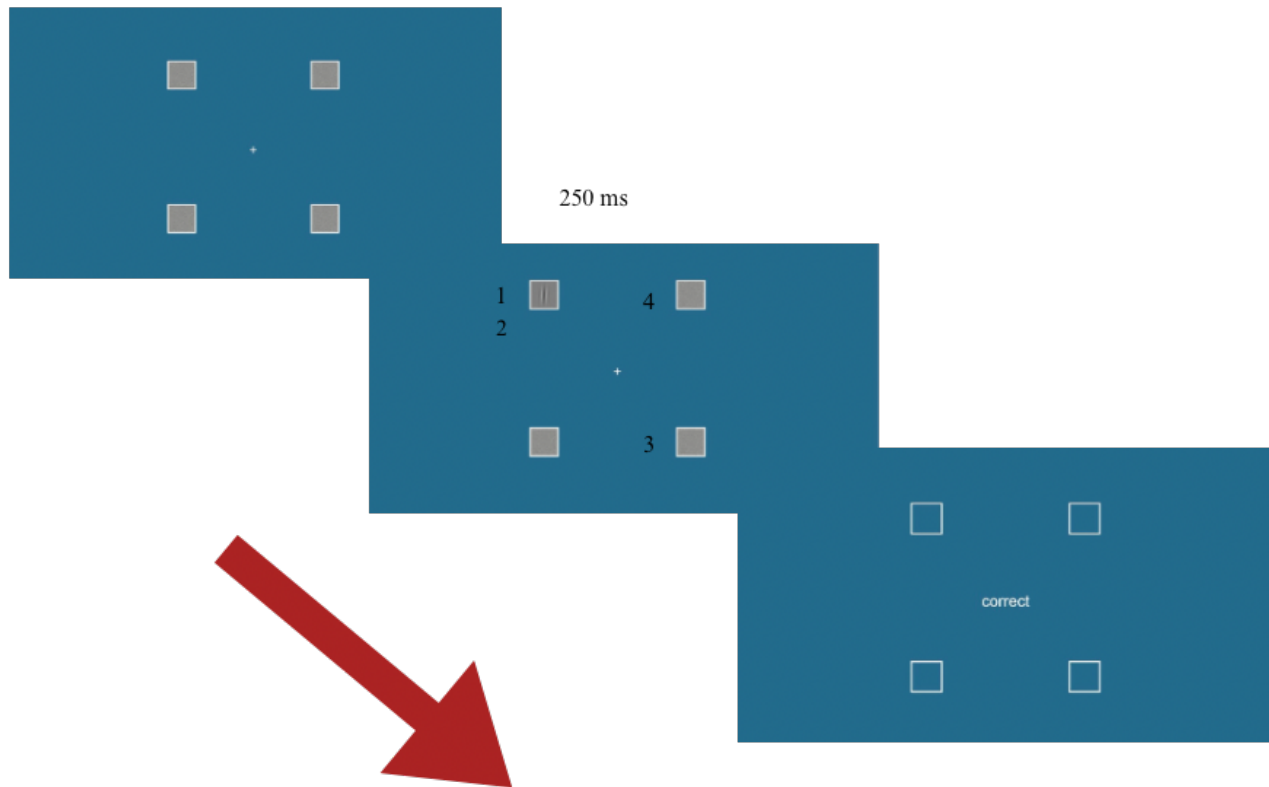
question: “Throughout the experiment, did you notice a pattern in the location of the images?” to which they responded “yes” or “no” using the mouse to click on their selected answer.

### Data Analysis

We excluded subjects who performed with less than 70% accuracy in the main task. This exclusion criteria left us with 64 subjects.



*Figure 1. Example trial of the learned sequence block of the main experiment. The tilted Gabor appeared in a series of locations that followed a clockwise circle. Stimuli were presented for 250 milliseconds and participants were presented with feedback after a decision about the Gabor's tilt was made. The background was green for these blocks.*



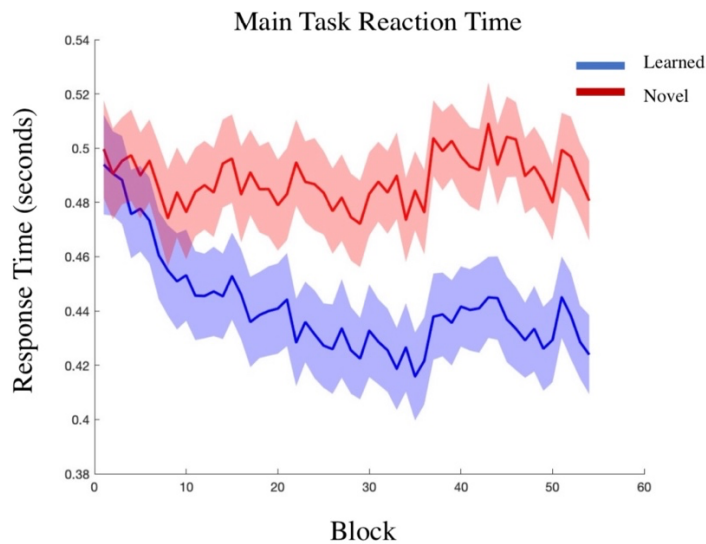
*Figure 2. Example trial of the random sequence block of the main experiment. The tilted Gabor appeared in a randomized series of locations. Stimuli were presented for 250 milliseconds and participants were presented with feedback after a decision about the Gabor's tilt was made. The background was blue for these blocks.*

## Results

### Main Task

Reaction times across the group for the main task are shown in Figure 3. We averaged participant's response times (in seconds) for each block of 16 trials. In accordance with our hypotheses, we observed a strong reaction time effect, with participants being faster to respond in the learned condition than in the novel condition. The difference between the two conditions began 11 blocks into the experiment. For accuracy, we averaged the proportion of correct responses for each block of 16 trials and also observed a strong effect (Figure 4). This difference between the two conditions began earlier than with reaction time, after six blocks. Because the

effects appeared to stabilize toward the end of the experiment, we decided to analyze the last 25 blocks. We computed a t-test of reaction time in the last 25 blocks of the experiment. This revealed a significant difference between the learned and novel conditions ( $p = 0.0069185$ ) (Figure 5). A t-test of accuracy between the two conditions in the last 25 blocks also revealed a significant difference ( $p = 7.9421e-07$ ) (Figure 6). We examined whether these effects were significant for individual subjects throughout the main experiment, and analysis revealed that 67.188% of participants demonstrated a significant effect for reaction time on an individual level (Figure 7) and 53.125% of participants demonstrated a significant effect for accuracy on an individual level (Figure 8).



*Figure 3: Average reaction time by block in the main task between the learned and novel conditions. Note that participants are significantly faster for the learned condition.*

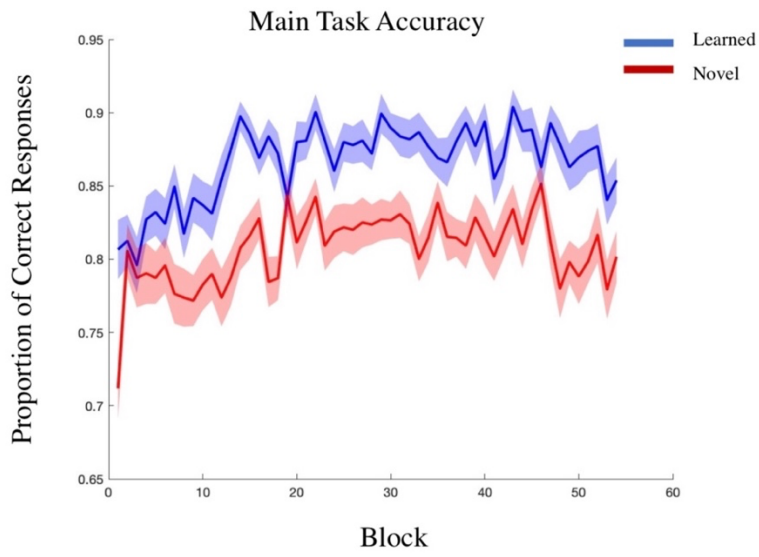


Figure 4: Average accuracy by block in the main task. Note that participants are significantly more accurate for the learned condition.

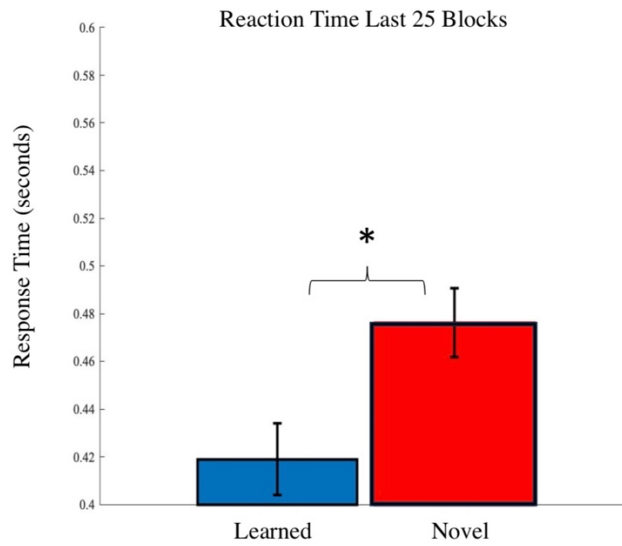


Figure 5: Bar graph comparing the average response time in seconds between the learned and novel conditions for the last 25 blocks of the main experiment. This remains significant as the effect levels out.

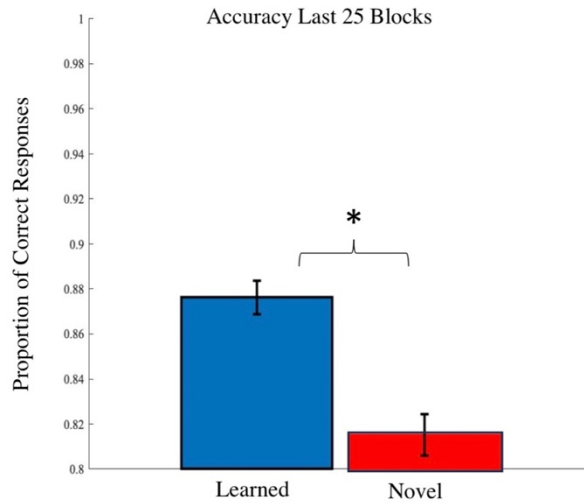


Figure 6: Bar graph comparing the average accuracy between the learned and novel conditions for the last 25 blocks of the main experiment. This remains significant as the effect levels out.

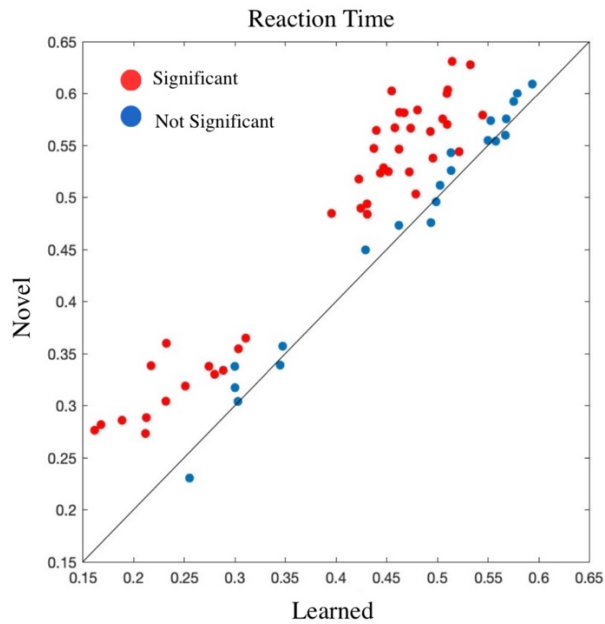


Figure 7: Scatterplot displaying individual subjects' average response times in seconds in the learned compared to the novel condition. Red indicates subjects that displayed a significant effect. All subjects above the line were faster to respond in the learned condition compared to the novel condition.

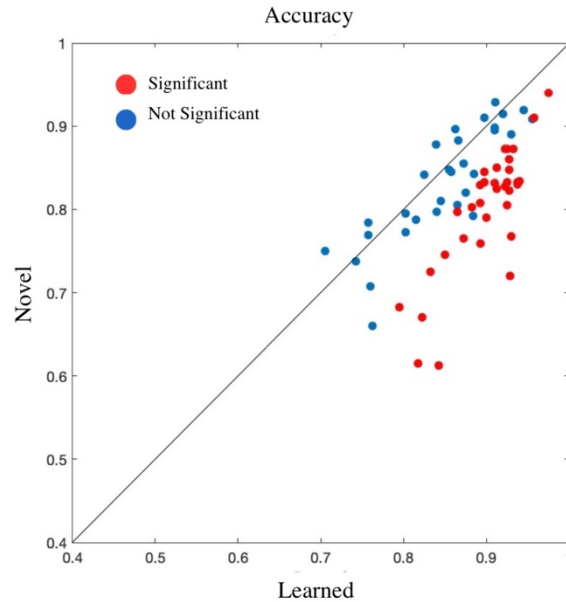


Figure 8: Scatterplot displaying individual subjects' average proportion of correct responses in the learned compared to the novel condition. Red indicates subjects that displayed a significant effect. All subjects below the line were more accurate in the learned condition compared to the novel condition.

### Altered Sequence

This portion of the task was implemented about halfway through data collection, so only 47 of the total 91 subjects completed the altered sequence, of which 33 were included in our analyses after the 70% accuracy cutoff. We averaged participants' response time (in seconds) and the proportion of correct responses for both critical (randomized location) and non-critical trials (other trials in the learned sequence). We conducted a t-test of their response times, which revealed they were significantly slower for the critical versus non-critical trials ( $p= 0.00047844$ ) (Figure 9). The t-test of accuracy between critical and non-critical trials was not significant, however, it was trending ( $p= 0.060063$ ) (Figure 10).

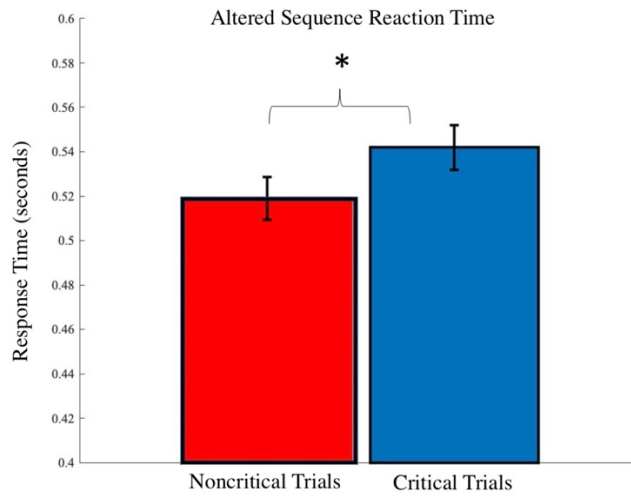


Figure 9: Bar graph comparing response times in seconds for the altered sequence portion of the task between the ‘critical trials’ (changed location in the learned sequence) and noncritical trials. Participants were significantly slower to respond for the critical trials.

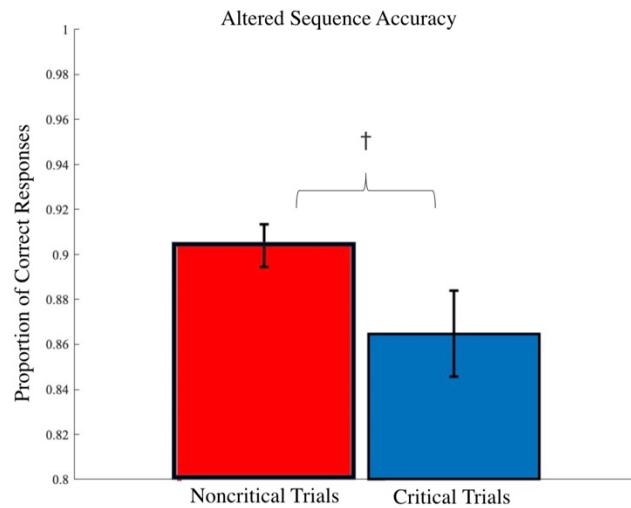
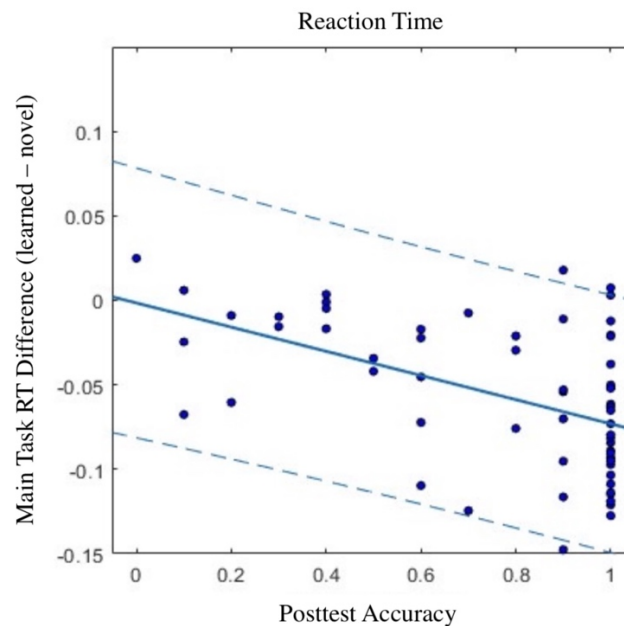


Figure 10: Bar graph comparing the proportion of correct responses for the altered sequence portion of the task between the ‘critical trials’ (changed location in the learned sequence) and noncritical trials. Participants were less accurate for these critical trials, however, this result is not significant.

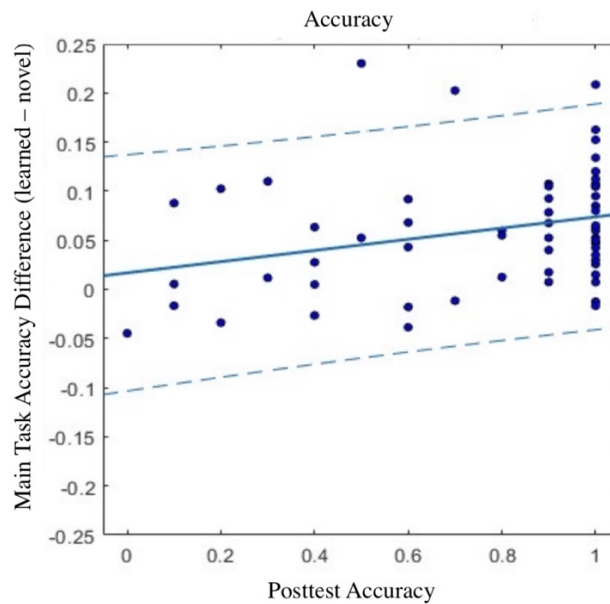
**Post-test**



Contrary to our hypotheses, 72 of all 91 subjects reported noticing a pattern. After the implementation of the exclusion criteria, 51 subjects indicated recognition of a pattern, while 13 indicated no recognition. 95% of subjects who displayed significant accuracy on the post-test indicated that they noticed the pattern. Of those who did not exhibit significant accuracy on the post-test, only half indicated noticing a pattern. A correlation test between accuracy on the post-test and reaction time effects in the main task (learned – novel RT) revealed a relationship ( $r=-0.49761$ ,  $p=2.8712e-05$ ) (Figure 12). A correlation test between post-test accuracy and accuracy effects in the main task (learned – novel accuracy) also revealed a significant relationship ( $r=0.2903$ ,  $p=0.019967$ ) (Figure 13).



*Figure 11: Participants' individual accuracy on the posttest plotted against their reaction time effects in the main task. There is a significant correlation. The more accurate participants were on the posttest, the stronger the reaction time effect they exhibited in the main task.*



*Figure 12: Participants' individual accuracy on the posttest plotted against their accuracy effects in the main task. There is a significant correlation. The more accurate participants were on the posttest, the stronger the accuracy effect they exhibited in the main task.*

## Discussion

The goal of this study was to modify the serial reaction time task to include spatial-temporal demands, probe sequentially guided attention, and investigate whether this type of attention demonstrates habit-like properties. The strong reaction time and accuracy effects demonstrated across the group suggest participants' learning of the repeated sequence, supporting the concept of attention driven by prior experience. The correlation of participants' accuracy on the post-test with effects for reaction time and accuracy in the main task suggests that participants who learned the sequence better displayed stronger effects. This suggests that repeatedly attending to specific locations can modulate our attention and facilitate search, enhancing task performance. We also were able to observe these effects at the level of individual subjects, something that other tasks aimed at investigating this type of attention, such as

contextual cueing, have failed to do. The altered version of the sequence demonstrated perseveration of the reaction time effect; participants were significantly slower to respond when the learned sequence was changed. Participants also tended to be less accurate for these altered trials, and although these results were not significant, this may be due to the smaller sample size for this portion of the task. These results provide some support for the inflexibility of learned attentional sequences.

One could argue whether this study demonstrates the acquisition of an attentional habit. Our findings challenge the widely accepted idea that attentional habits are acquired and used implicitly. Though our measures for this aspect of habitual attention possessed some limitations (self-report measure) a large proportion of participants reported that they did notice a pattern in the location of the images on the post-test. This presents some considerations when it comes to the conceptualization of habit. As discussed earlier, the variability in the definition of habit presents difficulties in establishing a behavior as habitual. While many researchers argue that attentional habits are used unconsciously, there is some evidence to suggest this may not be the case. Habits have often been grouped with other types of procedural memory that have been deemed as unconscious or implicit, such as classical conditioning and priming. However, they differ from these processes in the sense that they activate the repetition of a particularly well-learned response rather than a range of responses (Evans & Stanovich, 2013). Similarly, Wood et al deem habits as “learned automatic responses with specific features” instead of simply being analogous with the term automaticity (2014). Habits have also been termed as mental representations of goal-action links, and as behaviors are repeated, they become more habitual and less dependent on goal pursuit (Aarts & Dijksterhuis, 2000 & Wood & Runger, 2016). In the case of the present study, as participants repeatedly directed their attention to the locations of the

target in the learned sequence, the behavior likely became habitual and the decision to attend to those spots was no longer explicit. However, this does not mean that the participants could not have been explicitly aware of the sequence the target was appearing in, as they had to consciously decide where to attend before the habit was acquired. Another explanation for participants' explicit knowledge of the pattern is the simplicity of our learned sequence. Being that it was a clockwise circle, it is possible that this made it more obvious to participants and that they would not have been aware of the pattern had the learned sequence been more complex.

### **Limitations**

The present study possesses a few limitations. Firstly, the altered sequence portion of the task was underpowered. While there was a difference in accuracy between critical and non-critical trials, with only 33 subjects, the difference was not significant. Second, our attempts to measure the implicitness of the sequence learning effect had several issues. We suspect participants may have been more likely to answer yes to the final question of whether they noticed the pattern in the sequence due to response bias, reducing the validity of the measure. While the participants who answered no likely did not possess knowledge of the sequence, there is no way to determine what portion of the participants who answered yes actually were aware of the pattern. It is possible that subjects simply answered yes because they believed that was the answer we were looking for, or that they believed they had noticed a pattern that was not the same as the one in the learned sequence. As previously mentioned, the large number of subjects who reported explicit awareness of the pattern could also be due to the simplicity of the learned sequence.

### **Conclusions and Future Directions**

The present study developed a task that supports the idea that our attention can be modulated by selection history, which can enhance target search performance. The discovery of this type of attentional modulation could have many implications in the field of psychology, as it may be essential for allocating cognitive resources. Our task also demonstrated effects that can be quantified for individual subjects, unlike previous tasks developed to study this phenomenon. The learning of the repeated sequence proved to be inflexible and gradually learned but appeared to be explicit, challenging the extent to which this type of attentional modulation can be compared to habit formation. Future directions include the implementation of the task with a more complex learned sequence and an altered sequence with a larger sample size to further investigate these habit-like properties. We suggest the implementation of this task as an explicit version in comparison to a more complex implicit version. This research could also be expanded upon using fMRI to reveal the neural mechanisms of this new attentional system. Responses in the basal ganglia could be compared between learned and novel conditions of the task. The implication of these brain regions in this type of attention provides many opportunities for clinical intervention in disorders involving the basal ganglia, such as addiction, OCD, and ADHD. This future research could have implications for predicting risk factors, diagnosis, and potential interventions, such as the development of cognitive behavioral therapies for some patients (particularly those suffering from addiction).

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