SPATIAL CONTEXT TARGET RELEARNING IN MEMORY-GUIDED VISUAL SEARCH

by

Patrick Ryan Mead
A Dissertation
Submitted to the
Graduate Faculty
of
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The Requirements for the Degree
of
Doctor of Philosophy
Psychology

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DEDICATION

This dissertation is dedicated to my loving wife Allison and daughter Avery. Without you, my dreams are like a hot air balloon lifting off with no basket. However, your love, dedication, and sacrifice provide a basket that carries me wherever my dreams take me.

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I would like to thank the many friends, relatives, and supporters who have helped me through the trials that come with juggling life, family, work, and school. In particular, I would like to thank my wife, Allison, for sacrificing her time and energy supporting and encouraging me during this past four years. My parents, Tim and Denese, who instilled in me a love of learning and a drive to succeed. Drs. Peterson, Boehm-Davis, and Shaw who guided and coached me through the various stages of this process. The mentorship and encouragement of Dr. Peter Squire who gave me the push I needed to pursue my doctoral degree. Lastly, a special thank you to Dr. Elizabet Haro, whose mentorship, friendship and honesty supported both myself and my family as I pursued my degree.

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LIST OF ABBREVIATIONS AND SYMBOLS

Accuracy	ACC
Response Time	RT
Positive Spatial Cueing	PSC
Pixel	px
Milliseconds	ms
Centimeter	cm
Inches	”
Degrees	°
Plus or Minus	±
Percent	%

ABSTRACT

SPATIAL CONTEXT TARGET RELEARNING IN MEMORY-GUIDED VISUAL SEARCH

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The following dissertation presents two studies that explored the effects of unexpected target relocation events on spatial context target relearning during memory-guided visual search. In previous studies, learning and relearning were defined by the presence of a response time benefit for repeated search displays. In most cases, these studies failed to see relearning following an unexpected target relocation event, with only targets near the original location showing a benefit. These two studies showed that relearning does occur for new experimental conditions as well as experimental conditions where relearning was not observed. Furthermore, they showed that relearning is possible after single and multiple relocation events, and is not functionally limited by the distance of the target relocation from the initial location.

SPATIAL CONTEXT TARGET RELEARNING FOLLOWING A RELOCATION EVENT: NOT MISSION IMPOSSIBLE

Abstract

Our visual system relies on our memory to store and retrieve goal relevant structures and information within the environment for the purpose of cueing and optimizing the allocation of our attention. This concept, referred to as Contextual Cueing, was demonstrated using visual search tasks, wherein repeated visual contexts lead to a reduction in search times compared to random displays (Chun and Jiang, 1998). Subsequently, when an unexpected change occurs in the environment, or memory fails, a cognitive expense is incurred as the mind tries to resolve the conflict with the memory of the previous environment context (Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010).

How memory resolves these conflicts and is updated is of great interest, with previous studies exploring the effects of unexpected changes to the target location of a previously learned context. Previous studies showed that individuals were unable to associate a secondary target location with a previously learned spatial context following the relocation of the initially learned target (Zellin, Conci, Muhlenen, and Muller, 2011; Conci, Sun, and Muller, 2011; Conci and Muller, 2012; Zellin, Conci, Muhlenen, and Muller, 2013).

However, the results of this study showed, in two separate experiments, that relearning does occur for a secondary target and previously learned context. Furthermore, in experiment two, cueing benefits fully recover for the secondary location, achieving cueing levels equivalent to repeated displays not experiencing a target relocation event.

Keywords: Visual Search, Spatial Context Cueing, Multiple Targets, Learning

Introduction

Visual search is an inherent part of nearly every task whether skimming a work email for the time and location of a meeting, finding a tool needed to make a repair, or spotting your next turn or exit when driving in traffic. In most cases, the cognitive demands associated with visual search go relatively unnoticed because of the cues in our environment.

While performing even the most mundane tasks, relevant and predictive contextual features within the environment are stored and retrieved from memory, cueing our visual attention and improving search speeds. This concept, referred to as contextual cueing, was initially demonstrated using simple visual search tasks, wherein repeated visual search stimuli led to a reduction in search times compared to random stimuli (Chun and Jiang, 1998).

This important interplay between memory and visual attention has resulted in a wealth of research focused on the initial learning and performance outcomes of contextual cueing under varying conditions (Chun and Jiang, 1998; Chun and Jiang, 1999; Peterson and Kramer, 2001; Olson and Chun, 2002; Chun and Jiang, 2003; Endo and Takeda, 2004; Jiang and Wagner, 2004; Lleras and Muhlenen, 2004; Jiang and

Leung, 2005; Jiang and Song, 2005; Jiang, Song, and Rigas, 2005; Brady and Chun, 2007; Hout and Goldinger, 2012; Giesbrecht, Sy, and Guerin, 2013). Ultimately, these studies have shown that invariant and repeated contextual features (e.g., location, identity, motion) that are predictive of shared target features lead to an improvement in search response times. For example, if the locations of a set of distractors and target are stable over time, the distractor locations become predictive cues of the target's location, helping to guide our attention (Chun and Jiang, 1998).

Nevertheless, given the variability of real environments from day to day, contextual cueing would be very ineffective without the ability to associate more than one target of interest or to update previously learned contexts following changes to relevant features or targets. For example, we expect the steady layout of an office environment to cue multiple items (e.g., your desk, a water cooler, a shared printer). Furthermore, we expect that the association between the layout and elements within it would gradually be relearned following a change, such as a relocation, of any one or more items. Though it is reasonable to expect a temporary period of decreased search performance following an item relocation, like moving a printer, workers would be expected to relearn and quickly navigate to the printer after a relatively short number of exposures to the new location.

Although several studies have demonstrated the ability to associate more than one target to a given context (Chung and Jiang, 1998; Brady and Chun, 2007; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2011; Conci and Muller, 2012), results from studies on context changes, specifically the relocation of a target, have failed to show relearning following a target relocation event (Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013). This failure to observe relearning after a target relocation event is fundamentally inconsistent with our expectations for real-world environments. Instead, these results suggest that a target relocation event, like moving the printer to a new location within the office, would not be quickly associated with the previously learned layout.

One possibility leading to the failure of relearning in previous studies is that the search arrays lacked a sufficient number of cueing features (e.g., stimuli location, color, shape, or size) to relearn a new target location for a previously learned context. Following a relocation event, additional features such as target and distractor identities may be needed as supplemental cues when trying to associate a secondary target location to a previously learned spatial context.

In studies where relearning failed to occur, search arrays were presented using monochromatic (e.g. white or gray stimuli) or randomized color stimuli on a black or gray background, only maintaining target and distractor locations for repeated contexts (Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013). As such, only the spatial location of distractors was predictive of the target location. Presentation color may be important given that previous studies of non-spatial contextual cueing features have shown that identity features, such as shape and color, additively contribute to spatial contextual cueing (Endo and Takeda, 2004; Jiang and Song, 2005).

A second possibility that may contribute to a lack of relearning in previous studies is the failure to maintain the overall spatial configuration of the targets and distractors. For a target relocation event, targets can either swap positions with a distractor or move to a previously unoccupied location. For example, imagine that a specific star in a constellation is our target. Swapping its position with that of another star in the constellation would change which stars were nearest our target, but would not affect the overall pattern of the constellation. However, relocating the same target star to a blank space in the night sky would change the overall pattern of the constellation as well as which stars were nearest the target.

In the majority of studies where relearning was not observed, targets relocated to a previously unoccupied location resulted in changes to the overall spatial configuration (Mangenelli and Pollmann, 2009; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013). The overall spatial configuration may be important, as previous studies have shown that maintaining the spatial relationships of all stimuli contributes additively to the contextual cueing effect of the local spatial configuration (i.e. the spatial pattern formed by the target and its nearest distractors) (Jiang and Wagner, 2004; Brady and Chun, 2007). These results suggests that the overall and local spatial configurations serve as separate cues.

The current study was designed to address these two possibilities for the lack of relearning. Unlike previous research, this study presents search arrays in color, maintaining both the spatial and color properties of repeated contexts throughout the experiment. Additionally, where previous studies relocated targets to a previously unoccupied location, this study relocates targets to a previously occupied location, swapping the target with a previous distractor.

The hypothesis is that relearning will occur for repeated contexts that maintain both the color and spatial relationships of the targets and distractors, cueing both an initial and secondary target location. Furthermore, maintaining the overall spatial configuration by swapping the target with a previous distractor will lead to improved spatial cueing after a relocation event.

Alternatively, as with previous studies, if relearning is not observed following a relocation event, contextual cueing should still be present for the initially learned target location (Zellin, Conci, Muhlenen, and Muller, 2013). However, if relearning is successful for a secondary location, cueing should be temporarily lost for the initial location, requiring a subsequent learning period.

Finally, the second experiment of this study builds on that of previous designs by extending the period of observation (i.e. number of repetitions) for a returned target (Zellin, Conci, Muhlenen, and Muller, 2013; Zellin, Muhlenen, and Muller, Conci, 2014), and examines the effects of relearning on a returned target following single and multiple relocation events. If relearning does not occur for a secondary location, the amount of contextual cueing for the initial target location will be cumulative and continue to improve after multiple return events. However, a modest decrement immediately following a return event due to the unexpected nature of the return and interruption of the intervening relearning period is expected.

Experiment 1

The goal of Experiment 1 was to determine if participants are capable of relearning the association between a previously learned spatial context and a new secondary target location following an unexpected target relocation event. Furthermore, if learning occurred for both the initial and secondary spatial context target associations a positive spatial cueing benefit should be present for both locations when presented within the same block of trials. The experiment was divided into three phases (Learning, Relocation, and Return). Eight initial target location context pairs were randomly generated and presented over four Epochs of four blocks. Each target-context pair occurred once per block along with eight randomly generated new contexts (16 trials per block – 8 old, 8 new), with presentation order randomized within each block.

At the onset of the relocation phase, the initial target locations for all eight learned contexts were randomly relocated to one of the previously occupied distractor locations. This type of relocation maintains the overall spatial context, as compared to relocation of a target or distractor to an unoccupied location which changes both the overall and local spatial context (Chun and Jiang, 1998; Manginelli and Pollmann, 2009; Makovski and Jiang, 2010 Exp. 1; Zellin, Conci, Muhlenen, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013).

As with previous findings (Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013), we predicted that any positive spatial cueing developed in the learning phase should be eliminated following an unexpected target relocation event. However, if participants can relearn the association between a spatial context and a new secondary target location, then positive spatial cueing should reemerge. Finally, during the Return Phase, four of the repeated contexts were randomly selected, presenting both the initial and secondary target locations during the same block of trials, with the location alternating across trials. If relearning failed to occur during the Relocation phase we predict that no cueing should be present for secondary target spatial contexts, but cueing should still be present for initial target spatial contexts, similar to previous studies (Zellin, Conci, Muhlenen, and Muller, 2013). Alternatively, if participants successfully relearned the spatial context target associations for the secondary target location, we predict that cueing should be present for both the initial and relocated contexts.

Method

Participants

A total of 36 individuals participated in Experiment 1 (27 females; 9 males). The overall error rate for each participant was calculated with three participants identified as outliers (error rates greater than 10%). These three participants were excluded from the remainder of the analysis, resulting in a total of 33 participants (24 females, 9 males). The mean age was 21 ± 5 years, with a range of 18 to 37 years. All participants reported normal or corrected-to-normal vision. Participants were offered and received course credit for their participation in the study regardless of successful completion of the experiment.

Apparatus and Stimuli

Experiment search displays were generated and presented for each participant using an application created in Visual Studio 2012 C#/WPF. The application was run on a Dell PC using a Dell U2410 24” monitor (51.8 cm x 32.4 cm). Participants were seated at an unrestricted viewing distance of approximately 50 cm.

The resolution of the monitor was 1920 x 1200 pixels with the search area (1080 x 1080 px) subtending 32.5° by 32.5° of visual angle and was centered on the screen. Each search display consisted of one target (a T-shape randomly rotated 90° left or right) and eleven distractors (an L-shape randomly rotated 0°, 90°, 180°, or 270°). The stimuli subtended 0.87° by 0.87° of visual angle (28 x 28 px). Twelve search stimuli (1 target, and 11 distractors were presented in one of six colors (Cornflower Blue, Red, Green, Yellow, Violet, and Orange), with two stimuli of each color present (Figure 1) (Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013).

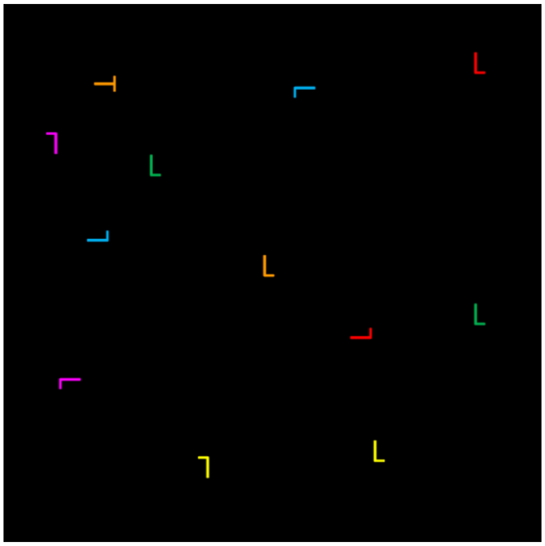


Figure 1. Experiment 1 - Example Search Array

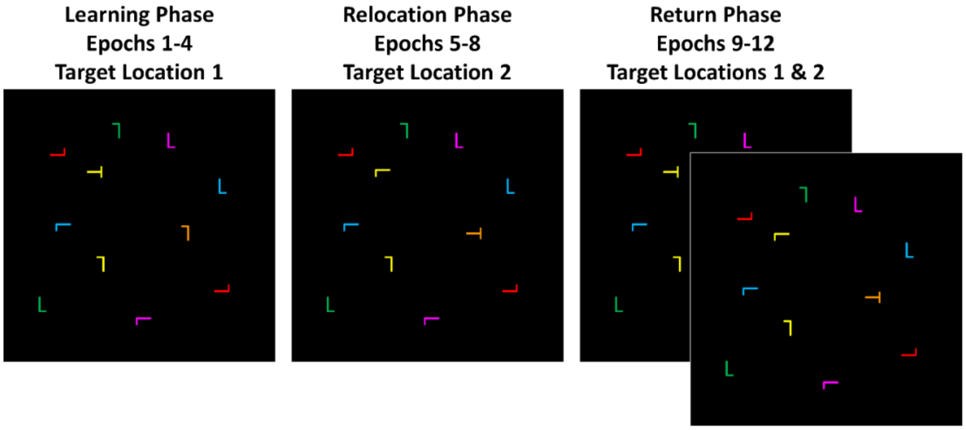
The stimuli within the search area were randomly assigned to one of 25 possible locations in a 5 x 5 grid, with an individual cell size subtending 6.67° by 6.67° (216 x 216 px) of visual angle. Additionally, all elements were randomly jittered ± 5.00° of visual angle (162 px) from the cell's center in both the x and y directions, consistent with the original spatial context cueing study (Chun & Jiang, 1998).

Design and Procedure

Experiment 1 used a repeated measures within-subject design broken into three Phases (Learning, Relocation, and Return), consisting of four Epochs and two Contexts (Old, New). Each Epoch consisted of four blocks of 16 trials comprised of eight repeated Contexts (Old) and eight randomly generated Contexts (New) per block (total of 768 trials) and required roughly 1-hour to complete. The presentation order of all Old and New contexts was randomized per block of 16 trials.

Each Old context was randomly generated for each participant, randomizing stimuli locations, color, and orientation, and randomly assigned two possible target locations. The distractor stimuli orientation and color remained consistent throughout the experiment, while target orientation was randomized for all trials to avoid repetition-priming effects.

During the Learning Phase (Epochs 1-4), targets were located at location one. At the start of the Relocation Phase (Epochs 5-8), targets were relocated to location two. When a target and a distractor location swapped, the color for the swapped locations remained the same, preserving the location color relationship. Finally, during the Return Phase (Epoch 9-12), four of the eight repeated contexts were selected, presenting both target location one and target location two at separate times during the same block of trials (i.e. alternating the location within a block). For example, during each block of trials in the Return phase participants would see the same Old Context twice, once with the target at location one and once at location 2 (Figure 2).



Learning Phase
Epochs 1-4
Target Location 1

Relocation Phase
Epochs 5-8
Target Location 2

Return Phase
Epochs 9-12
Target Locations 1 & 2

Figure 2. Experiment 1 - Target Location by Phase and Epoch.

Before the start of each trial, a central fixation cross, 1.2° by 1.2° (36 x 36 px), was presented. Participants were asked to fixate on the cross before the start of a trial and to hit the space bar when ready to begin the trial. In addition to the time required to hit the space bar, a minimum 300 ms inter-stimulus interval was included between hitting the space bar and onset of the search display. Each search display was presented until the participant had correctly made a speeded response by pressing either the left (the “F” key) or right (the “J” key). If a participant indicated the incorrect orientation, the display would remain visible until the correct key was pressed, recording the trial as incorrect. All participants were provided a brief practice session consisting of 16 trials before beginning the experiment and were instructed to search for the rotated “T” and determine its orientation as quickly and accurately as possible.

Results

Accuracy

Prior to assessing response time, it was important to ensure that accuracy remained stable over the course of the experiment, avoiding potential confounds associated with speed-accuracy tradeoffs. A repeated-measures analysis of variance (ANOVA) of Epoch (1-12) by Context (Old, New) showed no significant main effects for Epoch, F (11, 352) = 1.41, p = .167, η2 = .042, Context, F (1, 32) = .585, p = .45, η2 = .018, or interaction effects, F (11, 352) = 1.25, p = .254, η2 = .038, with an overall mean accuracy and standard deviation of 96.4 ± 0.004%.

Response Time (RT)

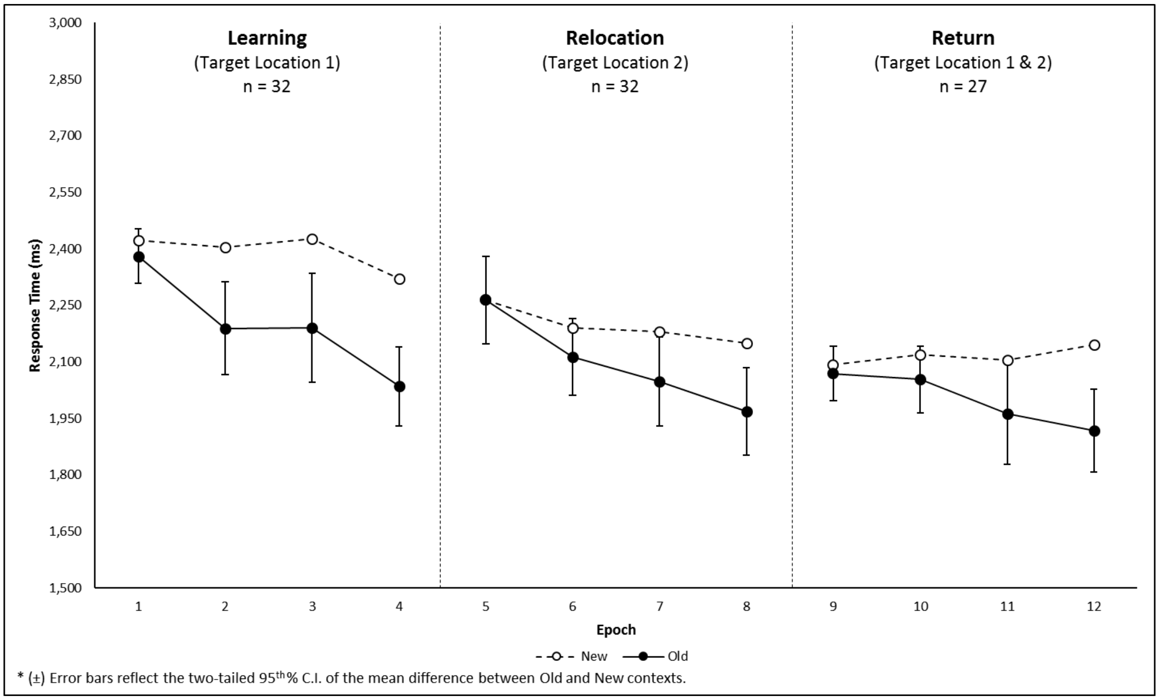
Next, RT was analyzed for each Phase (Learning, Relocation, and Return) of the experiment to determine whether learning and relearning of target context associations occurs prior to and after target relocation events. Prior to the analysis, the data set was cleaned, removing all error trials and trial RTs greater than 9000 milliseconds. A second pass of the data further removed trial RTs exceeding ± 3.0 standard deviations of the mean for each participant by Epoch (1-12) and Context (Old, New). The above outlier criteria resulted in the removal of 4.7% of all trials. Effects that did not meet the assumption of sphericity were adjusted using a Greenhouse-Geisser adjustment.

Since the focus of this experiment was determining whether relearning occurs following a relocation event for a secondary target location and a previously learned target context association, it was necessary to identify if that learning happened for the initial target locations. The mean cueing effect during the Learning Phase for each Epoch

(1-4) was calculated by participant ($RT_{New} – RT_{Old}$). A total of 32 of 33 participants showed evidence of initial learning, with positive cueing during at least one Epoch of the Learning phase.

Learning Phase

Once the data set was cleaned and participants were screened for evidence of initial learning, it was necessary to determine the presence and magnitude of the contextual cueing effect for the Learning Phase. It was predicted that Old contexts would become faster than New contexts over each Epoch. A two-way repeated measures ANOVA of Epoch (1-4) and Context (Old, New) was conducted revealing significant main effects of Epoch, F (3, 93) = 6.70, p < .001, η2 = .178, Context, F (1, 31) = 26.74, p < .001, η2 = .463, and a significant interaction effect for Epoch by Context, F (2.36, 73.23) = 4.86, p = .007, η2 = .135. Two-tailed paired-samples t-tests found that Old contexts became significantly faster than New contexts by Epoch two, (M = 216 ms, SE = 60 ms) t (31) = -3.58, p = .001, and remained significantly faster through Epoch four, (M = 285 ms, SE = 53 ms) t (31) = -5.51, p < .001) (Figure 3). The results confirmed the presence of initial learning.



* (±) Error bars reflect the two-tailed 95th% C.I. of the mean difference between Old and New contexts.

Figure 3. Experiment 1 - Response Time (RT) by Phase, Epoch, and Context.

Relocation Phase

Given the presence of initial learning, it was predicted that immediately following the target relocation event, positive spatial cueing will be lost due to the unexpected change in the target location. However, it was expected that relearning would still occur, with positive cueing returning by the end of the Relocation Phase. A two-way repeated measures ANOVA of Epoch (5-8) and Context (Old, New) was conducted, revealing significant main effects of Epoch, F (3, 93) = 12.52, p < .001, η2 = .288, Context, F (1, 31) = 5.72, p = .023, η2 = .156, and a significant interaction effect for Epoch by Context, F (3, 93) = 3.30, p = .024, η2 = .096.

As predicted, the target relocation event led to a loss of positive spatial cueing in Epoch five. However, two-tailed paired-samples t-tests showed that by Epoch seven, Old contexts had become significantly faster than New contexts (M = 133 ms, SE = 58 ms), t (31) = -2.30, p = .028 and continued to improve through Epoch eight, (M = 182 ms, SE = 57 ms) t (31) = -3.21, p = .003, (Figure 3). The return of positive spatial cueing for Old contexts confirms that relearning of the previously learned spatial context and the secondary target was successful.

Return Phase

During the Return Phase, the initial target location contexts were returned, with both the initial and secondary target contexts being randomly and separately presented during the same block of trials (once at locations one and two). Since relearning was successful, the next critical question to answer was whether positive spatial cueing was present for both target locations. To answer this question, it was necessary to determine which participants had shown successful learning and relearning and whether a there was a difference in RTs for Old contexts when the target was presented at location one or two.

The mean positive cueing (RT_{New} - RT_{Old}) was calculated for each participant by Epoch (5-8). A total of 27 out of the 32 participants showed positive spatial cueing on at least one Epoch of the Relocation Phase. Next, a two-way repeated measures ANOVA of Epoch (9-12) and Context (Old - Location 1, Old - Location 2) was conducted to determine if target location had an effect on RTs during the Return Phase. The results of the ANOVA, revealed a significant main effect of Epoch, F (3, 78) = 5.19, p = .003, $\eta 2$ = .166, with RT improving from Epoch nine to twelve, (M = 147 ms, SE = 47), t (26) =

3.07, $p = .005$. However, no significant effects of Context, $F(1, 26) = .008$, $p = .929$, $\eta 2 < .001$, or Epoch by Context, $F(3, 78) = 2.08$, $p = .109$, $\eta 2 = .074$. Since no effect of Context was present, the RTs of Old contexts locations one and two were collapsed.

Given that learning and relearning were successful for both locations, and no difference in RT was observed for locations one and two, it was predicted that positive spatial cueing should be present for Old contexts through the Return Phase. A two-way repeated measures ANOVA of Epoch (9-12) and Context (Old, New) did not reveal a significant main effect of Epoch, $F(3, 78) = 1.10$, $p = .356$, $\eta 2 = .04$, but did reveal a significant main effect of Context, $F(1, 26) = 13.57$, $p = .001$, $\eta 2 = .343$, and a significant interaction effect for Epoch by Context, $F(3, 78) = 3.80$, $p = .013$, $\eta 2 = .128$.

Contrary to our prediction, positive spatial cueing was not present at the onset of the Return Phase. However, two-tailed paired-samples t-tests showed that by Epoch 11, Old contexts were significantly faster than New contexts ($M = 143$ ms, $SE = 66$), $t(26) = -2.17$, $p = .039$, and continued to improve through Epoch 12, ($M = 227$ ms, $SE = 54$ ms) $t(26) = -4.15$, $p < .001$, (Figure 3).

One possible explanation for the initial loss of cueing is that the presentation of both locations led to an interference effect. However, an interference effect would likely prevent cueing from returning during the Return Phase. Alternatively, the lack of a RT difference for location one and location two, and the return of positive cueing in later Epochs suggests that the initial loss of cueing is likely due to the unexpected return of location one and the presentation of two locations within the same block of trials.

Ultimately, the presence of positive spatial cueing suggests that both target locations were successfully cued. Furthermore, this result is consistent with previous studies where two targets presented simultaneously and/or alternated were successfully cued (Chung and Jiang, 1998; Brady and Chun, 2007; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2011; Conci and Muller, 2012).

Target Relocation Distance

Lastly, positive spatial cueing was analyzed relative to Target Relocation Distance to determine whether cueing following a relocation event was driven by the proximity of the secondary target and its original location. The target relocation distance of each repeated target context pairing was calculated for each participant (Range: 6.63° - 33.28°, M = 17°, SE = .12°). Next, positive spatial cueing ($RT_{New} – RT_{Old}$) during the Relocation and Return phases were calculated for each Epoch by participant and Target Relocation Distance and aggregated by Epoch and Target Relocation Distance.

Previous studies found a significant negative correlation between Target Relocation Distance and the amount of positive spatial cueing in the Epoch immediately following the target relocation event (Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013). It was predicted that this negative correlation would also be present in this study, with positive spatial cueing increasing as Target Relocation Distance decreases.

A two-tailed Pearson’s correlation analysis of Target Relocation Distance and mean positive spatial cueing confirmed the significant negative correlation for the first Epoch of the Relocation phase, r = -.420, p = .033 and the first Epoch of the Return

Phase, r = -.437, p = .029, with positive spatial cueing increasing as the distance of the relocation decreases immediately following a target relocation event.

Given the presence of successful relearning, it was of interest to estimate if positive spatial cueing was limited to a specific Target Relocation Distance. A simple linear regression of Epoch and Target Relocation Distance as predictors of positive spatial cueing was conducted for each Phase (Relocation, Return) following a target relocation event to determine the maximum relocation distance for which positive spatial cueing would emerge.

Next, the mean positive spatial cueing was analyzed by Epoch and Target Relocation Distance to determine when and at what relocation distances could relearning occur and cueing return. Since the Target Relocation Distances were random per Context and each participant experienced only a subset of possible distances, a simple linear regression was run to model the amount of positive spatial cueing achieved for each Epoch and Target Relocation Distance. For the Relocation Phase, the resulting regression model was found to be significant, F (2, 101) = 9.49, p < .001, with an R2 = .158 (Eq. 1). Similarly, the regression model for the Return phase was also found to be significant, F (2, 97) = 9.49, p < .001, with an R2 = .307 (Eq. 2).

Equation 1. Relocation Phase - Positive Spatial Cueing as a function of Epoch and Relocation Distance.

$$\mathbf{PSC\ (ms) = 239 + 71 \times Epoch\ (0 \dots 3) - 12 \times Target\ Relocation\ Distance(^\circ\ Visual\ Angle)}$$

Equation 2. Return Phase - Positive Spatial Cueing as a function of Epoch and Relocation Distance.

$$\mathbf{PSC\ (ms) = 371 + 75 \times Epoch\ (0 \dots 3) - 19 \times Target\ Relocation\ Distance(^\circ\ Visual\ Angle)}$$

Next, the resulting regression models were used to predict the amount of positive spatial cueing by Epoch and Target Relocation Distance for distances between the minimum and maximum relocation distances used in the study (5° - 35° of visual angle). The estimates show that for Epoch five during the Relocation Phase, that targets relocated between 5° and 25° contributed to the positive spatial cueing benefit, while those greater than 25° led to a negative cueing cost. However, by the final Epoch of the Relocation Phase relocation distances from 5° and 35° of visual angle achieved a positive cueing effect (Table 1).

Table 1. Experiment 1 - Relocation Phase Positive Spatial Cueing Estimates by Epoch and Target Relocation Distance (Spatial Cueing less than or equal to zero highlighted in gray).

	Distance							
Epoch	**5**	**10**	**15**	**20**	**25**	**30**	**35**	***M***
5	249	187	126	64	3	-59	-120	64
6	320	259	197	136	74	13	-49	136
7	392	330	269	207	146	84	23	207
8	463	402	340	279	217	155	94	279

Similarly, the estimates for Epoch nine during the Return Phase show that targets separated between 5° and 20° of visual angle were positively cued, while those greater than 20° led to a cost. However, by the final Epoch of the Return Phase targets separated 5° and 30° of visual angle can achieve a positive cueing effect (Table 2).

Table 2. Experiment 1 - Return Phase Positive Spatial Cueing Estimates by Epoch and Target Relocation Distance (Spatial Cueing less than or equal to zero highlighted in gray).

	Distance							
Epoch	**5**	**10**	**15**	**20**	**25**	**30**	**35**	***M***
9	351	255	159	63	-33	-129	-225	63
10	427	331	235	139	43	-53	-149	139
11	502	406	310	214	118	22	-74	214
12	578	481	385	289	193	97	1	289

Not surprisingly, targets relocated a relatively short distance from their original location achieved the greatest amount of positive spatial cueing earliest. Consistent with what would be expected in a real-world situation, both the models for the Relocation and Return Phases suggest that given sufficient relearning time, positive spatial cueing can be achieved for small and large relocation distances.

Discussion

The purpose of Experiment 1 was to determine if relearning of a previously learned spatial context target association could occur for a secondary target location following an unexpected relocation event. Analysis of the RTs for repeated contexts showed definitive learning and relearning of both the initial and secondary target locations. Consistent with previous studies and current predictions, positive spatial cueing was achieved for the first target location, and immediately lost following the relocation (Manginelli and Pollmann, 2009; Makovski and Jiang, 2010 Exp. 1; Conci, Sun, and

Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013).

However, unlike studies which failed to see relearning of the secondary target location for a previously learned spatial context, positive spatial cueing did return during the Relocation Phase. More importantly, relearning was achieved in as few as 12 repetitions. This result contradicts previous studies that required substantial relearning time spread across several days (e.g., 80+ repetitions presented over three days) to overcome what was theorized to be proactive interference caused by the memory of the originally learned target location (Zellin, Conci, Muhlenen, and Muller, 2013).

Additionally, following successful relearning, the results of Experiment 1 showed that it was possible for both the initial and secondary target to be positively cued when presented during the same block of trials. The sudden return of the first target location and presentation of both targets led to a temporary loss of positive cueing. However, by the end of the Return Phase, positive spatial cueing had returned with no observable difference in RT when the target was in the first or second location. The return of positive cueing for both location is consistent with previous studies where multiple targets were associated with the same context, and supports the finding that multiple locations can be successfully associated with the same context (Chung and Jiang, 1998; Brady and Chun, 2007; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2011; Conci and Muller, 2012).

Finally, the results of Experiment 1 showed that positive spatial cueing returned for targets relocated at any distance, but targets at further relocation distances were harder to learn. This is somewhat inconsistent with previous studies that found a negative correlation between positive spatial cueing and Target Relocation Distance, with cueing exhibited following a relocation event or for multiple target context associations being driven only by targets located in close proximity (Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013).

Although targets located nearby exhibit greater levels of positive spatial cueing earlier than targets separated further apart, the results of Experiment 1 showed that the negative correlation between positive spatial cueing and Target Relocation Distance did not prevent cueing from returning for targets relocated at the furthest distances. Ultimately, our results suggest that it is more difficult, but not impossible, to relearn the location of an item relocated far from its original location.

Despite the successful observation of relearning and the association of two targets with the same context in Experiment 1, several issues remain. First, it is unclear what effect multiple relocation events will have on relearning or the positive spatial cueing for the initially learned target location. Second, it was not possible to determine if the loss of cueing in the first Epoch of the Return Phase caused by an interference effect.

As such, a second experiment was designed to explore these issues further, testing the impact to positive spatial cueing under no, single, and multiple relocation conditions, and eliminating the potential interference associated with showing the initial and secondary locations during the same block of trials. Exploring the differences in positive spatial cueing for single and multiple relocation event contexts with non-relocated contexts will help in identifying when and to what extent positive spatial cueing is recovered after a relocation. Additionally, by only showing a single location during the same block of trials, it will be possible to determine if the loss of cueing is due to the relearning effect or due to the interference of presenting two targets in the same block of trials.

Experiment 2

Method

Participants

A total of 35 individuals participated in Experiment 2 (28 females; 7 males). The overall error rate for each participant was calculated with three participants identified as outliers (error rates greater than 10%). These three participants were excluded from the remainder of the analysis, resulting in a total of 32 participants (26 females, 6 males). The mean age was 21 ± 3.71 years with a range of 18 to 34 years. All participants reported normal or corrected-to-normal vision. Participants were offered and received course credit for their participation in the study regardless of successful completion of the experiment.

Apparatus and Stimuli

See description from Experiment One Apparatus and Stimuli.

Design and Procedure

Experiment 2 used a repeated measures within-subject design consisting of twelve Epochs and four Contexts. The experiment was designed to determine how the number of target relocation events affects spatial target relearning. Each Epoch consisted of four blocks of 18 trials comprised of nine repeated contexts (Old) and nine randomly generated contexts (New) per block (total of 864 trials). The presentation order of all Old and New contexts was randomized per block of trials. Old contexts were equally divided among three relocation types: No Relocation, Single Relocation, and Three Relocations.

No Relocation contexts served as a cueing control and only experienced a Learning Phase (Epoch 1-12), with the target remaining in the same location for the entirety of the experiment. Targets for Single Relocation contexts were relocated once at the end of a Learning Phase (Epoch 1-3) and remained in the secondary location for the entirety of their Relocation Phase (Epoch 4-12). Targets for the Three Relocation contexts were relocated from location one to location two after a Learning Phase (Epoch 1-3), and subsequently relocated from location two back to location one following a Relocation Phase (Epoch 4-6). Finally, upon completing the first Return Phase (Epoch 7-9), the targets are again relocated to the second location for the remainder of the second Return Phase (Epoch 10-12) (Figure 4).

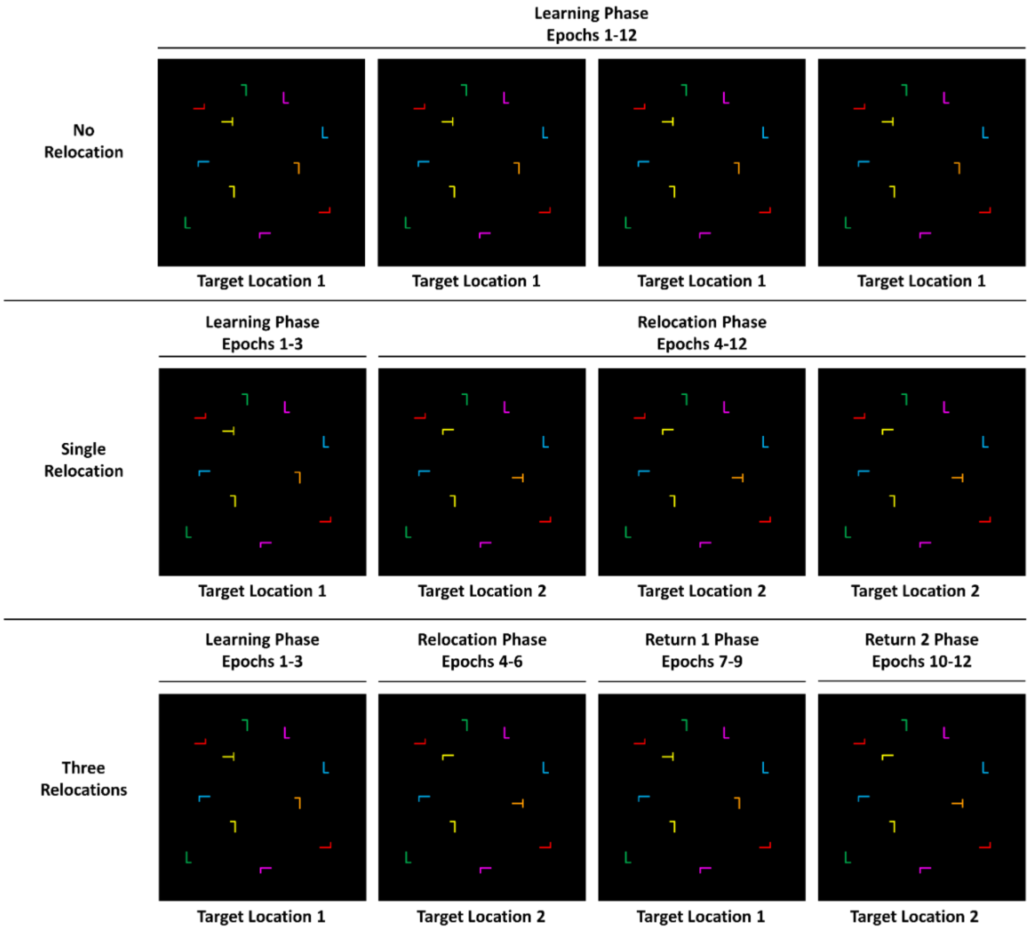


Figure 4. Experiment 1 - Target Location by Phase, Epoch, and Target Relocation Count.

Results

Accuracy

The mean accuracy for each participant was calculated by Epoch and Context to ensure that accuracy remained consistent over the entirety of the experiment, and that any changes in RT were not the result of speed-accuracy tradeoffs. A repeated-measures analysis of variance (ANOVA) of Epoch (1-12) by Context (No Relocation, Single Relocation, Three Relocations, New) showed no significant main effects for Epoch, *F*

(4.34, 134.47) = .84, *p* = .512, η2 = .026, Context, *F* (3, 93) = .57, *p* = .636, η2 = .018 or interaction effects, *F* (33, 1023) = .90, *p* = .639, η2 = .028 with an overall mean accuracy and standard deviation of 95.6 ± 0.004%.

Response Time (RT)

Next, RT was analyzed for each Context to determine how cueing is affected by the number of relocations, whether relearning is successful following a relocation event, as in Experiment 1, and to what extent cueing is recovered for relocated contexts compared with contexts experiencing no relocations. Before the analysis, the data set was cleaned, removing all error trials and trial RTs greater than 9000 ms. A second pass of the data further removed trial RTs exceeding ± 3.0 standard deviations of the mean for each participant by Epoch (1-12) and Context (No Relocation, Single Relocation, Three Relocations, New). The above outlier criteria resulted in the removal of 7.03% of all trials. Effects that did not meet the assumption of sphericity were adjusted using a Greenhouse-Geisser adjustment.

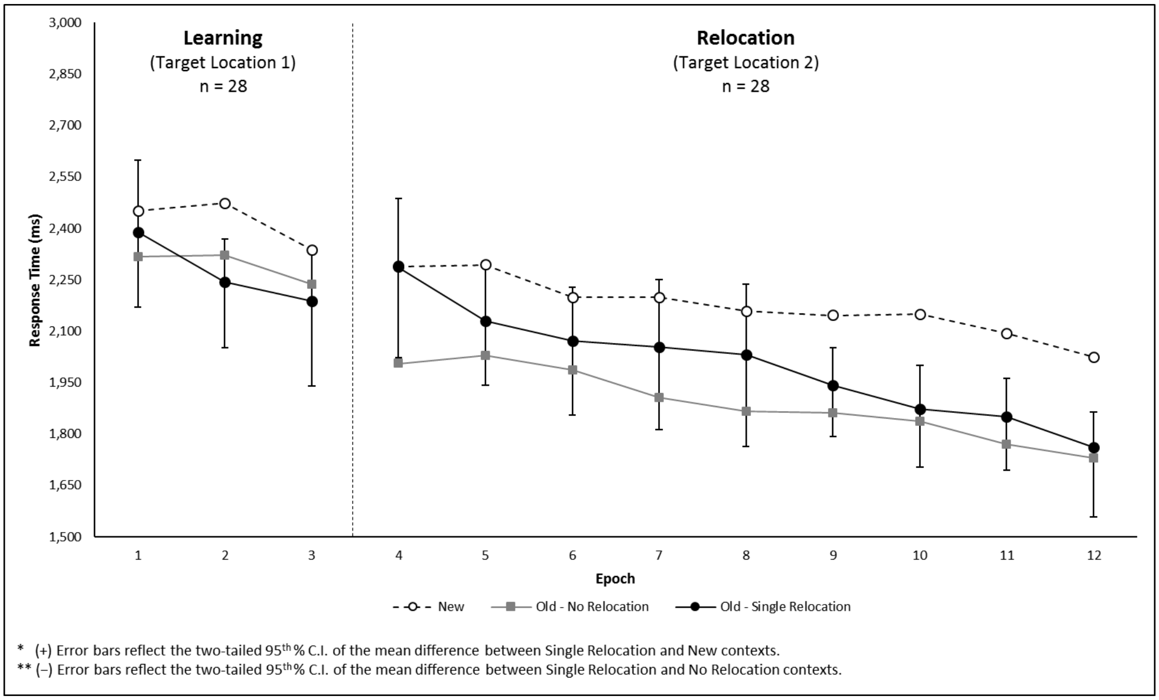
For the single, three, and no relocation conditions, it was expected that positive spatial cueing would emerge during the Learning Phase (Epochs 1-3) with Old contexts (No Relocation, Single Relocation, Three Relocations) becoming significantly faster than New contexts. However, for Contexts experiencing a target relocation event, it was predicted that positive spatial cueing would be temporarily lost following each relocation event.

More specifically, for Single Relocation Contexts, it was predicted that cueing would fully recover from the loss associated with the relocation event, achieving cueing levels equivalent to those of No Relocation Contexts. Alternatively, for Three Relocation Contexts, it was anticipated that relearning of the secondary target location would be successful during the Relocation Phase (Epoch 4-6) and that positive spatial cueing would be recovered for each returned target location during the Return 1 (Epochs 7-9), and Return 2 (Epochs 10-12) Phases. However, positive spatial cueing will not reach equivalency with that of No Relocation Contexts during the Relocation, Return 1, or Return 2 Phases due to the limited number of repetitions resulting from the increased number of relocation events.

Single Relocation

Since the focus of the experiment was again on relearning effects, it was necessary to determine if participants had successfully learned the initial target location context associations. The mean cueing effect was calculated for Single Relocation Contexts during the Learning Phase for each Epoch (1-3) by participant ($RT_{New} – RT_{Old}$). A total of 28 individuals showed positive spatial cueing for at least one Epoch during the Learning Phase, excluding four participants from the remainder of the analysis for Single Relocation Contexts.

Next, the RTs for Single Relocation and New Contexts were analyzed to determine whether learning had occurred for the initial target location context association and that positive spatial cueing was present. A two-way repeated measures ANOVA of the Learning Phase by Epoch (1-3) and Context (Single Relocation, New) revealed no main effect of Epoch, F (2, 54) = 2.61, p = .083, η2 = .088, and no significant interaction effect for Epoch by Context, F (2, 54) = 1.39, p = .258, η2 = .049. However, a significant main effect of Context, *F* (1, 27) = 6.83, *p* = .014, η2 = .202 was found with Single Relocation Contexts being faster (*M* = 147 ms, *SE* = 56 ms) than New contexts, suggesting learning was successful for Single Relocation Contexts (Figure 5).



* (+) Error bars reflect the two-tailed 95th% C.I. of the mean difference between Single Relocation and New contexts.
** (–) Error bars reflect the two-tailed 95th% C.I. of the mean difference between Single Relocation and No Relocation contexts.

Figure 5. Experiment 2 - Response Time (RT) by Phase, Epoch, and Context.

Next, it must be determined if relearning occurred following the target relocation event. A two-way repeated measures ANOVA of the Relocation Phase by Epoch (4-12) and Context (Single Relocation, New) revealed significant main effects for Epoch, *F* (5.13, 138.37) = 9.70, *p* < .001, η2 = .264, and Context, *F* (1, 27) = 15.24, *p* = .001, η2 = .361. A significant interaction effect for Epoch by Context was not observed, *F* (4.61, 124.36) = 1.63, $p = .163$, η2 = .057. A comparison of the first and last Epochs showed that RT decreased during the Relocation phase, (*M* = 394 ms, *SE* = 59 ms), *t (*27) = 5.42, $p < .001$, indicating a general improvement in search RT. More importantly, the comparison of each context showed that Single Relocation contexts were significantly faster than New contexts, (*M* = 177 ms, *SE* = 44 ms), *t (*27) = 3.90, $p = .001$, suggesting that relearning of the secondary target location was successful.

In order to compare Single Relocation and No Relocation Contexts to determine that positive spatial cueing was fully recovered following a relocation event, it was necessary to determine that No Relocation Contexts had achieved positive spatial cueing. A two-way repeated measures ANOVA of Epoch (1-12) and Context (No Relocation, New) revealed significant main effects of Epoch, *F* (5.83, 157.41) = 18.31, $p < .001$, η2 = .404 and Context, *F* (1, 27) = 15.02, $p = .001$, η2 = .357. The interaction of Epoch and Context was not significant, *F* (11, 297) = 1.64, *p* =.088, η2 = .057. Overall, RT decreased significantly between Epoch one and twelve (*M* = 507 ms, *SE* = 64 ms), *t (*27) = 4.567, $p < .001$, reflecting a general improvement in search RTs. Additionally, No Relocation Contexts were significantly faster than New contexts (*M* = 245 ms, *SE*= 63 ms), suggesting that target context association learning was successful.

Finally, Single Relocation and No Relocation Contexts were compared to determine if cueing had fully recovered following the relocation event. A two-way repeated measures ANOVA of Epoch (4-12) and Context (No Relocation, Single Relocation) revealed a significant effect of Epoch, *F* (5.23, 141.45) = 10.38, $p < .001$, η2 = .277, with RT decreasing from Epoch four to Epoch 12, (*M* = 400 ms, *SE* = 61 ms), *t*

(27) = 5.42, $p < .001$, again showing a general improvement in search RTs. No main effect of Context, F (1, 27) = 1.92, $p = .177$, $\eta2 = .066$ or interaction effect for Epoch by Context was observed, F (4.49, 121.14) = 1.33, $p = .231$, $\eta2 = .047$, suggesting that Single Relocation Contexts successfully recovered cueing benefits equivalent to that of No Relocation Contexts.

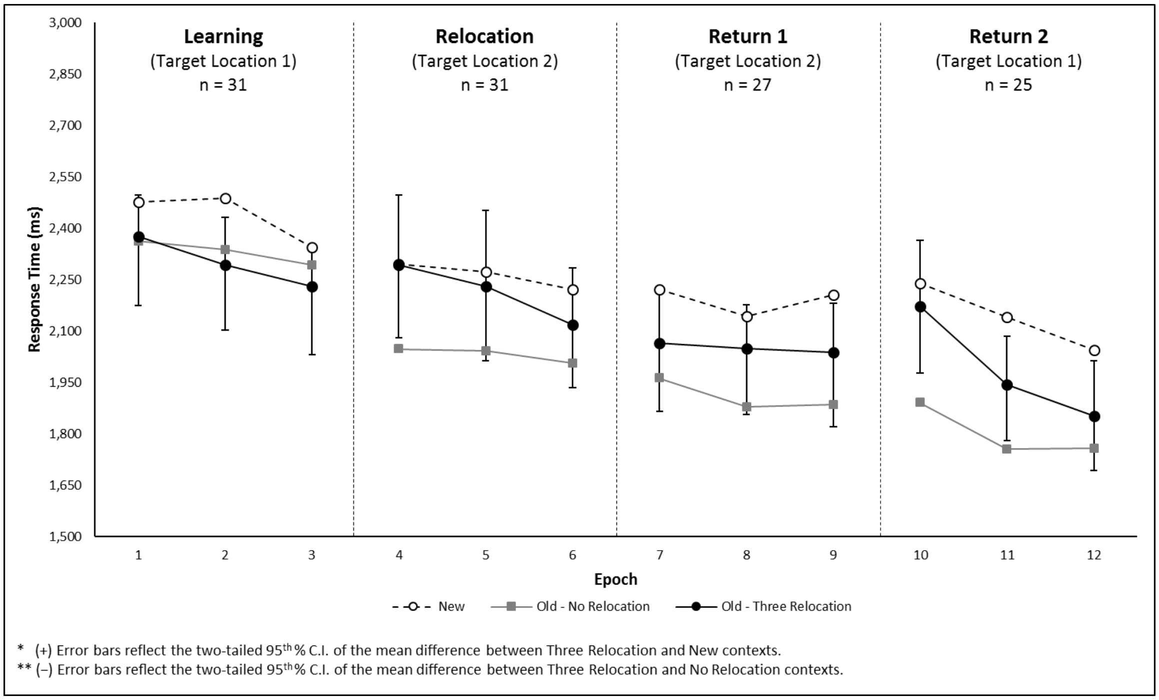
Finally, comparisons of Single, No Relocation, and New Contexts were conducted by Epoch to determine at what point positive cueing had fully recovered following the relocation event. Starting with the final Epoch and working backwards, paired-samples t-tests revealed that by Epoch nine, Single Relocation Contexts had become significantly faster than New contexts (M = 205 ms, SE = 54 ms), t (27) = 3.69, $p = .001$, and as fast as the No Relocation contexts, (M = 79 ms, SE = 73 ms), t (27) = 1.09, $p = .285$ (Figure 5 - Relocation). This result suggests that not only is relearning possible but that a secondary location can be cued equivalent well as an initially learned location, with positive spatial cueing recovering fully after a target relocation event.

Three Relocations

As with the Single Relocation Contexts, it was necessary to determine which participants showed learning for the initial target location during the Learning Phase (Epochs 1-3). The mean cueing effect was calculated by participant ($RT_{New} - RT_{Old)}$ for the Learning Phase, resulting in the removal of a single participant.

The next step was to confirm that learning was successful with positive spatial cueing emerging for the initial target location. A two-way repeated measures ANOVA of the Learning phase by Epoch (1-3) and Context (Three Relocation, New) revealed significant main effects of Epoch, *F* (2, 60) = 3.31, *p* = .043, η2 = .099, and Context, *F* (1, 30) = 11.86, *p* = .002, η2 = .283. The interaction effect for Epoch by Context, *F* (2, 60) = .859, p = .429, η2 = .028 was not significant. Overall RT was shown to decrease significantly from Epochs one to three, (*M* = 139 ms, *SE* = 64 ms), *t (*30) = 2.15, *p* = .043, while Three Relocation Contexts were found to be significantly faster than New contexts, (*M* = 136 ms, *SE* = 40 ms), *t (*30) = 3.44, *p* = .002, (Figure 6). The main effect of Context and emergence of positive spatial cueing suggests that learning of the target context association was successful.

Since initial learning was confirmed, it was then possible to determine if relearning of a previously learned context and a secondary location occurred following the target relocation event. A two-way repeated measures ANOVA of the Relocation phase by Epoch (4-6) and Context (Three Relocation, New) revealed a significant main effect of Epoch, *F* (2, 60) = 3.20, *p* = .048, η2 = .096, with overall RT decreasing between Epochs four and six, (*M* = 124 ms, *SE* = 54 ms), *t (*30) = 2.31 *p* = .028. The decrease in overall RT is reflective of general search improvement. The main effect of Context, *F* (1, 30) = .465, *p* = .501, η2 = .015 and interaction of Epoch by Context, *F* (2, 60) = .397, *p* = .674, η2 = .013 were not significant, suggesting that relearning was unsuccessful (Figure 6).



* (+) Error bars reflect the two-tailed 95th % C.I. of the mean difference between Three Relocation and New contexts.
** (–) Error bars reflect the two-tailed 95th % C.I. of the mean difference between Three Relocation and No Relocation contexts.

Figure 6. Experiment 2 - Response Time (RT) by Phase, Epoch, and Context.

However, if no relearning had taken place, then RTs for Three Relocation and No Relocation Contexts should be significantly different for each Epoch of the Relocation Phase (Epoch 4-6). Two-tailed paired-samples t-tests showed that immediately following the relocation event, Three Relocation Contexts became slower than the No Relocation Contexts, (*M* = 245 ms, *SE* = 104 ms), *t (*30) = 2.36 *p* = .025. Still, by Epoch five, the difference had decreased and was no longer significant, (*M* = 189 ms, *SE* = 107 ms), *t (*30) = 1.78, p = .086, and continued to decline through Epoch six, (*M* = 112 ms, *SE* = 90 ms), *t (*30) = 1.24, p = .224 (Figure 6). The decreasing trend in RT between Three Relocation and No Relocation Contexts suggests that relearning was taking place, but at a rate that was not sufficient to achieve significant positive spatial cueing by the end of the Phase.

The next step in the analysis was to determine the impact of relearning on positive spatial cueing when the target is returned to its original location. First, the mean cueing effect was calculated by participant (RT_{New} - $RT_{Old)}$ for the Relocation Phase. A total of 27 of the remaining 31 participants showed positive spatial cueing during at least one Epoch of both the Learning and Relocation Phases.

Next, a two-way repeated measures ANOVA of the first Return Phase by Epoch (7-9) and Context (Three Relocation, New) revealed a significant main effect of Context, *F* (1, 26) = 11.05, *p* = .003, η2 = .298, with Three Relocation Contexts being significantly faster than New contexts, (*M* = 140 ms, *SE* = 42 ms). This suggests that cueing was already present throughout the Return Phase. The main effect of Epoch, *F* (2, 52) = .260, *p* = .772, η2 = .010 and interaction effect of Epoch by Context, *F* (2, 52) = .319, *p* = .729, η2 = .012 were not significant (Figure 6). This suggests that neither the overall or individual RTs changed substantially over each Epoch.

A follow-on comparison of Three Relocation and No Relocation Contexts was conducted to determine if the level of cueing present in the first Return Phase was consistent with No Relocation Contexts. A two-way repeated measures ANOVA of Epoch (7-9) and Context (No Relocation, Three Relocations) revealed no significant main effects of Epoch, *F* (2, 52) = .392, *p* = .677, η2 = .015, Context, *F* (1, 26) = 2.98, *p* = .096, η2 = .103, or interaction effect of Epoch by Context, *F* (2, 52) = .260, *p* = .772, η2 = .010, suggesting the amount of cueing still present was not radically different from that of No Relocation Contexts (Figure 6).

Still, some level of relearning was observed in the Relocation Phase (Epoch 4-6), which should lead to a cueing cost when the target is returned during the first Epoch of the Return Phase (Epoch 7). If no relearning occurred, a significant positive cueing effect should be present at the onset of Return 1 (Epoch 7), with equivalent RTs for Three Relocation and No Relocation Contexts.

To test this hypothesis, Three Relocation and No Relocation Contexts were compared by Epoch. A two-tailed paired-samples t-tests showed that the positive spatial cueing effect was not significant for Epoch seven, with no significant difference in RT for Three Relocation Contexts and New contexts, (*M* = 157 ms, *SE* = 79 ms), *t (*26) = 2.00, *p* = .056. However, by Epoch nine, positive spatial cueing increased, with Three Relocation Contexts being significantly faster than New Contexts, (*M* = 167 ms, *SE* = 69 ms), *t (*26) = 2.39, *p* = .024 (Figure 6). These results suggest that some relearning occurred during the Relocation Phase resulting in a cueing cost that was later overcome through subsequent repetition of target location one.

The last step in the RT analysis was to determine if positive spatial cueing would emerge when the target was relocated back to the secondary target location. As with the Relocation Phase, it was expected that cueing would be lost following the relocation event. However, given the evidence of partial relearning from the RT analysis for the Relocation and first Return Phases, it was still predicted that second positive spatial cueing would emerge with subsequent repetition of the secondary target location.

As with previous Phases, the mean cueing effect was calculated by participant (RT_{New} - $RT_{Old)}$ for the first Return Phase. A total of 25 of the remaining 27 participants showed positive spatial cueing during at least one Epoch of Learning, Relocation and Return 1 Phases. Next, Three Relocation and New Contexts were analyzed to determine the presence of a positive spatial cueing effect. A two-way repeated measures ANOVA of the final Return phase by Epoch (10-12) and Context (Three Relocation, New) revealed significant main effects of Epoch, *F* (2, 48) = 10.62, *p* < .001, η2 = .307, and Context, *F* (1, 24) = 8.42, *p* = .008, η2 = .260. The interaction effect of Epoch by Context, *F* (1.52, 36.46) = .968, *p* = .387, η2 = .039 was not significant (Figure 6).

Response time was shown to decrease significantly from Epochs nine to twelve, (*M* = 257 ms, *SE* = 64 ms), *t (*24) = 3.75, *p* = .001, suggesting continued improvement with respect to overall search times. More importantly, Three Relocation Contexts were found to be significantly faster than New contexts, (*M* = 153 ms, *SE* = 53 ms), *t (*24) = 2.90, *p* = .008 suggesting that relearning was successful for target location two. Furthermore, this confirms that during the Relocation Phase, partial relearning had taken place, and that significant positive spatial cueing was achieved after subsequent reinforcement during the second Return Phase.

Given that relearning was finally successful, the next step was to determine if the amount of positive spatial cueing achieved was on par with that of No Relocation Contexts. As expected, following the relocation event back to location two, two-tailed paired-samples t-tests showed a loss of cueing, with Three relocation contexts being significantly slower than the No Relocation, (*M* = 280 ms, *SE* = 94 ms), *t (*24) = 3.01, *p* =

.006 and no faster than New contexts, (*M* = 67 ms, *SE* = 94 ms), *t (*24) = .722, *p* = .477. This result is consistent with previous target relocation effects on positive spatial cueing in this and other studies (Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013).

However, by Epoch twelve, Three Relocation Contexts were significantly faster than New contexts, (*M* = 193 ms, *SE* = 78 ms), *t (*24) = 2.47, *p* = .021, and equivalently fast compared to the No Relocation contexts, (*M* = 94 ms, *SE* = 77 ms), *t (*24) = 1.22, p = .233 (Figure 6). This result suggests that relearning a secondary target location may be more difficult, requiring more repetitions, but that the amount of cueing achieved during relearning is not limited by which target location is learned first.

Target Relocation Distance

Lastly, positive spatial cueing was analyzed relative to Target Relocation Distance to determine whether cueing following a relocation event was driven by the proximity of the initial and secondary targets. The target relocation distance of each repeated target context pairing was calculated for each participant (Range: 6.63° - 37.63 °, *M* = 17°, *SE* = .12°). Next, positive spatial cueing (RT_{New} – RT_{Old}) during the Relocation and Return phases were calculated for each Epoch by participant and Target Relocation Distance and aggregated by Epoch and Target Relocation Distance. As with Experiment 1, it was expected that Target Relocation Distance and positive spatial cueing would be negatively correlated.

Single Relocation

A two-tailed Pearson's correlation analysis of Target Relocation Distance and mean positive spatial cueing revealed a negative correlation for the first Epoch of the Relocation Phase, however it was not significant, $r = -.296$, $p = .151$. The lack of significance suggests that positive spatial cueing did not change relative to the proximity of target locations one and two.

Despite the lack of a significant correlation, the next step was to determine when and at what relocation distances positive spatial cueing was achieved. As with Experiment 1, a simple linear regression was run to model the amount of positive spatial cueing obtained for each Epoch and Target Relocation Distance during the Relocation Phase (Epochs 4-12). The resulting regression model was found to be significant, $F\ (2, 101) = 9.49$, $p < .001$, with an $R^2 = .158$, with Epoch contributing positively and Target Relocation Distance contributing negatively (Eq. 3).

Equation 3. Relocation Phase - Positive Spatial Cueing as a function of Epoch and Relocation Distance.

$$\mathbf{PSC\ (ms) = 417 + 29 \times Epoch\ (0 \ldots 8) - 24 \times Target\ Relocation\ Distance(^\circ\ Visual\ Angle)}$$

Next, the regression model was used to predict the amount of positive spatial cueing by Epoch for distances between the minimum and maximum relocation distances used in the study. The estimates show that at the onset of the Relocation Phase (Epoch 4), that only targets relocated between 5° and 15° still showed a cueing benefit, while those relocated further than 15° experienced a cueing cost. However, by the final Epoch, positive spatial cueing was achieved for targets relocated distances of up to 25° of visual angle (Table 3).

Table 3. Experiment 2 - Relocation Phase Positive Spatial Cueing Estimates by Epoch and Target Relocation Distance for Single Relocation Contexts (Spatial Cueing less than or equal to zero highlighted in grey).

	Distance								
Epoch	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	***M***
4	396	265	133	0	-131	-262	-394	-526	-65
5	420	288	157	25	-107	-239	-370	-502	-41
6	444	312	181	49	-83	-215	-346	-478	-17
7	468	336	204	73	-59	-191	-323	-454	7
8	492	360	228	96	-35	-167	-299	-430	31
9	516	384	252	120	-11	-143	-275	-407	54
10	539	408	276	144	12	-119	-251	-383	78
11	563	431	300	168	36	-95	-227	-359	102
12	587	455	324	192	60	-72	-203	-335	126

Intuitively, the results show that targets relocated near the originally learned location benefit the most and earlier than targets relocated further away. However, just as with Experiment 1 the model shows that targets relocated at further distances can be relearned, but require a greater number of repetitions before positive spatial cueing is achieved.

Three Relocations

Similarly, a two-tailed Pearson's correlation analysis of Target Relocation Distance and mean positive spatial cueing for the first and last Epochs was conducted for each Phase (Relocation, Return 1, Return 2). Again, the correlations were negative but not significant for the first Epoch of the Relocation, r = -.341, p = .095 and Return 2

Phases, $r = -.207$, $p = .331$. The correlation for the first Epoch of the Return 1 Phase was positive but not significant, $r = .122$, $p = .570$. These results suggest that positive spatial cueing did not change with the proximity of target locations one and two.

As before, a simple linear regression was conducted for the Relocation and Return 2 Phases to determine at what distances positive spatial cueing was achieved for the secondary target location. The resulting regression equations were found to be significant for the Relocation phase, $F(2, 72) = 8.79$, $p < .001$, with an $R^2 = .196$ (Eq. 4) and Return 2 Phase $F(2, 69) = 8.88$, $p < .001$, with an $R^2 = .205$ (Eq. 5).

Equation 4. Relocation Phase - Positive Spatial Cueing as a function of Epoch and Relocation Distance.

$$\mathbf{PSC\ (ms) = 531 + 19 \times Epoch\ (1 \ldots 3) - 28 \times Target\ Relocation\ Distance}(^\circ\ \mathbf{Visual\ Angle})$$

Equation 5. Return 2 Phase - Positive Spatial Cueing as a function of Epoch and Relocation Distance.

$$\mathbf{PSC\ (ms) = 562 + 21 \times Epoch\ (1 \ldots 3) - 24 \times Target\ Relocation\ Distance}(^\circ\ \mathbf{Visual\ Angle})$$

The models were used to determine in what Epoch each Target Relocation Distance achieved positive spatial cueing. During the Relocation phase, targets relocated less than 20° of visual angle immediately exhibited positive cueing following the relocation event (Table 4). By the final Epoch of the Relocation Phase, this had improved to targets relocated less than 25° of visual angle.

Table 4. Experiment 2 - Relocation Phase Positive Spatial Cueing Estimates by Epoch and Target Relocation Distance for Three Relocation Contexts (Spatial Cueing less than or equal to zero highlighted in gray).

	Distance								
Epoch	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	***M***
4	389	249	110	-29	-169	-308	-447	-587	-99
5	408	268	129	-10	-150	-289	-428	-568	-80
6	427	288	148	9	-131	-270	-409	-549	-61

Interestingly, when the targets were returned to the second location in the final Return Phase, positive cueing was still found for targets located less than 25° of visual angle, suggesting that relearning had occurred in the Relocation Phase. Subsequently, by the final Epoch of the second Return Phase, positive cueing was achieved for targets located less than 30° of visual angle from the original target location (Table 5). This supports the previous finding for Single Relocation Contexts that targets relocated further from the originally learned target location are harder to learn, with targets located in closer proximity benefiting the most and earliest.

Table 5. Experiment 2 - Return 2 Phase Positive Spatial Cueing Estimates by Epoch and Target Relocation Distance for Three Relocation Contexts (Spatial Cueing less than or equal to zero highlighted in gray).

	Distance								
Epoch	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	***M***
10	444	326	207	89	-29	-148	-266	-384	30
11	465	347	229	110	-8	-126	-244	-363	51
12	487	369	250	132	14	-105	-223	-341	73

Discussion

The purpose of Experiment 2 was to determine the level of positive spatial cueing after No, Single, and Three target relocations. For No Relocation Contexts, it was expected that positive spatial cueing would develop gradually over the course of the experiment, similar to the results observed in the earlier context cueing studies, with Old contexts becoming significantly faster than New contexts (Chun and Jiang, 1998). The analysis of RT for the No Relocation contexts confirmed this prediction with Old contexts becoming significant faster than New contexts by the fourth Epoch (16 repetitions).

Alternatively, for Single Relocation Contexts, it was predicted that positive spatial cueing would emerge during the Learning Phase and be subsequently lost following a target relocation event. However, based on the findings of Experiment 1, it was expected that positive spatial cueing would return before the end of the experiment. Again, the analysis of RT confirmed this prediction, with both the initial and secondary target locations showing positive spatial cueing during the Learning and Relocation phases. Furthermore, by Epoch nine (24 repetitions), Single Relocation Contexts became significantly faster than New Contexts and equivalently fast as No Relocation Contexts. This finding deviates dramatically from those of previous studies where relearning failed, and positive spatial cueing did not return (Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013).

Lastly, for the Three Relocation Contexts, it was predicted that if relearning occurred following a relocation event, then a return to the initially learned target location would have a loss of positive spatial cueing. Subsequently, if relearning did not occur during the Relocation Phase it was expected that positive spatial cueing would be present upon return to the initially learned target location.

Although the results for the Learning Phase did show successful learning for the initial target location, relearning was not completely successful for the secondary location during the Relocation Phase, with only a modest return of positive spatial cueing following the target relocation event. One hypothesis explaining this result is that the Relocation Phase lacked a sufficient number of repetitions for relearning to be successful.

Examining the number of repetitions for Single Relocation Contexts shows that relearning and full recovery of positive spatial cueing occurred after six Epochs (24 repetitions), whereas the Relocation Phase of the Three Relocation Contexts consisted of only three Epochs (12 repetitions). Interestingly, during the second Return Phase, relearning was successful for the secondary target location, with positive spatial cueing recovering fully by the final Epoch (24 cumulative repetitions). This suggests that relearning is a cumulative process and that limitations on the number of repetitions per Phase were indeed the likely cause of the weak relearning effect during the Relocation Phase.

Given the lack of a significant relearning effect during the Relocation Phase, it was predicted that positive spatial cueing would still be present when the target was relocated back to location one at the onset of the first Return Phase. Subsequently, upon returning to target location one, no significant difference was observed between the Three Relocation Contexts and either the New or No Relocation contexts. This suggests that our prediction did not accurately reflect the observed effect, with positive spatial cueing only partially returning. Consequently, the evidence of partial relearning during the Relocation Phase, and the partial loss of cueing at the onset of the first Return Phase suggests that the cueing cost of a target relocation event is proportional to the amount of positive cueing achieved before the relocation.

Finally, the amount of positive spatial cueing was evaluated relative to the Target Relocation Distance, to determine when and at what distances positive spatial cueing occurred after a relocation event, and if the amount of cueing was driven the proximity of the targets. As with previous studies (Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013) and Experiment 1, it was predicted that target relocation distance and the amount of positive spatial cueing would be negatively correlated, with cueing increasing as relocation distance decreased.

A negative correlation between positive spatial cueing and Target Relocation Distance was observed when the target was located in the secondary location, but not when the target was located in the initial location. However, these correlations were not significant, suggesting that proximity and positive spatial cueing were not related.

Subsequently, further analysis modeling positive spatial cueing by Epoch and Target Relocation Distance showed that targets relocated closest to the originally learned location achieved greatest positive spatial cueing the earliest. This suggests that proximity of the initial and secondary targets does matter and that secondary targets relocated at further distances take more time to learn. This is somewhat inconsistent with previous studies where relearning was not successful, with only targets located in close proximity showing a cueing benefit (Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013).

Conclusion

The results of Experiment 1 and 2 provide empirical evidence supporting spatial target relearning for a previously learned context and secondary target location following a target relocation event. The presence of relearning contradicts previous study findings in which positive spatial cueing failed to emerge following a relocation event (Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013). Moreover, the results of this study show that successful relearning occurred following single (Experiment 2 - Single Relocation Contexts), two (Experiment 1 - Old Contexts), and three target relocations (Experiment 2 - Three Relocation Contexts).

Although both experiments found target relocation distance and the amount of positive spatial cueing were negatively correlated when the target was in the secondary location, it was determined that with sufficient repetitions, targets relocated up to 35° of visual angle could be relearned and positively cued. This suggests that targets relocated in close proximity to the originally learned location benefit the most and earliest, and those relocated at greater distances benefiting the least, requiring greater exposure before relearning is achieved.

The results of this study provide evidence supporting our initial hypotheses that contextual identity features (e.g., color) and the overall spatial configuration support spatial target relearning after a target relocation event. However, additional studies are needed to determine which feature, identity or overall spatial configuration, led to differences in the results of this study, and those where relearning was unsuccessful (Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013).

Future studies, exploring the effects of search array presentation color (Black and White, Color) and the type of relocation (Occupied, Unoccupied) should be conducted in order to replicate the findings of this study and previous studies, and to determine if one or both determine the presence or absence of relearning following a relocation event.

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ARE THERE MODERATING FACTORS IN SPATIAL TARGET CONTEXT RELEARNING?

Abstract

Context formed by reoccurring and invariant structures and information in the environment are stored in memory and later retrieved and used to cue and optimize the allocation of attention. In a paradigm known as Contextual Cueing, research has shown that such context cues can lead to directly observable performance benefits, with repeated visual search contexts resulting in reduced search times (Chung and Jiang, 1998). However, it has also been shown that unexpected changes to the location of a target for previously learned spatial contexts results in a loss of the performance benefits that may not be recoverable (Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010).

In several follow-on studies, researchers have attempted to better understand the development and recovery of contextual cueing benefits before and after an unexpected target location change. However, in most cases individuals failed to associate a secondary target location with a previously learned spatial context, and were unable to recover a positive cueing benefit (Zellin, Conci, Muhlenen, and Muller, 2011; Conci, Sun, and Muller, 2011; Conci and Muller, 2012; Zellin, Conci, Muhlenen, and Muller, 2013).

Alternatively, in our studies, spatial context target relearning was observed after single and multiple target relocation events. Comparing our experimental design with those of previous studies, it was hypothesized that the diverging findings stemmed from two experimental factors: search array presentation color, and target relocation type. The previous studies in which relearning failed used search arrays of monochromatic stimuli on a uniform background with targets relocated to a previously unoccupied location (i.e. a blank location). Alternatively, in our studies where relearning occurred, search arrays were presented using stimuli of multiple colors on a uniform background with targets relocated to a previously occupied location (i.e. swapping with a distractor).

The current study was designed to determine if search presentation color or target relocation type were the underlying factors leading to these divergent results. Subsequently, the results of this study failed to find significant effects for either factor, with relearning occurring for all experimental factor combinations. This continues to contradict previous findings and suggests that relearning of the spatial target context associations is possible after a target relocation event.

Keywords: Visual Search, Spatial Context Cueing, Multiple Targets, Learning

Introduction

Whether browsing a retail website for a great deal, searching the living room for the TV remote, or looking for a spot in the parking lot at work, visual search is a critical part of everyday life. Nevertheless, the cognitive demands of most visual search tasks are rarely noticed, in part thanks to memory’s ability to leverage patterns and consistencies in the environment to cue and direct our attention to search targets.

As a search is performed, contextual features found in the environment, related to and predictive of the target, are stored in memory and later used to guide our attention and improve search times the next time the search is performed. This process, known as contextual cueing, was first demonstrated with basic visual search tasks, where repeated search displays, comprised of a fixed set of features, reduced search times compared to displays with randomized features (Chun and Jiang, 1998).

Given the important role memory plays in visual search, several studies have been conducted focusing on how and which features are learned, and under what conditions contextual cueing results in improved performance (Chun and Jiang, 1998; Chun and Jiang, 1999; Peterson and Kramer, 2001; Olson and Chun, 2002; Chun and Jiang, 2003; Endo and Takeda, 2004; Jiang and Wagner, 2004; Lleras and Muhlenen, 2004; Jiang and Leung, 2005; Jiang and Song, 2005; Jiang, Song, and Rigas, 2005; Brady and Chun, 2007; Hout and Goldinger, 2012; Giesbrecht, Sy, and Guerin, 2013). The findings from these studies suggest that consistent and repeated patterns of contextual features (e.g., location, identity, motion) that are predictive of shared features of the target help to more efficiently guide attention, resulting in faster search response times. A common example of this found in the literature is when the locations of the set of distractors are repeated over multiple trials, becoming predictive of the target's location, and resulting in reduced search times (Chun and Jiang, 1998).

However, the real world is rarely so stable, with many aspects and features of the environment changing on a regular basis. As such, contextual cueing benefits would be limited without the ability for memory to store multiple contextual cues, associate more than one target to the same cue, or update a previously learned context following a change to relevant feature or target.

For example, we expect the layout of our homes to remain relatively consistent over time and to cue multiple items (e.g., the toaster, coffee maker, and blender in the kitchen). Subsequently, it is reasonable to expect that a context would be gradually relearned if an item was relocated, such as moving the toaster to a new location within the kitchen. Although such a change may lead to a temporary loss in search performance, it is expected that the new location and its relationship in the context of the kitchen would be relearned rather quickly after only a few uses of the toaster.

Yet, evidence of memory's capacity to store large numbers of contexts, associate multiple targets to the same context, and to update and relearn contexts following a target change are mixed. Though it appears that memory capacity for contextual cues is high (Jiang, Song, and Rigas, 2005), studies of multiple targets for a single context conflict, with some showing learning of multiple targets (Chung and Jiang, 1998; Brady and Chun, 2007; Conci and Muller, 2012) and others showing learning for only a single dominant target (Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2011).

Additionally, our own studies of spatial target context relearning after a target relocation event, where relearning was observed, directly conflict with previous studies where relearning failed (Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013). Given that relearning the association of a previously learned context and a relocated target in real world search environments is rather common and intuitive, it is of interest to determine the possible factors contributing to such diverging results for basic visual search tasks.

Comparing the experimental designs of our own and previous studies, two factors, search array presentation color, and target relocation type, were identified as possible causes for the diverging results. In studies where relearning failed to occur, search array stimuli were monochromatic (e.g., white or gray) and presented on a black or gray background, maintaining only the target and distractor locations for repeated contexts (Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013).

Alternatively, our studies presented search stimuli in color, maintaining both the color and location features of targets and distractors for repeated contexts. Previous studies of non-spatial context features have shown that identity features, such as stimuli shape and color, additively contribute to contextual cueing (Endo and Takeda, 2004; Jiang and Song, 2005). One hypothesis it that the color feature in our study may have served as a complementary or supplemental cue supporting storage and differentiation the initial and secondary target locations during relearning.

Additionally, in a majority of studies where relearning was not achieved, the targets were relocated to a previously unoccupied location resulting in changes to both the local and overall spatial configuration of the target and distractors (Mangenelli and Pollmann, 2009; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013). In our studies where relearning was observed, targets were relocated to a previously occupied location, maintaining the overall spatial configuration by swapping with a distractor. Previous studies examining changes to the local and overall spatial configuration showed that maintaining the overall spatial configuration contributes additively to the contextual cueing benefits of maintaining the local configuration (i.e. nearest neighbors) of a target (Jiang and Wagner, 2004; Brady and Chun, 2007).

As an example, imagine a particular star of a constellation in the night sky is the target. Moving the star to an empty portion of the night sky would destroy the constellation as well as move the start away from its previous neighboring stars. However, if two stars of a constellation are swapped, the constellation is maintained only changing which stars neighbor the target star. A second hypothesis is that relearning is easier if the overall configuration is maintained (i.e. the constellation is preserved), with the initial and secondary targets benefiting from their association to their individual local configurations and the overall configuration.

The current study was designed to address both hypotheses, testing all four possible combinations of search array presentation color, white or color stimuli on a black background, and target relocation type targets relocated to a previously occupied or unoccupied location. This design allows us to replicate our own and previous study designs, and to determine if one or both features affect the presence or absence of relearning.

If the search array presentation color is the critical feature, relearning will occur for search arrays presented in color, but not for search arrays presented in black and white. Alternatively, target relocation type is the only critical feature, we predict that relearning will be present for targets swapped with a distractor, but absent for targets relocated to a previously unoccupied location.

Lastly, if the interaction of search array presentation color and target relocation type are both critical, we predict that the results will replicate our own and previous studies, with relearning present for color search arrays with occupied target relocations, and absent for black and white search arrays with unoccupied target relocations (Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013). Additionally, we predict that the remaining conditions (Color - Unoccupied, Black and White - Occupied) will achieve relearning but to a lesser extent than those presented in color with an occupied switch.

Experiment 3

Method

Participants

A total of 69 individuals participated (43 females; 26 males). The overall error rate for each participant was calculated with three participants identified as outliers (Error Rates greater than 10%). These three participants were excluded from the remainder of the analysis, resulting in a total of 66 participants (42 females, 24 males). Ages ranged from 18 to 35 (*M* = 22, *SE* = 3.73). All participants reported normal or corrected-to-normal vision and successfully passed a color vision test. Participants were offered and received course credit for their participation in the study regardless of successful completion of the experiment.

Apparatus and Stimuli

Experiment search displays were generated and presented for each participant using an application created using Visual Studio 2012 C#/WPF. The application was run on a Dell OptiPlex 580 using a Dell P2714T 27” monitor (59.79 cm x 33.63 cm). Participants were seated at an unrestricted viewing distance of approximately 50 cm.

The resolution of the monitor is 1920 x 1080 pixels. The search area subtended 37.2° by 37.2° of visual angle (1080 x 1080 px) and was centered on the screen. Each search display consisted of one target (a T-shape randomly rotated 90° left or right) and eleven distractors (an L-shape randomly rotated 0°, 90°, 180°, or 270°). The stimuli subtended 1.3° by 1.3° (36 px x 36 px) of visual angle. The search stimuli for the Color condition were presented in one of six colors (Cornflower Blue, Red, Green, Yellow, Violet, and Orange) on a black background (Mangenelli and Pollmann, 2009). Two stimuli of each color were presented in each search display. The stimuli for the Black and White (B&W) condition were presented with white stimuli on a black background (Figure 7) (Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013).

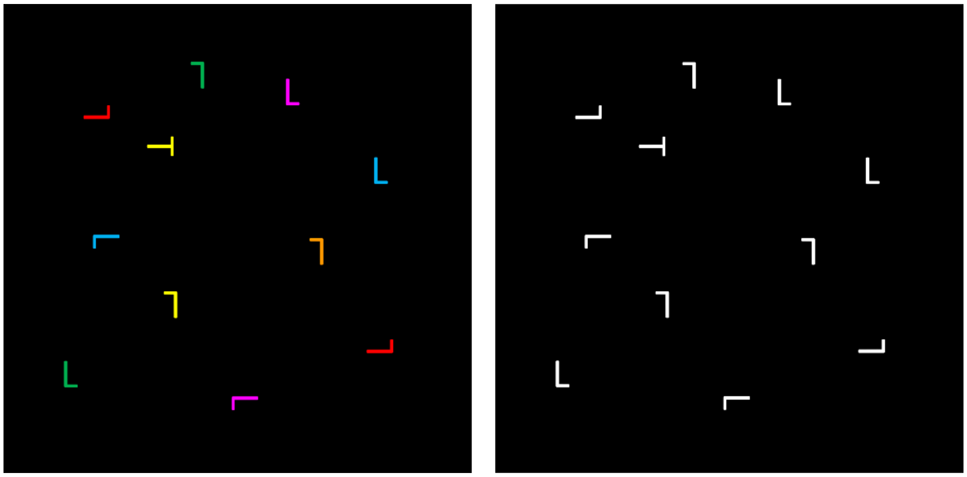


Figure 7. Experiment 3 - Example Search Arrays by Search Array Presentation Color.

Targets were randomly assigned to one of 24 possible locations in a 5 x 5 grid, excluding the central cell. Distractors were randomly assigned to one of 25 possible locations in a 5 x 5 grid. Individual cell size subtended 7.7° by 7.7° of visual angle. Additionally, all stimuli were jittered (± 5.7° of visual angle from the center) randomly within their cell in both x and y directions (Chung and Jiang, 1998). Before each trial, a central fixation cross, 1.3° by 1.3° (36 px x 36 px), was presented.

Design and Procedure

The experiment followed a mixed repeated-measures design broken into two Phases (Learning and Relocation) with two within-subject factors, Epoch (1-4; 5-10) and Context (Occupied, Unoccupied, and New) and one between-subject factor, search array Color (B&W, Color). The experiment was designed to determine if search array presentation Color (B&W) and Target Relocation Type (Occupied, Unoccupied) affect the presence or absence of spatial target relearning following a target relocation event for repeated Old Contexts (Figure 8).

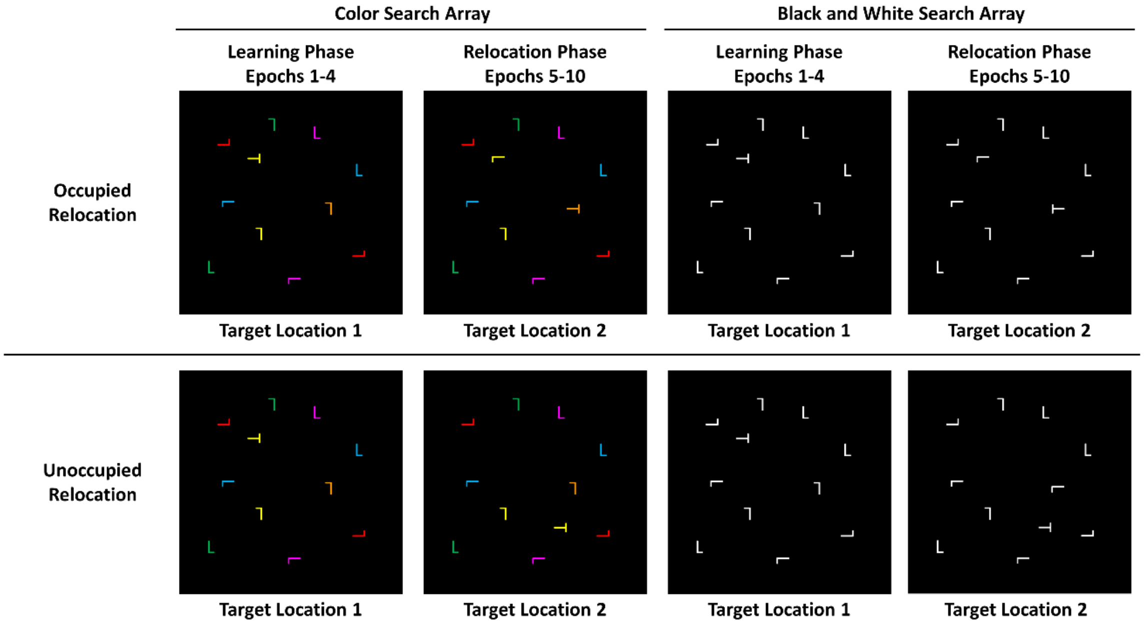


Figure 8. Experiment 3 - Target Location by Presentation Color, Target Relocation Type, Phase, and Epoch.

New Contexts were search arrays randomly generated at the start of each block of trials. Each New Context was randomly assigned a unique target location from one of the 24 possible search array locations per block of trials. Distractor locations, color, and orientations were fully randomized for each New Context per trial.

Old Contexts were randomly generated at the start of the experiment and were repeated for each block of trials. Distractor stimuli for each Old Context were randomly assigned and maintained their location, orientation, and color for the duration of the experiment. Old Contexts were evenly divided and assigned one of two Target Relocation Types (Occupied, Unoccupied), and randomly assigned an initial and secondary target location.

A total of 24 unique target locations, 12 initial and 12 secondary, were generated and allocated to the set of Old Contexts per participant, selecting targets randomly without replacement from one of 24 possible search array locations. The target was presented at the first location during the Learning Phase (Epochs 1-4), and at the second location during the Relocation Phase (Epochs 5-10), following the target relocation event. Occupied Context targets were relocated to a location previously occupied by a distractor. Unoccupied Context targets were relocated to a previously empty location (Figure 8).

Before the start of the experiment, participants were provided a brief practice session consisting of 24 total trials and instructed to search for the rotated “T” amongst “L’s” and to indicate its orientation as quickly and accurately as possible. A fixation cross was presented before the start of a trial. When ready, participants would hit the space bar to begin the trial. In addition to the time required to hit the space bar, a 300 ms inter-stimulus interval was included between hitting the space bar and onset of the search display. Each search array was displayed until the participant made a correct speeded response by pressing either the left (the “F”) or the right (the “J”) keys. The presentation order of all Old and New Contexts was randomized for each block of trials to avoid ordering effects. Additionally, target orientation was randomized for each trial to avoid repetition priming effects.

Results

Accuracy (ACC)

The mean accuracy for each participant was calculated by search array presentation Color, Epoch and Context to ensure that accuracy remained consistent by condition over the entirety of the experiment and any changes in RT were not the result of speed-accuracy tradeoffs. A repeated-measures analysis of variance (ANOVA) of Color (B&W, Color) by Epoch (1-10) and Context (Occupied, Unoccupied, New) found no significant main effects for Color, F (1, 64) = .878, p = .352, η2 = .029, Epoch, F (3.51, 224.65) = 1.89, p = .123, η2 = .029, or Context, F (1.62, 103.71) = 2.00, p = .139, η2 = .030. Additionally, no two or three-way interactions of Color, Epoch, or Context were observed, confirming that accuracy was stable across conditions and over the Epochs of the experiment.

Response Time (RT)

Since the focus of this experiment was to determine which factors contribute to spatial target context relearning, it was necessary to determine that participants had successfully learned the initial target context associations. First, all individual error trials and trial RTs greater than 9000 ms were excluded from the analysis as extreme outliers. Next, RTs exceeding ± 3.0 standard deviations of the mean for each participant by presentation Color (B&W, Color), Epoch (1-10) and Context (Occupied, Unoccupied, New) were removed as condition based outliers. The above criteria resulted in the removal of 4.52% and 3.75% of all trials for B&W and Color presentation conditions respectively.

Last, participants were screened for a presence of positive spatial cueing during the Learning Phase (Epoch 1-4), as learning must be present for the initial target location to test for relearning after the relocation event. Participants who failed to show positive spatial cueing (RT_{New} - RT_{Old}) for at least one Epoch of the Learning Phase were excluded from the remainder of the RT analysis. A total of 26 of 33 participants in the Color search condition and 29 or 33 participants showed positive spatial cueing for at least one Epoch for both Occupied and Unoccupied Contexts. To maintain equivalent sample sizes, the first 26 participants collected who showed learning were selected from each group of search array presentation Color (B&W, Color) and included in the analysis of RT (52 total participants). Effects that did not meet the assumption of sphericity were adjusted using a Greenhouse-Geisser adjustment.

Occupied vs. Unoccupied Switch

One possible factor contributing to differences in the presence or absence of relearning following a target relocation event is the type of Target Relocation event (Occupied, Unoccupied). In previous studies where positive spatial cueing failed to return, the predominant type of relocation was to a previously unoccupied location (i.e. an empty non-distractor location) (Mangenelli and Pollmann, 2009; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013). However, in our experiments, using a relocation to a previously occupied location (i.e. swapping with a distractor), resulted in the return of positive spatial cueing.

Visual inspection of the resulting mean RTs for search arrays presented in black and white (Figure 9) and Color (Figure 10) showed little difference in RT with respect to Target Relocation Type.

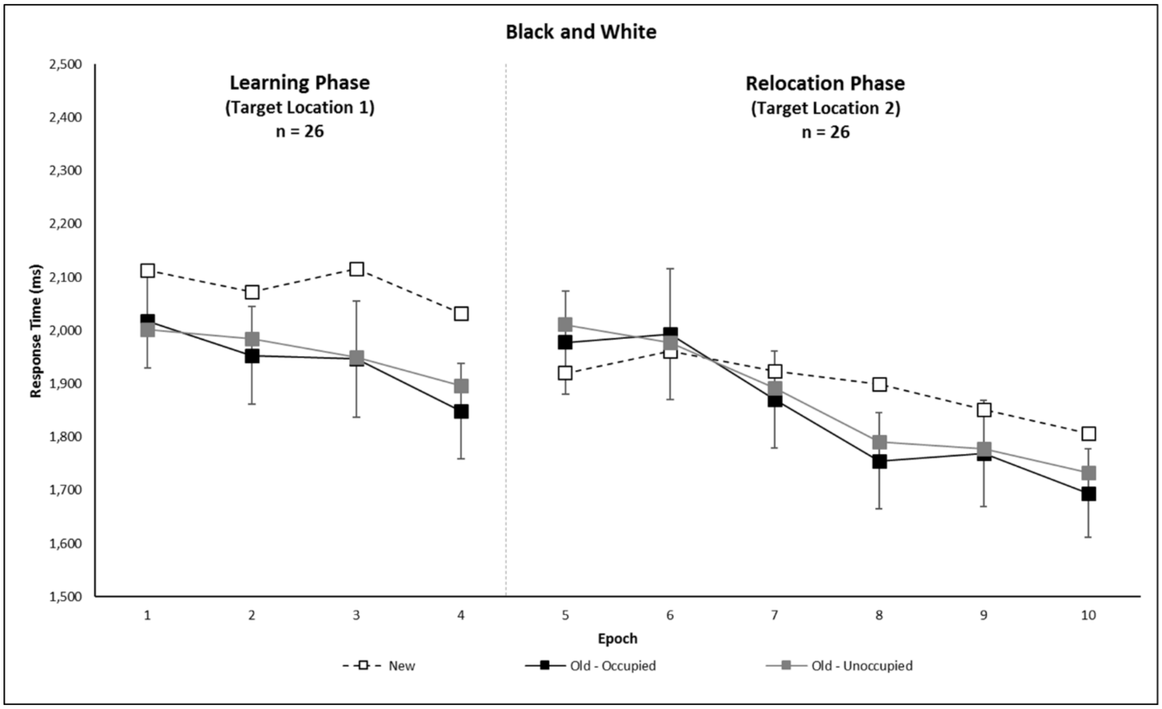


Figure 9. Experiment 3 - Response Time (ms) by Epoch and Context for B&W search arrays.

If Target Relocation Type (Occupied, Unoccupied) and its interaction with search array presentation Color (B&W, Color) are not critical in spatial target relearning then the RTs for targets relocated to a previously occupied or unoccupied location should be equivalent before and after the relocation event, regardless of the search array presentation color. To test this hypothesis, RTs were compared using a mixed repeated-measures ANOVA of Epoch (1-10) and Context (Occupied, Unoccupied) by Color (B&W, Color).

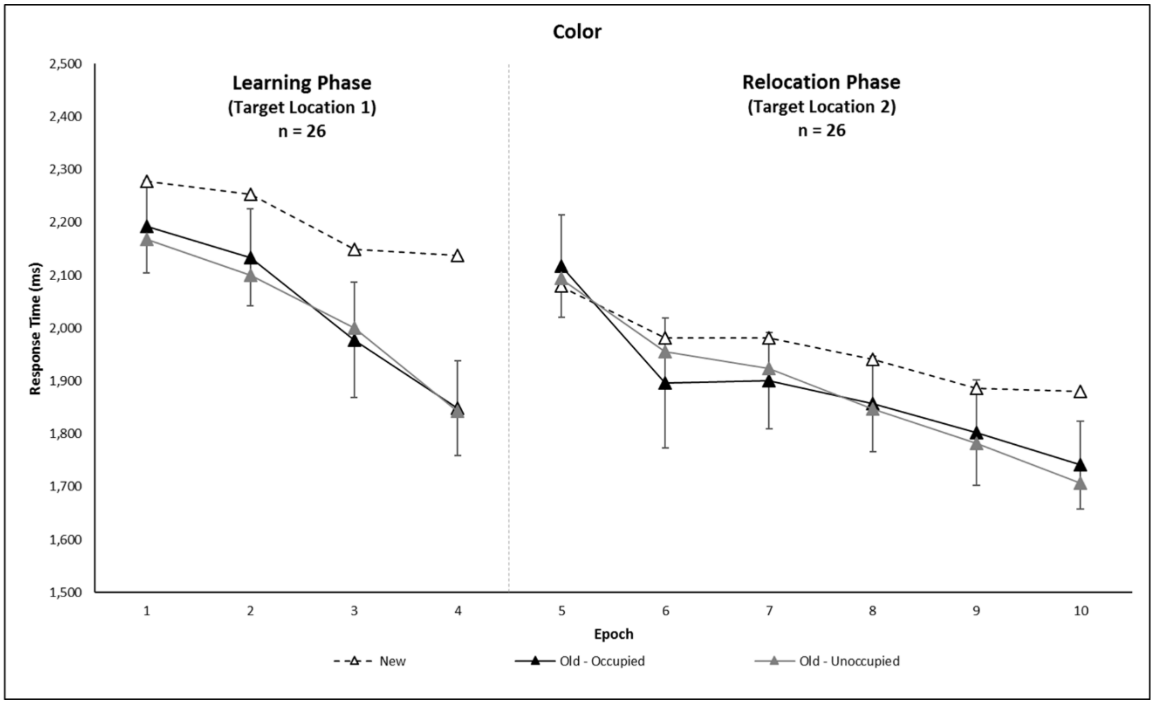


Figure 10. Experiment 3 - Response Time (ms) by Epoch and Context for Color search arrays.

The results of the test revealed only a significant main effect of Epoch, *F* (4.09, 204.58) = 24.30, *p* < .001, η2 = .327. Two-tailed paired-samples t-tests showed that RT decreased between Epochs one and four of the Learning Phase (*M* = 235 ms, *SE* = 32 ms), *t* (51) = 7.28, *p* < .001, followed by a significant increase in RTs immediately following the relocation event (*M* = 190 ms, *SE* = 42 ms), *t* (51) = 4.54, *p* < .001. In turn, from Epochs five to ten RTs again decreased (*M* = 331 ms, *SE* = 36 ms), *t* (51) = 9.31, *p*

< .001. This pattern of RTs is indicative of the development of positive spatial cueing prior to and after a target relocation event (Figure 11).

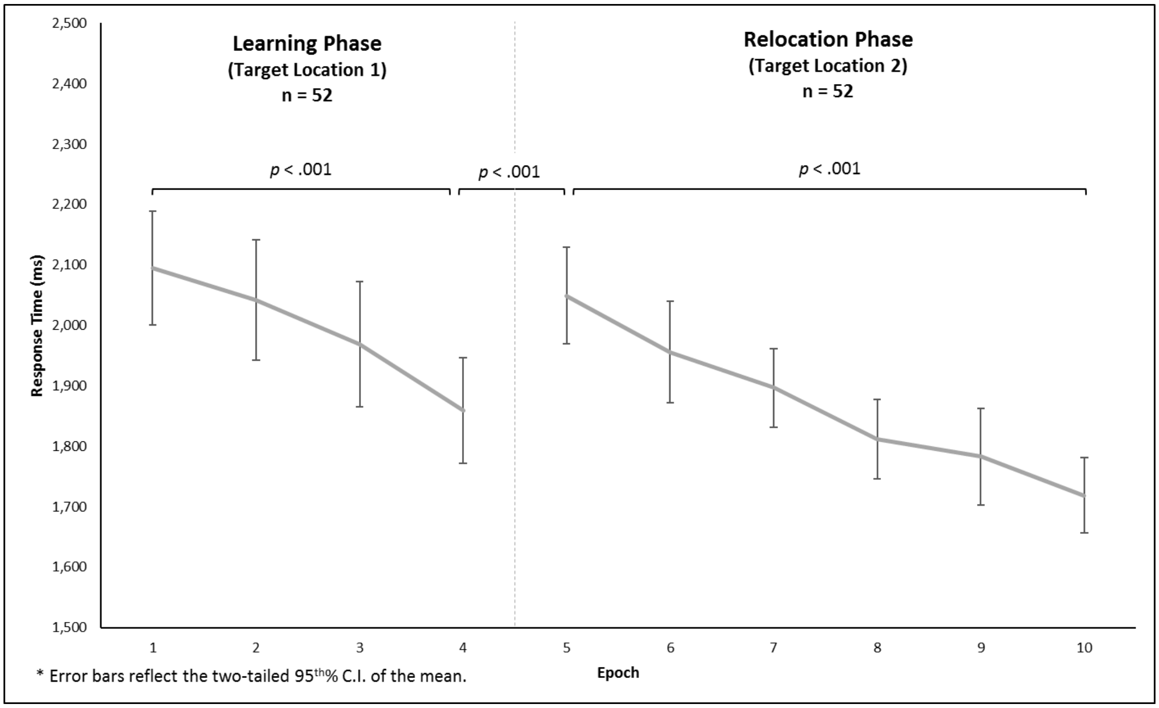


Figure 11. Experiment 3 - Response Time (ms) by Epoch for Old Contexts.

No main effect of Context, *F* (1, 50) = .092, *p* = .763, η2 = .002, or interactions of Epoch and Context, *F* (4.61, 230.66) = .144, *p* = .977, η2 = .003, Epoch and Color, *F* (4.09, 204.58) = 2.134, *p* = .076, η2 = .041, Context and Color, *F* (1, 50) = .265, *p* = .609, η2 = .005, and Epoch, Context, and Color, *F* (4.61, 230.66) = .404, *p* = .831, η2 = .008 were observed. Additionally, the between-subjects effect of Color was also not significant, *F* (1, 50) = .598, *p*= .443, η2 = 012. The lack of significant main or interaction effects of Context suggests that the type of Target Relocation Event (Occupied, Unoccupied) does not affect RTs with respect to spatial target context relearning. As such, Occupied and Unoccupied Contexts were collapsed into a single Context (Old) for the remainder of the analysis.

Black and White vs. Color

The second factor of interest in this study was the search array presentation color. Previous studies presented in black and white failed to see a return of positive spatial cueing following a relocation event, (Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013). However, in our experiments, using color search arrays, positive spatial cueing did return.

If the presentation color of the search array affects the amount of positive spatial cueing following a relocation event, then the results of this experiment should replicate the findings of our own and those of previous studies, with positive spatial cueing returning only for contexts presented in color. However, if search array presentation Color does not affect the return of positive spatial cueing, it is predicted that cueing will be seen for both black and white and color search arrays, or for neither.

First, RTs were analyzed to confirm that the initial target context associations were learned during the Learning Phase (Epochs 1-4). A mixed repeated measures ANOVA of Epoch (1-4) and Context (Old, New) by Color (B&W, Color) revealed a significant main effect of Epoch, *F* (3, 150) = 15.47, *p* < .001, η2 = .236, Context, *F* (1, 50) = 84.61, *p* < .001, η2 = .629, and significant interaction effect for Epoch and Context, *F* (3, 150) = 5.10, *p* = .002, η2 = .092 and Epoch and Color, *F* (3, 150) = 3.80, *p* = .012, η2 = .071. The interaction effects for Context and Color, *F* (1, 50) = 1.32, *p* = .256, η2 = .026 and Epoch, Context, and Color, *F* (3, 150) = 1.75, *p* = .158, η2 = .034 were not significant.

The presence of significant interaction effect of Epoch and Color suggests that overall RTs were different in some ways based on search array presentation Color. Independent-samples t-tests were performed by Epoch to identify the differences in RTs for B&W and Color search arrays.

The t-tests revealed no significant difference between B&W and Color search arrays for Epochs one through four. However, Epochs one (*M* = 166 ms, *SE* = 93 ms), *t* (25) =1.82, *p* =.080 and two (*M* = 164 ms, *SE* = 88 ms), *t* (25) = 1.91, *p* = .067 exhibited a near significant difference, with RTs for Color search arrays being slower than B&W search arrays. Nevertheless, by Epochs three (*M* = 36 ms, *SE* = 93 ms), *t* (25) =.393, *p* =.698 and four (*M* = 39 ms, *SE* = 82 ms), *t* (25) = .481, *p* =.635 neither a practical or statistical difference was present (Figure 12). This result suggests that Color search arrays may have been more difficult at the start of the experiment, but that after an initial warm-up period the difficulty was overcome, with no difference in RTs based on search array presentation Color.

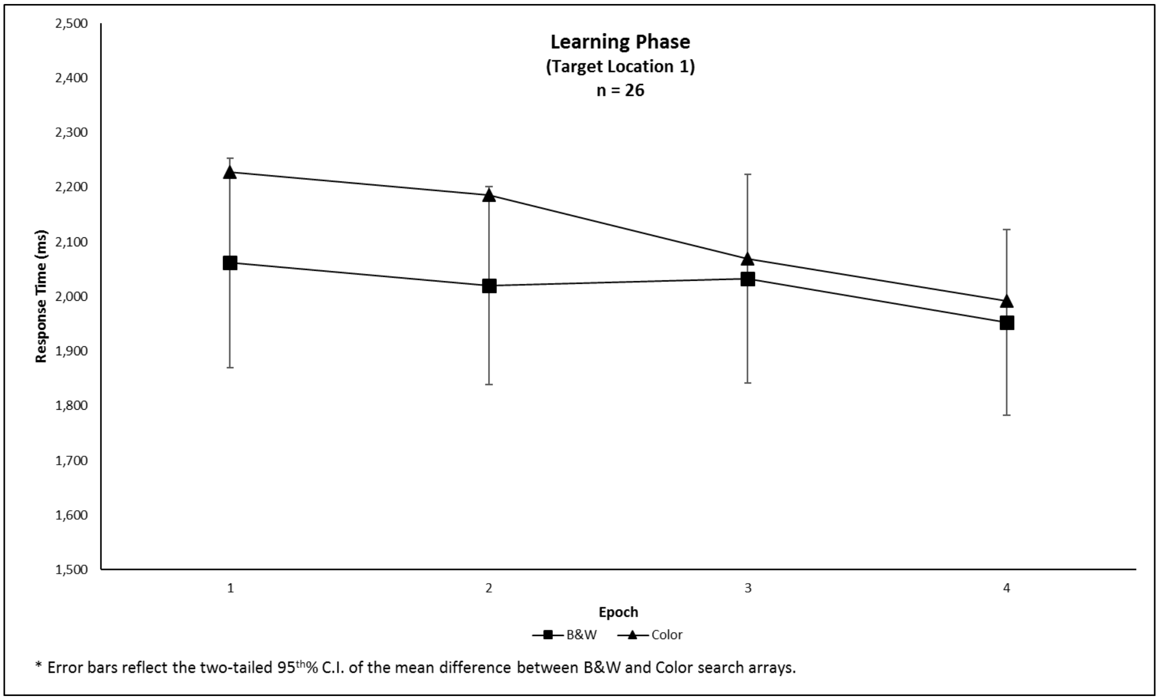


Figure 12. Experiment 3 - Response Time (ms) by Epoch and Search Array Presentation Color.

Next, the interaction of Epoch and Context was examined to determine if positive spatial cueing was achieved for Old Contexts. Two-tailed paired-samples t-tests showed that by Epoch one, (*M* = 101 ms, *SE* = 28 ms), *t* (51) =3.65, *p* =.001 positive spatial cueing was present, and continued to increase through Epoch four, (*M* = 225 ms, *SE* = 24 ms), *t* (51) =9.23, *p* < .001 (Figure 13). This suggests that regardless of search array presentation Color that the initial target context associations were learned.

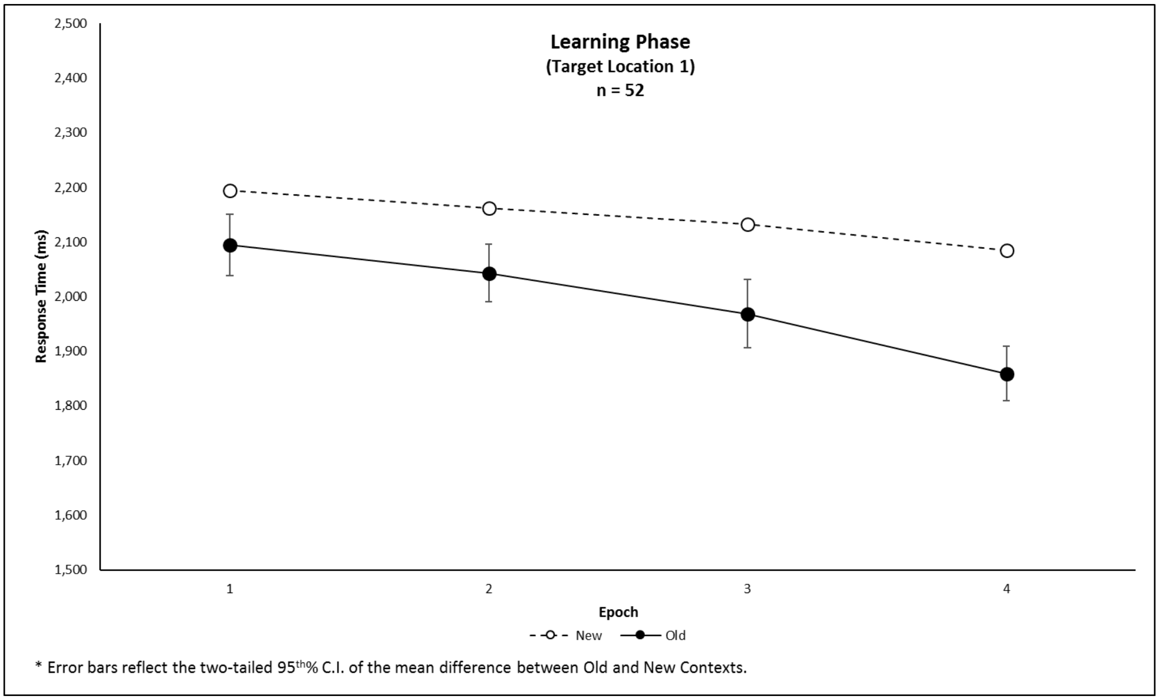
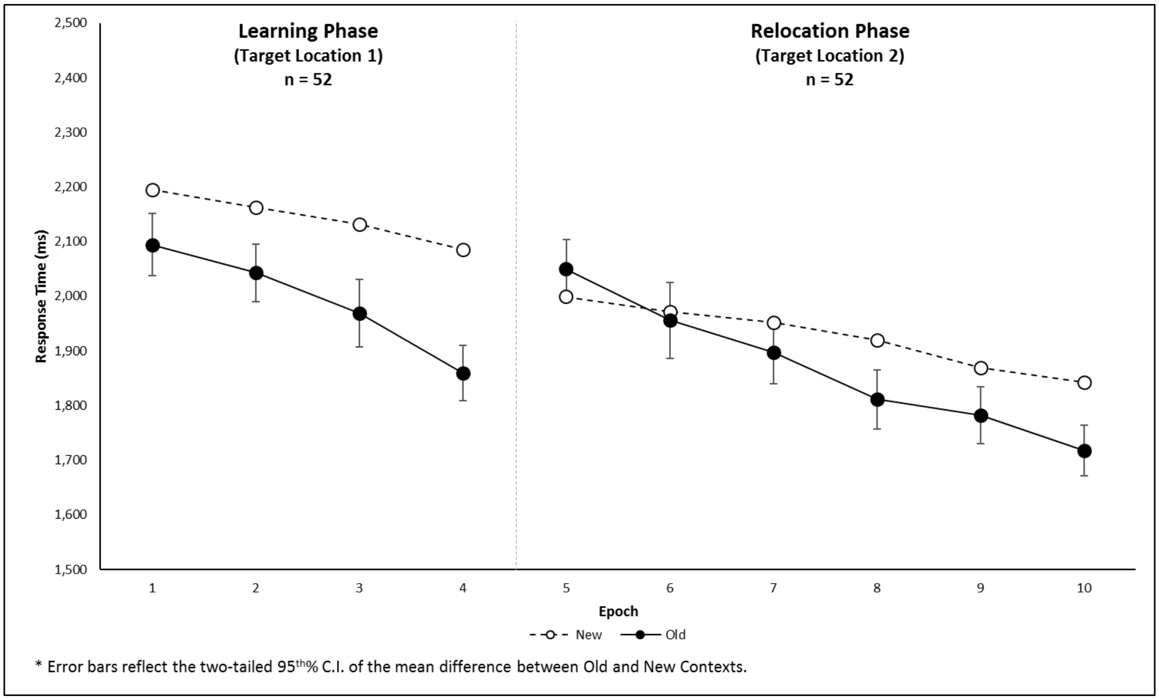


Figure 13. Experiment 3 - Learning Phase Response Time (ms) by Epoch and Context.

Finally, since learning was present for the initial target context associations the next step was to determine if search array presentation Color affects relearning of the secondary target location after the relocation event. A mixed repeated measures ANOVA of Epoch (5-10) and Context (Old, New) by Color (B&W, Color) revealed significant main effects of Epoch, *F* (3.61, 180.72) = 24.61, *p* < .001, η2 = .330 Context, *F* (1, 50) = 11.98, *p* = .001, η2 = .193 and the interaction of Epoch and Context, *F* (5, 250) = 7.65, *p* < .001, η2 = .133 (Figure 14).



* Error bars reflect the two-tailed 95th% C.I. of the mean difference between Old and New Contexts.

Figure 14. Experiment 3 - Learning and Relocation Phase Response Times (ms) by Epoch and Context.

The interaction effects of Epoch and Color, *F* (3.61, 180.72) = 1.94, *p* = .089, η2 = .037 Context and Color, *F* (1, 50) = 1.12, *p* = .294, η2 = .022 and Epoch, Context, and Color, *F* (5, 250) = .755, *p* = .583, η2 = .015 were not significant. Additionally, between-subject effect of Color was not significant, *F* (1, 50) = .677, *p* = .415, η2 = .013. The lack of a significant effect of Color or its interaction with Epoch or Context suggests that search presentation Color does not affect RT, or the presence or absence of relearning.

Finally, the last step was to determine when relearning occurred following the target relocation event. Given the significant interaction effect of Epoch and Context, it was expected that Old Contexts should show a loss of cueing at the onset of the

Relocation Phase (Epoch 5-10), with positive spatial cueing gradually returning before the end of the experiment.

Two-tailed paired-samples t-tests confirmed that positive spatial cueing was lost immediately following the target relocation event, with Old Contexts becoming marginally slower than New Contexts, (*M* = 50 ms, *SE* = 26 ms), *t* (51) = 1.93, *p* =.059. This suggests that participants were still being cued to the first location, misdirecting their attention and resulting in a cueing cost. Conversely, by Epoch eight, (*M* = 109 ms, *SE* = 26 ms), *t* (51) = 4.12, *p* < .001 positive spatial cueing had returned with Old Contexts becoming significantly faster than New Contexts, and continued to increase through Epoch ten, (*M* = 126 ms, *SE* = 22 ms), *t* (51) = 5.62, *p* < .001. This shows that relearning occurred, regardless of search presentation color, with participants associating the secondary target location with the previously learned context (Figure 12).

Overall, the lack of a significant between subject's effect of Color and any significant interactions with Epoch or Context during the Learning and Relocation Phases suggests that search array presentation Color does not affect the presence or absence of learning or relearning of spatial target context associations

Slope

As a final step, a comparison of the individual estimated slopes and constants for each search presentation Color (B&W, Color) and Context (Old, New) was conducted evaluating the effect of Color on RT trends and the amount of positive spatial cueing experienced before and following the relocation event. If the search presentation Color does not affect the base rate or rate of change of RT during the Learning and Relocation phases, then no significant differences in the estimated slopes or constants should be present for Old and New contexts with respect to Color during either Phase.

A simple linear regression analysis was run for each participant broken down by Phase (Learning: Epoch 1-2, Learning: 3-4, Relocation: Epoch 5-10), Color (B&W, Color), and Context (Old, New) with Epoch as a predictor of RT. The Learning phase was divided in half as Epochs one, and two showed a potential difference in the RT analysis with respect to search presentation Color, while Epochs three and four showed no significant difference in RT. Once the estimated slopes and constants were calculated for each participant, two-tailed independent samples t-tests were conducted to determine if a difference exists with respect to Color for Old and New Contexts.

The results for the first half of the Learning Phase (Epochs 1-2) showed no significant difference for the estimated mean slopes with respect to Color (B&W, Color) for Old, (*M* = 20 ms/Epoch, *SE* = 55 ms/Epoch), *t* (25) = .373, *p* = .712 or New Contexts, (*M* = 17 ms/Epoch, *SE* = 58 ms/Epoch), *t* (25) = .290, *p* = .774. However, the estimated constants did approach significance for both Old, (*M* = 169 ms, *SE* = 93 ms), *t* (25) = 1.85, *p* = .077 and New Contexts, (*M* = 164 ms, *SE* = 101 ms), *t* (25) = 1.66, *p* = .109 (Figure 13). As previously concluded, this suggests that the search arrays presented in Color may have been more difficult at the start of the experiment.

Subsequently, the results for the second half of the Learning Phase (Epochs 3-4) showed no significant difference for the estimated mean slopes with respect to Color (B&W, Color) for Old, (*M* = 67 ms/Epoch, *SE* = 48 ms/Epoch), *t* (25) = 1.41, *p* = .170 or New Context, (*M* = 73 ms/Epoch, *SE* = 72 ms/Epoch), *t* (25) = 1.01, *p* = .318, and that the difference in the estimated constant dropped dramatically for Old, (*M* = 40 ms, *SE* = 103 ms), *t* (25) = .390, *p* = .699 and New Contexts, (*M* = 33 ms, *SE* = 92 ms), *t* (25) = .356, *p* = .725 (Figure 13). This suggests that by Epoch three, the base RT for B&W and Color search arrays were equivalent, and were improving at similar rates for both Old and New Contexts.

Finally, the results for the Relocation Phase (Epochs 5-10) showed no significant difference for the estimated mean slopes for Old, (*M* = 7 ms/Epoch, *SE* = 13 ms/Epoch), *t* (25) = .502, *p* = .620 with respect to Color (B&W, Color) or New Context, (*M* = 11 ms/Epoch, *SE* = 14 ms/Epoch), *t* (25) = .836, *p* = .411, with respect to Color (B&W, Color). Similarly, Color did not result in a significant difference of the estimated constant for Old Contexts, (*M* = 47 ms, *SE* = 78 ms), *t* (25) = .609, *p* = .548 or New Contexts, (*M* = 94 ms, *SE* = 70 ms), *t* (25) = 1.35, *p* = .188 (Figure 15). This suggests that search array presentation Color does not affect the base RT or change in RT for Old and New Contexts during the Relocation Phase.

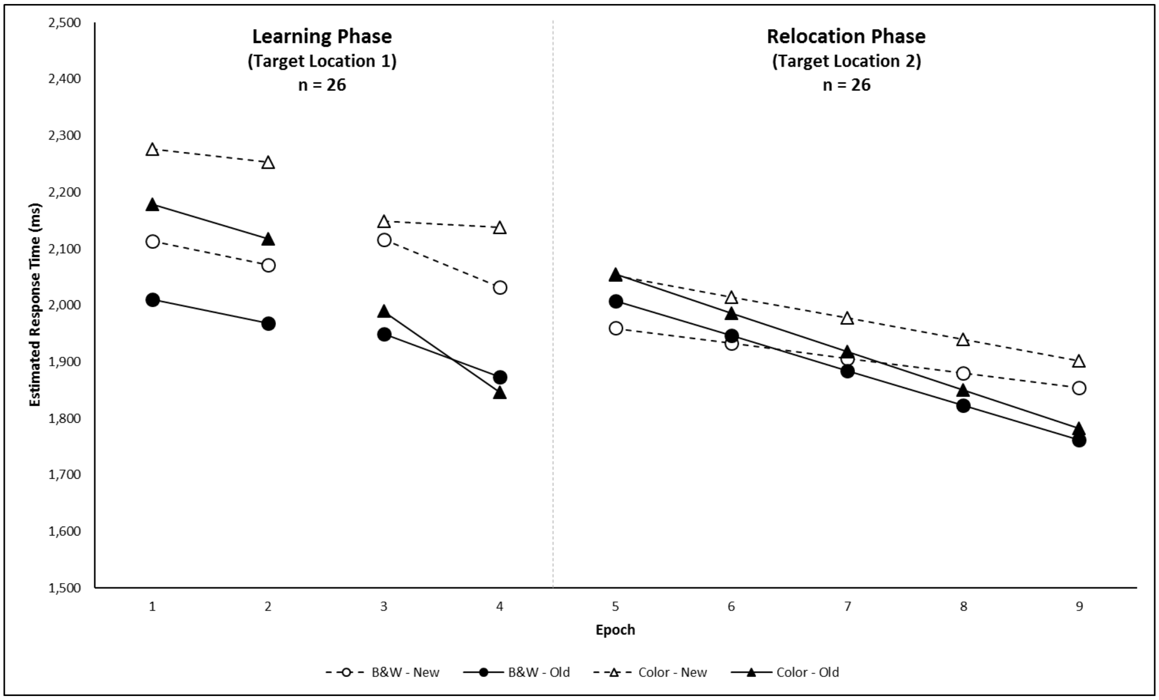


Figure 15. Experiment 3 - Estimated Response Time (ms) by Epoch, Context, and Color.

As a final step, the estimated slopes and constants for Old and New Contexts were compared for each Phase (Learning, Relocation) to determine if learning and relearning were present. If spatial target context learning or relearning occurred in either Phase, then a significant difference between Old and New Contexts should be found for the estimated slopes and the constants. Two-tailed paired-sample t-tests showed that Old contexts had a significantly greater negative slope compared to New contexts during the Learning, (*M* = 42 ms/Epoch, *SE* = 11 ms/Epoch), *t (*51) = 3.81, *p* < .001 and Relocation phases, (*M* = 33 ms/Epoch, *SE* = 5 ms/Epoch), *t (*51) = 6.72, *p* < .001. This suggests that learning and relearning were present in both Phases.

Furthermore, a significant difference in the estimated constants was found for the Learning Phase, with Old Contexts being faster than New Contexts, (*M* = 89 ms, *SE* = 24 ms), *t (*51) = 3.77, *p* < .001, suggesting that spatial context learning had occurred as early as the first Epoch. Conversely, no significant difference was found for the estimated constant during the Relocation Phase, with Old Contexts being marginally slower than New Contexts, (*M* = 25 ms, *SE* = 23 ms), *t (*51) = 1.11, *p* = .272 in the first Epoch of the Relocation Phase. This suggests that the cueing benefit was lost following the target relocation event.

Next, a comparison of the slopes and constants across each Phase was conducted to see if the general rate of search time improvement and the rate of cueing development changed between Phases. A comparison of the slopes and constants for New Contexts during the Learning and Relocation Phase found no significant difference in slope (*M* = 4 ms/Epoch, *SE* = 17 ms/Epoch), *t (*51) = .247, *p* = .806, but that the estimated constants for New Contexts were significantly faster at the start of the Relocation Phase than the Learning Phase, (*M* = 192 ms, *SE* = 38 ms), *t (*51) = 5.08, *p* < .001. This suggests that general improvement in the search task was constant over the course of the experiment and that participants had become faster by the Relocation Phase.

Additionally, a comparison of the slopes and constants across each Phase was conducted to determine if Old Contexts improved at the same rate before and after the target relocation event. A two-tailed paired-sample t-test found no significant differences in the slopes for Old Contexts between the Learning and Relocation Phases, (*M* = 13 ms/Epoch, *SE* = 14 ms/Epoch), *t (*51) = .955, *p* = .344, or estimated constants (*M* = 77 ms, *SE* = 42 ms), *t (*51) = 1.85, *p* = .071. The lack of difference between slopes suggests that development of the cueing benefit is consistent across phases. However, the lack of a significant difference in the constants suggests that the target relocation event led to RT cost at the onset of the Relocation Phase.

To better understand the cost of the relocation event, the estimated slopes and constants were used to plot an estimate of RT for the Old and New contexts. The results provided a prediction for the total amount of positive spatial cueing achieved in Epoch four of the Learning phase (215 ms) and the associated RT cost following the target relocation event in Epoch five of the Relocation Phase (25 ms). Combining these amounts provides an estimate of the net loss of positive cueing following the target relocation event (215 ms + 25 ms = 240 ms).

Dividing this net loss by the difference in the estimated slopes of the Old and New contexts during the Relocation Phase provides an expected recovery time (i.e. the number of Epochs) needed for positive spatial cueing to fully recover (240 ms ÷ 33 ms/Epoch = 7.3 Epochs or 37 repetitions). The expected recovery time, 7.3 Epochs, was greater than the six Epochs of the Relocation Phase and suggests that the Relocation Phase would have needed two more Epochs for positive spatial cueing to recover fully (Figure 16).

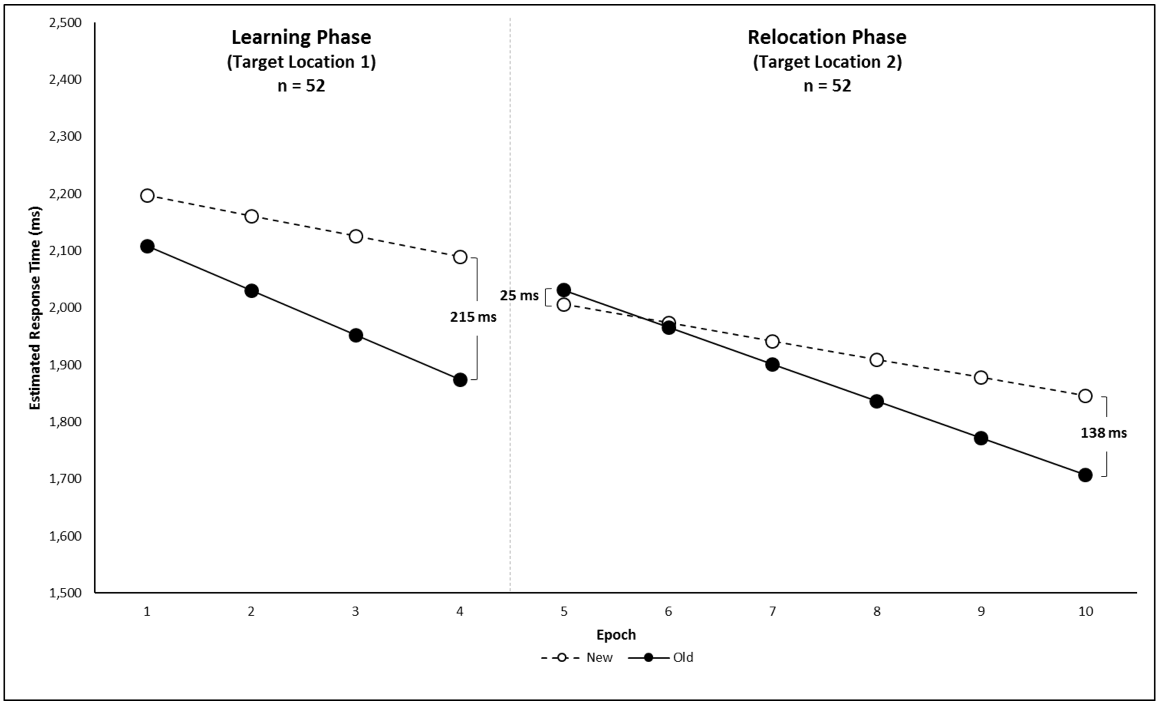


Figure 16. Experiment 3 - Estimated Response Time (ms) for Old and New Contexts by Phase.

Target Relocation Distance

Finally, positive spatial cueing was analyzed with respect to Target Relocation Distance to determine whether cueing following a relocation event was driven by the proximity of the secondary target and its original location. The target relocation distance of each repeated target context pairing was calculated for each participant (Range: 7.6° - 43.3°, *M* = 21°, *SE* = .37°).

Next, positive spatial cueing ($RT_{New} – RT_{Old}$) during the Relocation Phase was calculated for each Epoch by participant and Target Relocation Distance and aggregated by Epoch and Target Relocation Distance. In previous studies, including our own, a significant negative correlation between target relocation distance and the amount of positive spatial cueing was observed. It was predicted that this negative correlation would again be present, with positive spatial cueing increasing as target relocation distance decreases.

A two-tailed Pearson’s correlation analysis of Target Relocation Distance by Epoch and mean positive spatial cueing confirmed the presence of a significant negative correlation for Epoch five of the Relocation Phase, $r = -.507$, $p = .007$, with positive spatial cueing decreasing as Target Relocation Distance increased. This suggests that immediately following a target relocation event, targets located close to their original location will still benefit from the cue for the original location.

Next, the mean positive spatial cueing was analyzed by Epoch and Target Relocation Distance to determine when and at what relocation distances cueing returns. Since the Target Relocation Distances were random per Context and each participant experienced only a subset of possible distances, a simple linear regression was run to model the amount of positive spatial cueing achieved for each Epoch and Target Relocation Distance. The resulting regression equation was found to be significant, F (2, 159) = 26.80, $p < .001$, with an $R^2 = .252$ (Eq 6.).

Equation 6. Relocation Phase - Positive Spatial Cueing as a function of Epoch and Relocation Distance.

$$\mathbf{PSC\ (ms) = 180 + 35 \times Epoch\ (0 \dots 5) - 9 \times Target\ Relocation\ Distance}(°\ \mathbf{Visual\ Angle})$$

The amount of positive spatial cueing was estimated by Epoch and Target Relocation Distance for the Relocation Phase (Epochs 5-10) using the resulting model, for distances between the study relocation minimum and maximum (5° to 45° of visual angle). The estimates show that in Epoch five, immediately following the target relocation event targets located between 5° and 15° of visual angle showed a positive cueing benefit, with those relocated beyond 15° visual angle experiencing a cueing cost. However, by the final Epoch targets that had been relocated up to 35° of visual angle achieved positive cueing. This suggests that targets located near the original location will be cued earlier and greater than those relocated furthest away, but that relearning can occur with sufficient repetition of the new location (Table 11).

Table 6. Experiment 3 - Estimates of Positive Spatial Cueing for the Relocation Phase.

	Distance									
Epoch	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	***M***
5	132	85	38	-9	-56	-103	-150	-198	-245	-56
6	168	120	73	26	-21	-68	-115	-162	-210	-21
7	203	156	108	61	14	-33	-80	-127	-174	14
8	238	191	144	96	49	2	-45	-92	-139	49
9	273	226	179	132	84	37	-10	-57	-104	84
10	308	261	214	167	120	72	25	-22	-69	120

Discussion

The purpose of this study was to replicate the results of previous spatial context target relocation studies and to identify the factors leading to differences in the presence or absence of relearning in our own and previous studies. Previous studies using monochromatic search arrays and an unoccupied target relocations failed to see relearning following a target relocation event (Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Conci and Muller, 2012; Zellin, Conci, Muhlenen, and Muller, 2013). However, our studies presented in color and using an occupied relocation type consistently showed a relearning effect.

It was predicted that the Target Relocation Type (Occupied, Unoccupied), search array presentation Color (B&W, Color), or both were the contributing factors to these diverging results. If relocation type was the key factor, it was anticipated that positive cueing would be present for B&W and Color presentations, but only for Occupied relocations. Alternatively, if Color was the driving factor, it was predicted that positive spatial cueing would reemerge only for the search arrays presented in Color, but for both Occupied and Unoccupied target relocations. Finally, if an interaction of Color and Relocation Type was the driving factor, then it was expected that relearning would be highest for Color search arrays with Occupied relocations, and still be present but lower for Color search arrays with Unoccupied relocations and B&W search arrays with Occupied relocations.

Ultimately, the analysis of RT showed that neither Relocation Type, Color, or the interaction of Relocation Type and Color had an effect on spatial target learning or relearning before or after a relocation event. Rather, relearning occurred for all possible combinations of Relocation Type and Color, further replicating our own findings and directly contradicting those of previous studies where relearning was unsuccessful (Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Conci and Muller, 2012; Zellin, Conci, Muhlenen, and Muller, 2013).

First, Relocation Type was shown to have no effect on RT with respect to Old contexts, suggesting that maintaining the overall spatial Context was not necessary for spatial target context relearning. Subsequently, Relocation Type was collapsed into a single factor level (Old), and compared to New contexts with respect to Epoch and presentation Color.

Subsequently, no effect of Color was found with respect to Old and New Context RTs during the Learning Phase, with Old contexts becoming significantly faster than New context before the relocation event. Additionally, no main or interaction effects of search array presentation Color were observed during the Relocation Phase, with successful relearning for both B&W and Color Contexts. This suggests that identity context features are not required in addition to spatial context features for relearning to occur.

As a precaution, the estimated slope and constants for Old and New Contexts RTs were also compared with respect to presentation Color. Again, no significant differences in estimated slope were found with respect to color. Also, a comparison of the Old and New slopes for each phase showed that the Old contexts had a significantly greater negative slope compared to New contexts, providing evidence that learning and relearning occurred in each Phase.

Furthermore, a comparison of Context slopes across phase showed that the RT slopes of New contexts were equivalent in both phases, suggesting general search improvement was consistent over the course of the experiment. Similarly, Old contexts slopes were equivalent between Phases, suggesting that the rate learning is equivalent before and after a target relocation event. These results further support that context identity features, such as Color, are not a prerequisite for spatial context target relearning.

Although the results clearly demonstrate that relearning occurs, it is important to note that the target relocation event did lead to a cueing cost. The loss of cueing was estimated for the Epoch following the target relocation event (approximately 240 ms). Dividing this cost by the difference in the slopes of the Old and New Contexts estimated that positive spatial cueing would fully recover to levels achieved in the Learning phase after 7.3 Epochs (37 repetitions), which was a recovery time nearly double the initial learning period of four Epochs (20 repetitions).

Finally, the results of the correlation analysis for Target Relocation Distance and positive spatial cueing confirmed the expected negative correlation of positive spatial and Target Relocation Distance, with cueing increasing as relocation distance decreased. However, unlike previous studies which suggested that positive spatial cueing was limited to only targets located in proximity, (Conci, Sun, and Muller, 2011; Conci and Muller, 2012; Zellin, Conci, Muhlenen, and Muller, 2013), a simple linear regression of Epoch and Relocation distance showed that positive spatial cueing emerged for relocation distances of up to 35° of visual angle. This is consistent with our previous findings and intuitively suggests that while targets relocated shorter distances benefit the most and earliest, targets relocated larger distances can be relearned achieving positive cueing given sufficient repetitions of the new location.

Conclusion

The purpose of this study was to identify the factors leading to the presence or absence spatial context target relearning following a relocation event. Based on experimental differences in those studies that failed to see relearning after the relocation event, (Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Conci and Muller, 2012; Zellin, Conci, Muhlenen, and Muller, 2013) and our own it was determined that search array presentation Color (B&W, Color) and/or Target Relocation Type (Occupied, Unoccupied) may be possible factors leading to the diverging results. However, the results of this study showed that neither factor significantly affects relearning, with relearning occurring for all possible factor combinations tested.

Despite not being able to identify the potential cause of differences in our findings and those of previous studies, the results of this study provide strong evidence that relearning of the target context association is possible following a target relocation event, and is not functionally limited by the relocation distance. While the amount of positive cueing and target relocation distance were found to be negatively correlated, the results showed that with enough repetitions that positive spatial cueing could be achieved for distance up to 35° of visual angle.

While the results of this study are compelling, possible factors remain that may shed light on the differences seen in our studies and previous studies were relearning failed to occur, such as the search array size and shape, and subject sample size

(Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Conci and Muller, 2012; Zellin, Conci, Muhlenen, and Muller, 2013).

Future studies should be conducted to explore whether such factors are the cause of these divergent findings.

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CONCLUSIONS (STUDY 1 & 2)

Basic Conclusions

The goals of Studies 1 and 2 were to determine 1) whether spatial context target relearning occurs following a relocation event, 2) the effect of multiple relocation events on relearning, and 3) whether search array presentation Color and Target Relocation Type determine the presence or absence of relearning.

The results of Study 1 consistently showed a relearning effect with positive spatial cueing returning following target relocation events. Furthermore, the relearning effect occurred for contexts experiencing one, two, and three relocation events. This directly conflicts with results of previous studies where positive spatial cueing failed to return following a single target relocation (Mangenelli and Pollmann, 2009; Makovski and Jiang, 2010; Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013). A comparison of previous experimental designs and our own revealed several major differences, including the number of repetition blocks following a relocation, search array presentation Color, and Target Relocation Type.

First, our results suggest that the lack of relearning effects in Mangenelli and Pollmann, 2009 and Makovski and Jiang, 2010, was the result of insufficient repetitions during the Relocation Phase, regardless of Color or Relocation Type. In each study, the number of repetitions (3 and 10 respectively) in the Relocation Phase were substantially lower than those of the learning phase (24 and 20). Consequently, our results show that, at a minimum, the number of repetitions required for target relearning must be greater than or equal to that of the Learning Phase.

However, previous studies using monochromatic search arrays and unoccupied target relocation events still failed to observe relearning, despite a sufficient number of repetitions following a relocation event (Conci, Sun, and Muller, 2011; Zellin, Conci, Muhlenen, and Muller, 2013). As such, we predicted that other factors such as the search array presentation Color and or Target Relocation Type were the cause of the diverging results.

Consequently, Study 2 revealed that neither Color nor Relocation Type affects the presence or amount of relearning following a relocation event. Instead, all factor combinations tested did show evidence of relearning following a relocation event. As a result, it remains unclear what led to the failure of relearning in previous studies (Conci, Sun, and Muller, 2011; Conci and Muller, 2012; Zellin, Conci, Muhlenen, and Muller, 2013). This result replicates the findings from Study 1 and provides strong evidence that spatial context target relearning is possible.

Furthermore, in both Study 1 and 2 our results showed that target relocation distance effects the development of positive spatial cueing during the relearning period, with targets relocated near their original location benefiting the most and earlier than targets relocated at greater distances away. However, our results also suggest that target relocation distance is not a limiting factor on relearning and that with sufficient exposure relearning occurs for both small and larger relocation distances. This again contradicts the findings of previous studies that suggested positive cueing was limited to targets relocated near their original locations (Conci, Sun, and Muller, 2011; Conci and Muller, 2012; Zellin, Conci, Muhlenen, and Muller, 2013).

Finally, if relearning was only possible for targets located in proximity, then increasing the search area size and subsequently, the average target relocation distance should make relearning less likely. However, despite Studies 1 and 2 having larger average search area size and relocation distances compared with previous studies (Conci, Sun, and Muller, 2011; Conci and Muller, 2012; Zellin, Conci, Muhlenen, and Muller, 2013), relearning was repeatedly and consistently observed. This further strengthens our conclusion that spatial context target relearning occurs following a relocation event.

Applied Considerations

From a broader applied perspective, the results of Study 1 and 2 have very relevant human factors considerations, particularly with respect to the design and redesign of systems. At its core, these studies suggest that task performance can be improved by consciously considering how the system or environment features and information form task relevant contexts that are predictive of our surroundings or tasks.

Subsequently, these studies predict that a change in the target of a previously learned system or environment context will lead to a temporary but potentially substantial performance loss. Furthermore, in order to overcome this loss, a relearning period is necessary to regain previous performance benefits and may be dependent on the degree of change, and exposure time and benefit of the previous target context association.

These predictions are particularly relevant to high stress/risk work environments such medical, maintenance, and military environments where the gain, loss, and return of performance benefits associated with designed contextual cues have critical safety and risk implications. Additionally, time/cost dependent environments such as manufacturing, office, and retail environments, where even a temporary loss in performance can have long-term implications for schedule and cost, may benefit from these applied considerations.

While the results of our studies show that a target change can be relearned with respect to a previously learned context, they also showed that the time of recovery is dependent on how long the previous contexts were in use and the degree of change. For example, in both studies, short target relocation distances had very little impact on cueing performance, with targets located in proximity to their original location benefiting more and earlier than those relocated further away. Similarly, the greater amount of positive spatial cueing achieved for the initial target context pairs, the greater amount of time to fully recover positive cueing for the secondary location.

From an applied perspective, these results would predict that the smaller the change, the less time required for relearning to occur. However, for a previously learned design context used more frequently or for longer periods of time and larger cueing benefits, the relearning time may be substantial regardless of the degree of change. Additionally, the predicted loss of cueing and estimated relearning time have implications with respect to the decision to make a change, as well as when and how often to evaluate performance after a change.

First, if the task or design to be changed has critical safety or risk implications, an assessment of how a temporary loss of performance will affect critical measures of risk will be necessary. In some cases, even a small performance loss associated with a change may not be worth the risk. However, additional controls, training, staff, or evaluation checks may be able to mitigate such risks.

Second, from an evaluation perspective, the frequency and duration of performance assessment of a new design will need to be adjusted relative to the use frequency/duration of the previous design and the severity of the change. For example, a change to a target element or task for a routine procedure is likely to require a greater relearning period (i.e. more training/exposure/repetitions), compared to less a frequent procedure, while small design changes would likely require less time than more extensive changes.

One potential task environment where these predictions are highly relevant is that of an operating room. Operating rooms and surgical teams rely on the use of highly procedural tasks, rigorous checklists, and extensive tool management systems to ensure that speed, accuracy, and precision of procedures are optimized and maintained from patient to patient and that risks such as a procedural error or leaving an instrument in a patient are reduced. In this type of environment, it is critical that even a temporary loss in performance be predicted and accounted for with respect to speed and may require additional safety and procedural checks or staff until the changes have been fully adopted and performance recovered. Additionally, the frequency and duration of evaluation may need to be increased, accessing performance on multiple occasions following the change to ensure that performance benefits are returning and have fully recovered or surpassed those of the previous design.

Ultimately, Study 1 and 2 suggest that accounting for, controlling, and consciously designing the contextual elements of a task can improve performance and that a change to the target elements or step for a previously learned context can be successfully relearned. Additionally, the results provide a very basic model for visual search RT performance which can be approximated to more complex applied task models, with RT decreasing before a change, temporarily increasing following a change, and gradually recovering during a relearning period.

Future Studies

In Study 1, a key limitation of Experiment 1 during the Return Phase was the presentation of the initial and secondary target locations within the same block of trials. This potentially masked any positive spatial cueing retained for the initial target location in the first return Epoch and may have led to interference effects for the secondary target location. As such it is unclear if positive spatial cueing for the initial location was lost due to relearning of location two during the Relocation phase, or the loss of positive cueing for locations one and two were the result of an interference effect.

Experiment 2 corrected this limitation by only presenting the initial and secondary target locations in separate blocks of trials. However, the complex experimental design decreased the number of repeated context displays per condition, which may have reduced the ability to detect the effect of positive spatial cueing. Since positive spatial cueing is based on the aggregate RT for repeated contexts, it is possible that by having fewer contexts per condition, that condition variance was increased, masking potential differences in the condition effects. Future studies should replicate Experiment 2, but leverage a mixed repeated measures design, separating the relocation number into three between subject groups, No, Single, and Three relocations. This would allow each condition to have a larger number of repeated display contexts, and ideally lead to improved RT variance by condition, improving the detection of effects, and resolving the ambiguity in the Return Phase of Experiment 1.

Finally, Study 2 failed to identify the factors leading differences in relearning between our own and previous studies. One factor unexplored in Study 2, which may provide insight, is the size of the search areas. A review of the previous relocation studies showed that search array sizes in were about half to two-thirds the area of the search areas used in Study 1 and 2. This in turn led to faster mean RTs compared to our studies.

As RTs approach the perceptual and physical response limits, this may decrease the size of the positive spatial cueing effect, reducing an experiment's sensitivity to the effect. By comparison, increasing the search area should lead to slower search times and may benefit more from the contextual cueing effect. Future studies, replicating Study 2 with smaller search areas should be conducted to explore this hypothesis, and test whether an interaction of search area size occurs with Color and Target Relocation Type.

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BIOGRAPHY

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