

May 2014

Is Contextual Cue Learning Flexible? an Eye-movement Study of the Contextual Cueing Task

Youcai Yang

University of Wisconsin-Milwaukee

Follow this and additional works at: <http://dc.uwm.edu/etd>

 Part of the [Neuroscience and Neurobiology Commons](#), and the [Other Psychology Commons](#)

Recommended Citation

Yang, Youcai, "Is Contextual Cue Learning Flexible? an Eye-movement Study of the Contextual Cueing Task" (2014). *Theses and Dissertations*. Paper 434.

Is Contextual Cue Learning Flexible?

An Eye-Movement Study of the Contextual Cueing Task

by

Youcai Yang

A Thesis Submitted in

Partial Fulfillment of the

Requirements for the Degree of

Master of Science

in Psychology

at

The University of Wisconsin–Milwaukee

May 2014

ABSTRACT
IS CONTEXTUAL CUE LEARNING FLEXIBLE?
AN EYE-MOVEMENT STUDY OF CONTEXTUAL CUEING TASK

by

Youcai Yang

The University of Wisconsin-Milwaukee, 2014
Under the Supervision of Professor Anthony J. Greene

Visual searching can be facilitated without awareness when the target is repeatedly presented in an invariant context in tasks such as contextual cueing (Chun & Jiang 1998). A behavioral cost (increased reaction time) was observed when the target was moved to a new location but no such cost was observed when the target returned to the initial location. The lack of cost for return suggests two possible explanations: One is that the learning can update the initial learning to acquire both target locations, which suggests the implicit learning is flexible. The other is that the contextual cue learning cannot update the initial learning but perseverates for the initial target location, which would not provide evidence the learning is flexible. To clarify the mechanism by which returns impose no behavioral cost, thirty-two participants were recruited for a contextual cueing task with both eye-movement and reaction time as dependent variables. All participants were required to identify the orientation of target in each array. After nine blocks (phase A₁), the target in repeated array swapped with a distractor in the diagonal quadrant for another nine blocks (phase B), then the target returned to its initial location (phase A₂). A behavioral cost of reaction time was observed after the initial swap in phase B. No significant contextual cueing effect was observed until the last epoch of phase B.

However, no evidence of a behavioral cost was observed after the return in phase A₂. Further analysis showed the behavioral cost in Phase B was found to be due in part to proactive interference from learning in Phase A₁. The mechanism for immediate recovery after return in phase A₂ was likewise perseveration of learning from Phase A₁, which in most instances was sustained throughout all Phase B. The present study shows no evidence that participants could learn two targets locations which were subsequently presented in the same context in the contextual cueing task within the limited time available to them. Therefore, no evidence was found to support the flexibility of implicit learning in this task.

TABLE OF CONTENTS

Introduction.....	1
Characterization of explicit and implicit memory	1
Flexibility of implicit and explicit memory	2
Contextual cueing task.....	5
Behavioral cost of relocated target.....	5
Proactive interference of initial predictive experience.....	6
Adaption of two target locations simultaneously present.....	8
Opposite views: Studies of flexible adaptation of relocated target.....	8
Research questions and preliminary method.....	9
Study purpose and hypotheses.....	10
Method.....	11
Participates.....	11
Materials.....	12
Procedure.....	15
Results.....	18
Data Elimination.....	18
Recognition Test.....	18
Target Detection: Behavioral response.....	18
Eye movement.....	23
Discussion	30
Conclusion.....	35
References.....	36

LIST OF FIGURES

Figure 1: Sample array was used in this study.....	13
Figure 2: Schematic examples of the task.....	16
Figure 3: Mean reaction times for novel and repeated arrays across epochs.....	20
Figure 4: Mean reaction times of novel and repeated arrays across blocks.....	22
Figure 5: Mean reaction time across epochs (Novel vs. SO vs. NSO array).....	25
Figure 6: Mean number of fixations required to find targets (SO array).....	27
Figure 7: Trials searching the diagonal quadrant to the target quadrant (SO array).....	28
Figure 8: Trials in which the target was found by the first saccade (SO array).....	30

Introduction

Memory is often categorized as either explicit or implicit (Graf & Schacter, 1985; Schacter, 1987; Shimamura, 1986). Explicit or declarative memory refers to knowledge for which we have conscious access. Explicit memory is further divided into episodic memory and semantic memory (Tulving, 1985). Episodic memory is referred to as autobiographical memory for specific personal experiences from a particular time and place, such as a basketball game, or a job interview. Semantic memory on the other hand is conscious recollection of factual information and general knowledge about the world, and allows us to recall the names, which constitutes knowledge. Additionally, there is no requirement that a particular episodic memory is associated with semantic information.

Implicit memory refers to the memory revealed when previous experience facilitates performance on a task without the necessity of conscious awareness of these experiences (Cohen, Eichenbaum, Deacedo, & Corkin, 1985; Schacter, 1987). Procedural memory, perceptual facilitation, classical conditioning and nonassociative learning are all examples of implicit memory. Procedural memory is the learning of a variety of motor and cognitive skills, such as how to ride bicycle, how to read and how to type. Accuracy and speed are improved by implicit memory when performing, even without awareness. Perceptual performance can likewise be improved by experience. Perceptual facilitation, or priming refers to a change in the response to, or ability to identify a stimulus as the result of prior exposure to that stimulus. For example, one can complete the incomplete word 'MOT__' with letters "IF" after prior exposure to a complete word 'MOTIF', and are more likely to do that than to complete the stem with "el" since they have not studied the word 'MOTEL'. The effects of priming can be very salient and long lasting (Tulving,

Daniel, Schacter, & Heather, 1982), and work best when the stimuli are in the same modality and semantically related words (Friederici, Steinhauer, Frisch, 1999; Zurif, Swinney, Prather, Solomon, & Bushell, 1993). For example, visual priming worked best with visual cues, semantic priming works between related words such as 'car' and 'fuel'. In general, priming is said to occur when prior experience results in perception that is more accurate, identification occurs more quickly, or primed targets are more readily selected.

Flexibility in memory allows previous learned information to be recalled and applied to novel situations when presented with similar contingencies or a subset of the original materials (c.f., generalization; Postman, 1951). This adaptive function of memory engages novel information into established mnemonic traces (Hunt & Einstein, 1981). Implicit learning has historically been thought to be closely tied to the surface features of the input stimuli for its inflexibility (Sperling, 1960). Tulving (1990) found priming diminishes when there are surface-level discrepancies between the study and test. Roediger (1987) also found priming is specific to stimulus features, such as shape or size between study and test items; changes in stimulus features results in decreased priming. In contrast, explicit learning has historically been considered to be highly flexible allowing transfer between various stimulus domains and modalities. Dienes and Berry (1997) concluded that implicit knowledge was often relatively inflexible in transfer to different domains (see also Cohen & Eichenbaum, 1993; Cohen, Poladrack, & Eichenbaum, 1997; Reber, Knowlton, & Squire, 1996; Squire, 1992, 1994; Stadler, Warren, and Lesch, 2002), which suggested implicit learning is unable to be updated from the existing learning. However, Willingham (1997) argued that the inflexibility of

implicit memory and the flexibility of explicit memory have been vastly over-stated, ignoring a great deal of evidence for flexible implicit memory and inflexible explicit memory. For example, motor skill learning, thought to be largely implicit learning, can be high flexibility as evidenced by good transfer under many conditions, including such things as the manipulation of effectors, scaling to different timing demands (e.g., Schmidt, 1988). Explicit memory shows inflexibility when participants are cued to think of one property of a word at encoding and later shown a retrieval cue that emphasizes a different property (Barclay, Bransford, Franks, McCarrell, & Nitsch, 1974). Accordingly, the extent of flexibility is not determined principally by whether it is implicit or explicit memory but more upon the experiment design (e.g., Stadler, 1997). A change between encoding and retrieval may cause inflexibility of memory if the change affects some parts of the representation that supported perceptual learning. Otherwise, the same transfer manipulation does not appear affect task performance (Kolers & Roediger, 1984; Morris, Bransford, & Franks, 1977; Tulving & Thomson, 1973).

Perceptual priming is considered to be implicit learning and implicit sequence learning tasks have also been used to examine perceptual flexibility. Willingham, Nissen, and Bullemer (1989) found that changing item colors in a perceptual learning condition may lead to an elimination of the learned response when participants were required to make a particular motor response according to item color; this task is primarily a perceptual rather than motor learning process. However, early artificial grammar learning studies performed by Reber (1969) suggest implicit learning is not necessarily perceptually inflexible. Participants' classification performance was significantly impaired by a change to the grammar, but not by a change to the letter set, in three

conditions of altered letters of strings, altered grammar, or both. In a similar experiment, participants who received a new letter set every week over a four-week period performed as well as control participants who received the same letter set throughout the experiment (Mathews, Buss, Stanley, Blanchard, Cho, & Druhan, 1989). Thus, it is problematic to assert that perceptual inflexibility is a defining feature of implicit learning.

It is worth mentioning that there is some debate over the clarity of these findings as some of the learning might not be entirely implicit. There are two considerations that have been proposed: (1) partial or correlated explicit knowledge might not have been measured by efficient awareness tests, and (2) the participants may transmit more information in their task performance than in tests of awareness since the performance tests are more sensitive to whatever conscious information was encoded (Tomiczek & Burke, 2008). Another argument against implicit flexibility is that adaptable manipulation of contingencies requires deliberation, especially when the complexity of the relationship increases (Clark & Squire, 1998).

The theory of relational learning provides a new account of flexibility in memory that does not propose awareness or deliberation were the critical factors for flexibility. Most learning occurs in settings wherein the details provide predictive context. Associations are bound such that learned relations are true in some contexts but not in others (Eichenbaum, 2007). However, a growing body of evidence suggests that implicit memory is able to encode context flexibly (Gross & Greene, 2007; Kristjansson & Campana, 2010; Ostreicher, Moses, Rosenbaum, & Ryan, 2010). Accordingly, recognition may be high even when explicit memory levels are low during or immediately after encoding and both implicit and explicit learning were found depend on

similar mnemonic process (Voss, Baym, & Paller, 2008; Voss, Lucas & Paller, 2010; Voss & Paller, 2008). Recent experiments suggested implicitly learned information can be context dependent and applied to novel situations (Greene, 2007; Greene, Gross, Elsinger, & Rao, 2007; Gross & Greene, 2007; Greene, Spellman, Dusek, Eichenbaum, & Levy, 2001; Leo & Greene, 2008; Reber, Luechinger, Boesiger & Henke, 2012). For instance, Greene et al. (2001) demonstrated that when participants were trained on context-dependent pairs (AB, BC, CD, DE), they were able to infer the relationship between items from a new, unstudied pair (BD). Thus, contextual relations may be elaborately encoded and available to both implicit and explicit processes.

A notable relational learning task of context-dependent implicit memory was developed by Chun and Jiang (1998). Participants were asked to locate rotated target “T” among distractor “L”s in each screen. Half of the arrays were repeated and half were novel. The configuration of distractors in repeated arrays serves as contextual information to cue target location. While participants improved on both trial groups indicating improved task skill, the effect of interest was that they quickly showed significantly faster reaction time (RT) for repeated than novel trials. Eye movement data also showed fewer fixations were required to find the target for repeated trials (Peterson & Kramer, 2001). Despite differential performance for novel versus repeated trials, participants showed no evidence of conscious recognition for any trials (Chun & Jiang, 1998, 1999; Chun & Jiang, 2003; Greene & Gross, 2007; Peterson & Kramer, 2001), even when they were informed of repeated arrays prior to experiment (Chun & Jiang, 2003).

Contextual cue learning may adapt to changes when participants learn multiple target locations (Conci, Zellin, & Müller, 2012). However, the contextual cueing effect

was not observed in several studies after targets were relocated within invariant context (Chun & Jiang, 1998; Chun & Olson, 2004; Conci, Sun, & Müller, 2011; Makovski & Jiang, 2010; Manginelli & Pollman 2009; Jiang, Swallow, Rosenbaum, & Herzig, 2013; Zellin, von Mühlenen, Müller, & Conci, 2013). A contextual cost is observed when the target is swapped to a distractor location (Conci et al., 2011; Makovski & Jiang, 2010; Hanson & Greene, 2011) or an empty location (Makovski & Jiang, 2010; Manginelli & Pollman, 2009; Zellin, Conci, von Mühlenen, Müller, 2011; Zellin et al., 2013).

Moreover, the cost is greater when the target is swapped with a distractor (Makovski & Jiang, 2010). For clearly understanding the mechanism, the eye movement was measured and showed that the swap distance between new and old target locations affected the contextual cueing effect differently. A far swap distance caused greater cost than a local swap (Makovski & Jiang, 2010). Zellin et al. (2011) offered two possible explanations for this phenomenon. One is that contextual cueing is essentially limited to single-target learning. Each old configuration can only be associated with one repeated target location (and its immediate surrounding; see also Makovski & Jiang, 2010). Other target locations are not guided by the same old configuration. The other explanation is that relocated targets are not expected to appear at previous empty locations for condition of swapping with empty locations (Jiang, Swallow, Rosenbaum, & Herzig, 2013; see Clark, 2013, for a theoretical approach to cognitive prediction models). In other words, the relocated target locations were not predictable, which could prevent their integration into the old configuration. However, two locations may be acquired but only via early exposure.

Other studies also presented similar views, suggesting participants form an implicit prediction about future occurrence of familiar visual events based on their

predictability (Beesley & Le Pelley, 2010; Dale, Duran, & Morehead, 2012; Reder, Weber, Shang, & Vanyukov, 2003; Turk-Browne, Scholl, Johnson, & Chun, 2010; see also Neider & Zelinsky, 2006, for more naturalistic scenes). It is reasonable to ask if participants are shown context without association with a target before context associated with a target, will the first unpredicted experience interfere with the performance of contextual learning? Jungé, Scholl and Chun (2007) manipulated the presentation sequence of predictable contexts (signal, target location was predictable) and unpredictable contexts (noise, target location was unpredictable) to see the interference of the initial prediction. One is the *signal first* condition, which consists of three predictable context epochs followed by one unpredictable context epoch before the test epoch. The other is the *noise first* condition, which is one unpredictable context epoch followed by three predictable context epochs. The results show only the signal first condition produces a subsequent contextual cueing effect. It suggests the initial prediction experience is critical for subsequent contextual learning and initial contextual cue learning unlikely to be updated. Similarly, in a recent study (Zellin, von Mühlénen, Müller, & Conci, 2013), the target locations of two predictable contexts exchanged after 3 epochs. Significant contextual cueing effect was observed after transiently influence right after the swap. The result suggests that initially learned implicit context-target associations were not affected by repeated presentations of relocated targets (see Zellin et al., 2013, for a comparable finding). In contrast, in a second group, the target locations were exchanged between predictable and unpredictable contexts. The contextual cueing effect was reversed and did not occur again during the entire exchange phase. It suggests that the initial unpredictable experience did interfere with the adaptation to relocated

target locations. Thus, the initial prediction experience greatly influences subsequent learning and this effect can last for a long period. The initial contextual cue learning seems cannot be updated which suggests such learning is not flexible.

If there are two target locations simultaneously present in the same context, can both locations be learned and predicted? Conci, Sun and Müller (2011) reported successful contextual learning of two predictable target locations presented within one invariant context. During their experiment, two targets were displayed in the same context simultaneously (one was oriented left/right, one was oriented upward/downward). Participants were asked to search for one type target in the first half of the experiment and then search for the other type target in the next half of the experiment. The results showed that the response change led to an overall slowing of RTs, but no significant reduction of the contextual-cueing effect. This suggests that both target locations are predictable when they appear simultaneously in the same repeated context. This also suggests multiple target locations can be learned for a single array (Brady & Chun, 2007; Chun & Jiang, 1998; Conci & Müller, 2012; Kunar & Wolfe, 2011). However, Zellin and Conci (2011) found no contextual cueing effect when invariant contexts were paired with three rather than one or two possible target locations. A capacity of the contextual cueing with multiple target locations exists.

Adaptation to global changes was observed by Jiang and Wagner (2004) when contextual cueing was sustained after the entire displays were resized suggesting contextual cue learning may be flexible. Similarly, relatively small and transient cost was observed after large-scale (i.e. global) change in natural scenes (Brockmole & Henderson, 2006). Together, the findings suggest a change of target-to-context relation may disrupt

contextual cueing, while global changes can be dynamically adapted to and compensated for (Conci, Sun, & Müller, 2011), which suggest old contextual cue learning can be updated. Thus, two distinct views exist. One view is that the initial contextual cue learning cannot be updated which suggests this learning is inflexibility. The other view is the initial contextual cue learning can be updated which suggests it is flexible. The flexibility or adaption of contextual cue learning may be dependent on the experiment design, and no consistent conclusion has been made.

The present investigation: a closer examination of changed contingencies as a test of flexibility. Recall that changing the target location in a particular array may (Chun & Jiang, 1998; Jiang and Wagner, 2004; Brockmole & Henderson, 2006), or may not result in new learning (Conci, Sun, & Müller, 2011; Hanson & Greene, 2011; Makovski & Jiang, 2010; Manginelli & Pollman 2009; Zellin, von Mühlennen, Müller, & Conci, 2013). The proactive interference of initial experience may make it difficult or impossible to adapt to the new association. The capacity to update and revise existing learning is perhaps a fundamental test of flexibility (Bo, Jenet, & Seidler, 2011). If it can be convincingly demonstrated that learning in the contextual cueing task can be recovered, it would be an excellent argument for flexibility in this task. Moreover, to fully understand the influence of proactive interference, a return can establish the persistence of initial learning (Zellin, von Mühlennen, Müller & Conci, 2013). If proactive interference prevents new learning, no significant contextual cueing effect will be observed when the target is relocated and then a return to the initial contingencies should come at little or no cost. Two studies reported that no significant contextual cueing effect was observed during the entire swapping phase but was observed immediately after target was returned

to its original location. This suggests the proactive interference interfered with new learning and preserved original target location searching, thus demonstrating no evidence of flexibility in the contextual cueing task (Hanson & Greene, 2011; Zellin, von Mühlennen, Müller & Conci, 2013). However, the preliminary results of one of these studies (Hanson and Greene, 2011) with similar learning and swap phase found significant contextual cueing effect during the swap phase, which suggests both target locations were learned. However, the one target location learning view also can explain this significant contextual cueing effect at the end of swap phase. That is, if one target location learning view is true, this significant contextual cueing effect might be caused by the arrays whose only new target locations were learned. Therefore, the conclusion of flexibility made by the overall RT may not be reliable. The mechanism of lack of behavioral cost is not clear.

The purpose of this study is to explore the flexibility of contextual cueing learning by investigating the mechanism underlying the lack of behavioral cost observed upon reversal. Accordingly, we examined two possible explanations for this absence of behavioral cost. One is that the contextual cue learning can be updated from the initial learning to acquire both target locations. Which would suggest implicit learning is flexible. The second is the contextual cue learning cannot be updated from the initial learning but perseverates on the initial target location, which would suggest implicit learning is inflexible. To fully understand these issues, we measured eye movements and RT while participants performed a contextual cueing task in which the target location was first in one location (learning phase) then it was moved to a diagonal quadrant by swapping with a distractor (swap phase) then eventually returned to its initial location

(return phase). We chose to use eye movement measurement because of the following reasons: First, experience-dependent eye movement can represent implicit memory without awareness (Conci, & Mühlénen, 2011; Hannula & Ranganath, 2009; Peterson, & Kramer, 2001; Ryan, Althoff, Whitlow, & Cohen, 2000). Second, only eye movement data can indicate if eye kept searching the original target location when target was relocated. Third, overall RT was not able to represent original and new target location learning separately.

The present study tested two hypotheses. One hypothesis is that participants may update their initial learning to acquire both target locations, which supports the flexibility, If this hypothesis is true, than it is expected that: 1) RT for relocated repeated configurations will decrease over time and a significant contextual cueing effect would be observed at the end of swap phase; and participants' search strategy should not prioritize the initial target location. The other hypothesis is that participants cannot update the initial learning and consequently only learn one of the two target locations can be learned which supports the inflexibility. If this hypothesis is true, then it is expected that a significant decrease in RT for relocated repeated configurations is unlikely to occur in swap phase; and participants' search strategy should always prioritize initial target location.

Method

Participants

Thirty-two participants (16 males and 16 females), between the ages of 19 and 31, were recruited from the University of Wisconsin-Milwaukee. They participated for extra credits or as paid volunteers (\$10 per hour for 2 hours). All participants had normal color

vision and were able to search targets on display with naked eyes. Fourteen participants were unable to complete the task due to a technical problem with eye-tracker calibration. Three fell asleep during the task. All analysis was based on the data of 18 participants.

Materials and Procedure

Materials. The visual stimuli were similar to those used by Chun and Jiang (1998). One target and 11 distractors appeared on each screen. The target was a 90° or 270° clockwise rotated “T”, meaning its stem pointed to the left or right (see Figure 1). The lengths of two lines making up the “T” were the same, with visual angle of 1.88° tall and wide. Distractors were 0° and 180° rotated normal or mirrored-imaged “L”s. The lengths of two lines of the “L” were the same tall and wide as the target. The horizontal line of the “L” exceeded 20% out of the vertical line, so that “L”s were somewhat similar to the “T”, but still could be recognized as an “L” (Duncan & Humphreys, 1989). The colors of the targets and distractors were randomly assigned for each trial, including blue, green, red and yellow. Each color was equally represented in each array. The backgrounds were set as gray (Chun & Jiang, 1998, Chun & Phelps, 1999).



Figure 1. Sample of an array used in this study. One target and 11 distractors appeared on each screen. The target was a 90° or 270° clockwise rotated “T”, meaning its stem pointed to the left or right. Distractors were 0° and 180° rotated normal or mirrored-imaged “L”s. The colors of the targets and distractors were randomly assigned for each array, including blue, green, red and yellow. Each color was equally represented in each array. The backgrounds were set as gray.

The entire array subtended a visual angle of 36.8×23.5 degrees when measuring from 24 inches from the display. The array was divided into an invisible 8×6 grid, consisting of four 4×3 quadrants. No items would appear in the central four slots around the fixation cross and four slots in the corners (Brady & Chun, 2007). One target and 11 distractors items were distributed into these 40 slots with three items in per quadrant. Three target locations were assigned for each quadrant. In order to prevent collinearities with other stimuli, all items randomly jittered within slots in steps of 0.2° with a range of $\pm 0.8^\circ$ along the vertical or horizontal axis. Arrays had been generated by the Presentation[®] program, and visually were checked. Any arrays with two stimuli being closer than a visual angle of 2.7° were discarded (Peterson and Kramer, 2001). This provided at least 0.5° so the eye-tracker can distinguish two close fixations, so the fixations to nearby the objects could be differentiated.

This experiment used an “ABA” design to manipulate the predictability of the target location. A given repeated array had a predictable target location throughout phase A_1 , then the new location for all of phase B, and then the target was returned to its original location for that last A_2 phase. A total of 27 blocks were divided into the three phases, with each phase consisting of three epochs and each epoch consisting of three blocks (c.f., Chun & Phelps, 1999). Each block consisted of 12 repeated arrays and 12 novel arrays, for a total of 648 trials for the whole experiment. The repeated arrays maintained the color and location for each distractor and target, but the orientation of the target was randomized to prevent participants from simply learning to respond “left” or “right” to particular arrays. Each novel trial consisted of an array that appeared only once throughout the experiment. The colors and orientations of all stimuli were randomly assigned. To rule out the location probability effect (a repeated array could accidentally be identical to a novel array), 12 particular locations were used for targets in repeated configurations and 12 separate locations were used in novel configurations without overlap (c.f., Chun & Phelps, 1999). The target would appear equally in each of 24 locations throughout the experiment, so the target location likelihood would not affect performance. For counterbalancing, the set of locations for repeated configurations would be swapped with the set of locations for novel configurations for half of the participants.

The first three epochs was designated as the phase “ A_1 ”. In phase A_1 , the 12 repeated configurations appeared once per block from Block 1 to Block 9 along with 12 novel arrays in each block. The presentation sequences of the 12 repeated arrays and the 12 novel arrays in each block were random throughout the experiment. During the following three epochs (Block 10 -18, designated phase “B”), all the repeated arrays were

modified by swapping the target with a single distractor in each diagonal quadrant. The colors were bound to locations. For example: If the target was a red “T” and swapped with a green distractor “L”, then, the new “T” would be green and the “L” will be red. The orientation of the distractor was preserved but the orientation of target was still randomly assigned. Also, to avoid the possible overlap of target locations, the swapped distractor’s location did not overlap with any target location. In phase A₂, the targets in repeated configurations returned to their original locations.

Procedure. The distance between the participants’ eyes and display was 24 inches. The participants were given a short oral instruction about the visual search task. A color photocopy of a sample configuration was shown so that participants saw how targets and distractors were. They were not informed about the repetition of some arrays and not asked to explicitly memorize arrays. All participants were asked to search for the targets only and respond as quickly and accurately as they can.

Each trial began with a central fixation cross and participants were asked to keep their eyes on the cross (see Figure 2). When the participants’ eyes located within 2.5° around the cross for one second, the experimenter pressed the space bar to start the trial. The test array with stimuli appeared on the screen without pause then participants started to search the targets among distractors. If the stem of target “T” pointed to left, participants should press “1” on keyboard. If it pointed to right, “2” should be pressed. The search time was also unlimited. A 1000ms visual feedback was given to participants after they made response. A green capital “CORRECT” indicated correct response, and a red capital “INCORRECT” indicated an incorrect response. Then a fixation would appear

again for next trial without break. A 10s mandatory break was given at the end of each complete block. Recalibration was given before each block or when it was necessary.

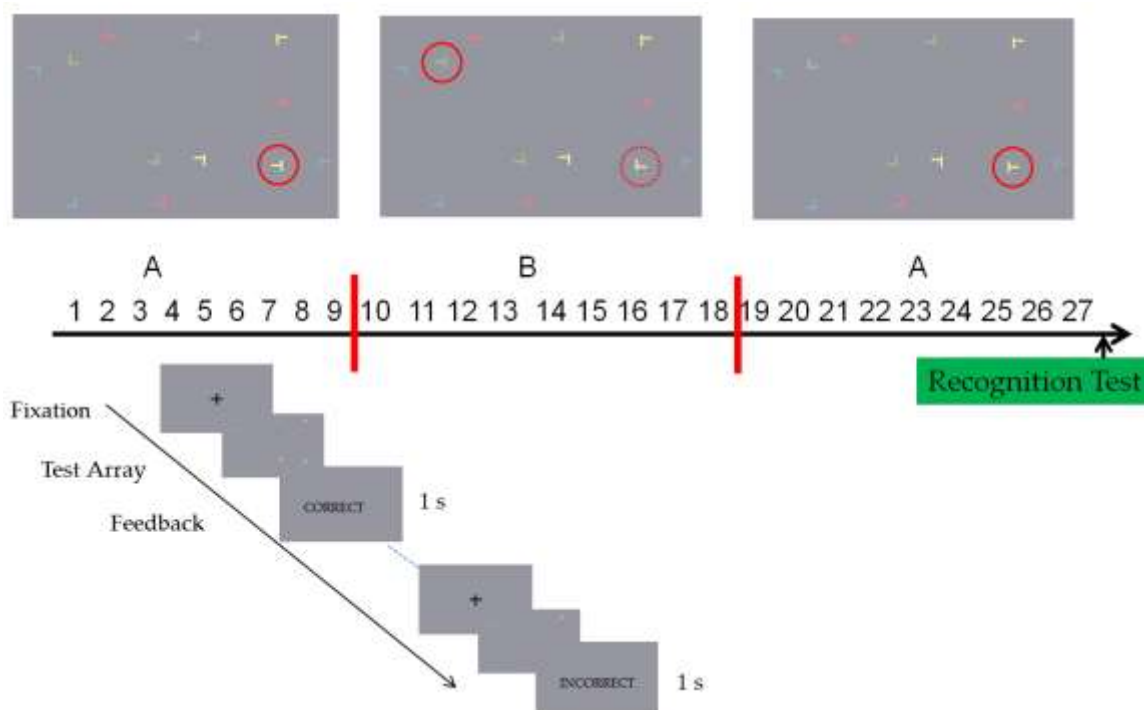


Figure 2. Schematic of the searching task and experimental procedure used in this study. (a) This contextual cueing task consisted of 27 blocks and a recognition test. In each block, 12 repeated arrays appeared once per block along with 12 novel arrays. The presentation sequences of the 12 repeated arrays and the 12 novel arrays in each block were random throughout the experiment. The three groups of 9 blocks were successively designated as the phase A₁, B and A₂. During phase B, each repeated array was modified by swapping the target with a single distractor from the quadrant diagonal to the original target location. The colors were bound to locations. The orientation of the distractor was preserved but the orientation of the target was still randomly assigned. Also, to avoid the possible overlap of target locations, the swapped distractor's location did not overlap with any target location. The filled-line circle indicates the target location and dotted-line circle indicates the previous target location in the phase B. During phase A₂, the targets in repeated arrays returned to their initial locations. (b) Each trial began with a central fixation cross. When the participants' fixation fell within 2.5° around the cross for one second, the experimenter would press the space bar to begin the trial. The duration of the fixation was not limited. After fixation, the test array with stimuli appeared on the screen without pause, then participants started to search the targets among distractors. If the stem of target "T" pointed to left, participants should press "1" on keyboard. If it pointed to right, "2" should be pressed. The search time was also unlimited. A 1000ms visual feedback was given to participants after they made response. A green capital "CORRECT" indicated correct response, and a red capital "INCORRECT" indicated an incorrect response.

A computer-based recognition test was given to participants at the end of experiment. Before they began the recognition test, they were informed that some configurations were repeatedly presented from block to block in the previous task. The first question appearing on the screen was “Did you notice any configurations repeated from block to block? 1-Yes, 2-No”. If the answer was “No”, the recognition test was active. If the answer was “Yes”, the following question was “Did you explicitly try to memorize the patterns? 1-Yes, 2-No.” The recognition ensued no matter whether the answer was “Yes” or “No”. The recognition test was one block (24 trials) of visual recognition consisting of 6 random repeated configurations from phase A, 6 random repeated configurations from phase B, and 12 completely novel configurations they had never seen before. Participants were instructed to respond “1 - I have never seen it before” if they did not recognize this configuration or “2 - I have seen it before” if they thought this configuration occurred in the initial task. No feedback was given.

The fixation was defined as a discrete pause of the eyes on a display. A successfully recorded single fixation met the requirement of less than 1° of gaze position change combined with a minimum duration of 100ms. If fixation landed within 1.3° from a stimulus, it was counted as landing on the stimulus.

The model of 19-inch LCD monitor was AUSU[®] VW198, with resolution was set as 1280×800 . Eye movement was recorded by ASL EYE-TRAC[®]6 with a 0.5° spatial resolution. Computer was the Intel[®] Core™ i5 650@320GHz. Operation system was Window XP[®] Service Pack 3. Data was analyzed by SPSS[®] 21.

Results

Data Elimination

This study eliminated 1.67% of trials due to incorrect responses; 1.00% of trials because RTs were longer than 3.0 standard deviations of the mean RT for each block for each array; 6.83% trials because the viewing time was shorter than 65% of the corresponding RT; and 0.21% of trials due to the four minimal trials requirement for per array (repeated and novel) in each block (e.g. If there are 3 repeated trials and 8 novel trials left for block 2, because the number of repeated trial is less than four, which may make the comparison unreliable, so all trials left in such unqualified blocks were completely excluded). Overall 90.29% trials remained after elimination.

Recognition Test

The hit rate of repeated array was 45.37%. The false alarm rate of novel arrays was 43.06%. There was no significant difference between hit rate (mean = 0.454) and false alarm rate (mean = 0.431; $p = 0.785$, Cohen's $d' = 0.092$). The accuracy for novel arrays was higher than repeated arrays ($t_{(34)} = 2.378$, $p = 0.023$), but the accuracies for both conditions were not significantly different from chance (Novel: $p = 0.274$; Repeated: $p = 0.430$). Therefore, awareness was not observed (see also Chun & Jiang, 1998; Chun & Phelps, 1999; Chun & Jiang, 2003; Greene, Gross, Eichenbaum, & Levy, 2007; Peterson & Kramer, 2001; Manginelli & Pollmann, 2009; Zhao, Liu, Jiao, Li & Sun, 2012).

Target Detection: Behavioral response

Figure 3 shows the mean RTs across epochs for each array condition (novel vs. repeated) based on the mean RTs for each participant. A behavioral cost of RT for

repeated arrays is readily seen right after the target was swapped in epoch 4, but such behavioral cost was not observed after the target was returned in epoch 7. Significant contextual cueing effect was observed during all three phases. This suggests both the original and new target locations might be learned. However, because the one target location learning is possible, so the overall RT was not able to represent the original and new target location memories separately, accordingly, the significant contextual cueing effect of the last epoch of swap phase might be caused by the repeated arrays in which only the new target location were learned. No reliable conclusion of flexibility can be made.

A 2 (arrays: repeated vs. novel) \times 9 (epoch) repeated measure analysis of variance (ANOVA) yielded significant main effects of epoch ($F_{(8, 136)} = 9.590, p < 0.001$) and array ($F_{(1, 17)} = 47.330, p < 0.001$). No significant interaction between epoch and array ($p = 0.133$) was observed. This indicates the swap and return did not significantly affect the RT of repeated and novel arrays separately entirely. This result is consistent with a previous finding (Zellin, von Mühlennen, Müller, & Conci, 2013).

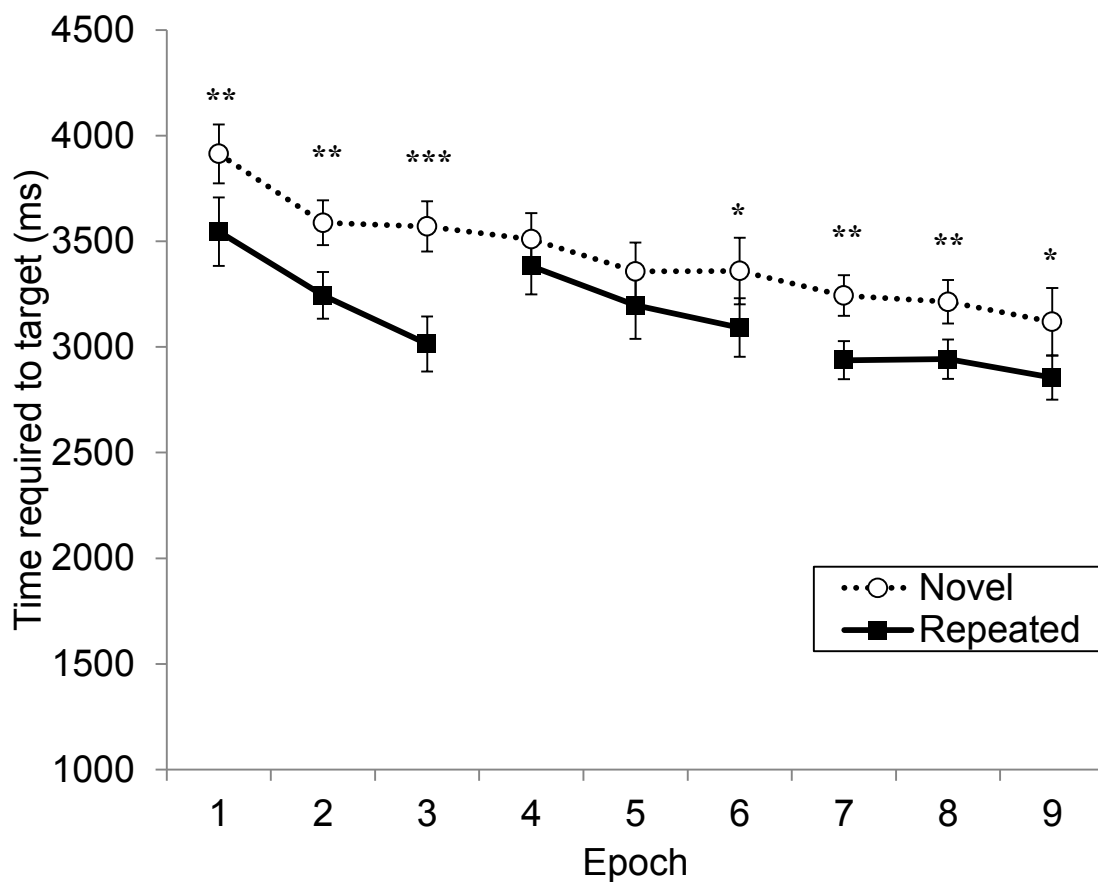


Figure 3. Mean reaction times (RTs; in ms with associated standard errors) of novel and repeated arrays across epochs. Epochs 1-3 represents phase A₁; epochs 4-6 represents phase B and epochs 7-9 represents phase A₂. Unfilled circles and filled squares respectively represent novel and repeated conditions. Error bars represent the standard error of the mean. Asterisk represents significant contextual cueing effect. * $p < 0.05$; ** $p < 0.01$.

To investigate the behavioral cost, a 2 (array) \times 2 (epoch) repeated measure ANOVA between epoch 3 (last epoch of learning phase) and epoch 4 (first epoch of swap phase) was conducted. This ANOVA yielded an significant interaction between epoch and array ($F_{(1, 17)} = 17.227$, $p = 0.001$) and a main effect of array ($F_{(1, 34)} = 17.486$, $p = 0.001$). The main effect of epoch was not significant. This suggests the swap influenced the RT for repeated and novel arrays differently. The RT for repeated arrays changed from faster than novel arrays in epoch 3 ($t_{(17)} = 5.777$, $p < 0.001$, Cohen's $d' = 1.052$) to

not significant different in epoch 4. The RT for repeated arrays became slower after the swap ($t_{(17)} = -2.501$, $p = 0.023$) while the RT for novel arrays became not significantly faster.

To investigate the lack of behavioral cost after return, another 2 (array) \times 2 (Epoch) repeated measure ANOVA between epoch 6 (last epoch of swap phase) and epoch 7 (first epoch of return phase) was carried to see if there was a similar behavioral cost after return as from epoch 3 to epoch 4. Unlike the finding for the swap, no significant interaction between epoch and array and no significant main effect of epoch were observed. The main effect of array was also significant ($F_{(1, 34)} = 15.538$, $p = 0.001$). This suggests the return did not influence the RT for repeated and novel differently. Significant contextual cueing effect was observed in both epochs 6 ($t_{(17)} = 2.733$, $p = 0.014$, Cohen's $d' = 0.426$) and 7 ($t_{(17)} = 2.994$, $p = 0.008$, Cohen's $d' = 0.776$). The RT for repeated arrays did not become slower as happened after swap, but inversely, significantly faster than novel arrays in epoch 7. The facilitation of searching for repeated arrays kept from epoch 6 to epoch 7. No significant difference between epochs 3 and 7 was found for repeated arrays, which suggests the searching for repeated arrays was preserved after the swap phase. However, as mentioned above, the significant contextual cueing effect might be caused by repeated arrays in which only the new targets were learned, further investigation with eye movement will be conducted.

To clarify the exact RT changes right after the swap and after the return, an analysis of the mean RT performance for each array across blocks was conducted (see Figure 4). Significant RTs differences between novel and repeated conditions were observed from block 3. An interaction between block and array ($F_{(1, 17)} = 4.912$, $p =$

0.041) was observed between block 9 (last block of learning phase) and block 10 (first block of swap phase) but not between block 18 (last block of swap phase) and block 19 (first block of return phase; $p = 0.862$). This also suggests the RT of repeated and novel arrays were affected by the swap but not the return.

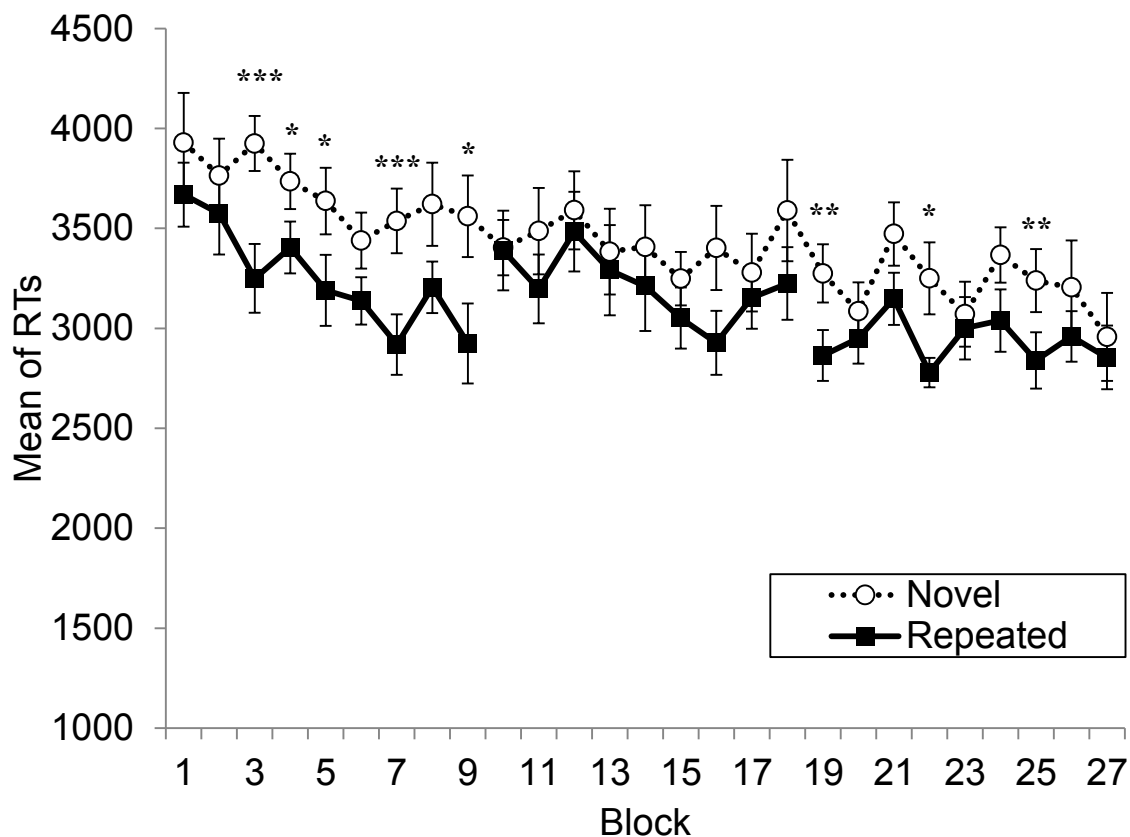


Figure 4. Mean reaction times (RTs; in ms with associated standard errors) of novel and repeated arrays across blocks. Block 1-9 represents phase A₁; blocks 10-18 represents phase B and blocks 19-27 represents phase A₂. Unfilled circles and filled squares respectively represent novel and repeated conditions. Error bars represent the standard error of the mean. Asterisk represents significant contextual cueing effect. * $p < 0.05$; ** $p < 0.01$.

The RTs for repeated arrays were faster than novel arrays in block 9 (the last block before swap; $t_{(17)} = 2.353$, $p = 0.031$) and block 19 (the first block after return; $t_{(15)}$

= 3.482, $p = 0.003$), but not in block 10 (the first block after swap) and block 18 (the last block after swap). No significant difference of RT was observed for repeated arrays between blocks 19 and 9.

Eye movement

Division of arrays. As described in the introduction, all the new contextual cues might not be learned successfully for the reasons of contextual differences and varied context designs. In the last epoch of phase B, for each individual participant, some of the new contextual cues might be learned after swap, and these target predictions would lead eyes to the new target locations without searching the original target location areas (Did not search the original target quadrant (NSO) array). Some of the new contextual cues may be unsuccessfully learned after swap, and eyes might keep searching the original target location areas after swap (search the original target quadrant (SO) array). The 12 repeated arrays were categorized for each participant, based on the criterion of whether there were any fixations landed on the original target quadrant during the last epoch of phase B. That is, if there was no fixation landed on the original target quadrants in epoch 6 (last epoch of phase B), then this array was categorized as NSO array for this participant, otherwise it was SO array. We found an average of only 18.45% of repeated arrays were in the NSO array and 81.55% were in the SO array, which meant the new contextual cues in very few repeated arrays could be implicitly learned. Therefore, for each participant, nearly 2 out of 12 new contextual cues were successfully learned during the phase B, and these arrays were categorized as NSO array in each block or epoch for comparing with the novel array, as well as SO array.

Mean RTs of Novel, SO and NSO array across Epochs. Figure 5 shows the RTs changes of novel, SO and NSO arrays across epochs. For major repeated arrays-SO arrays, no significant contextual cueing effect was observed during the entire swap phase, but during learning and return phase. This suggests only the original target location of the SO arrays were learned, which supports the one target location learning hypothesis. For the NSO array, significant contextual cueing effect was only observed during the swap phase, but not during the learning and return phase. This suggests only the new target location for NSO arrays were learned, which also supports the one target location learning hypothesis. Therefore, the significant contextual cueing effect observed in the last epoch of swap phase for overall RT might due to the NSO arrays.

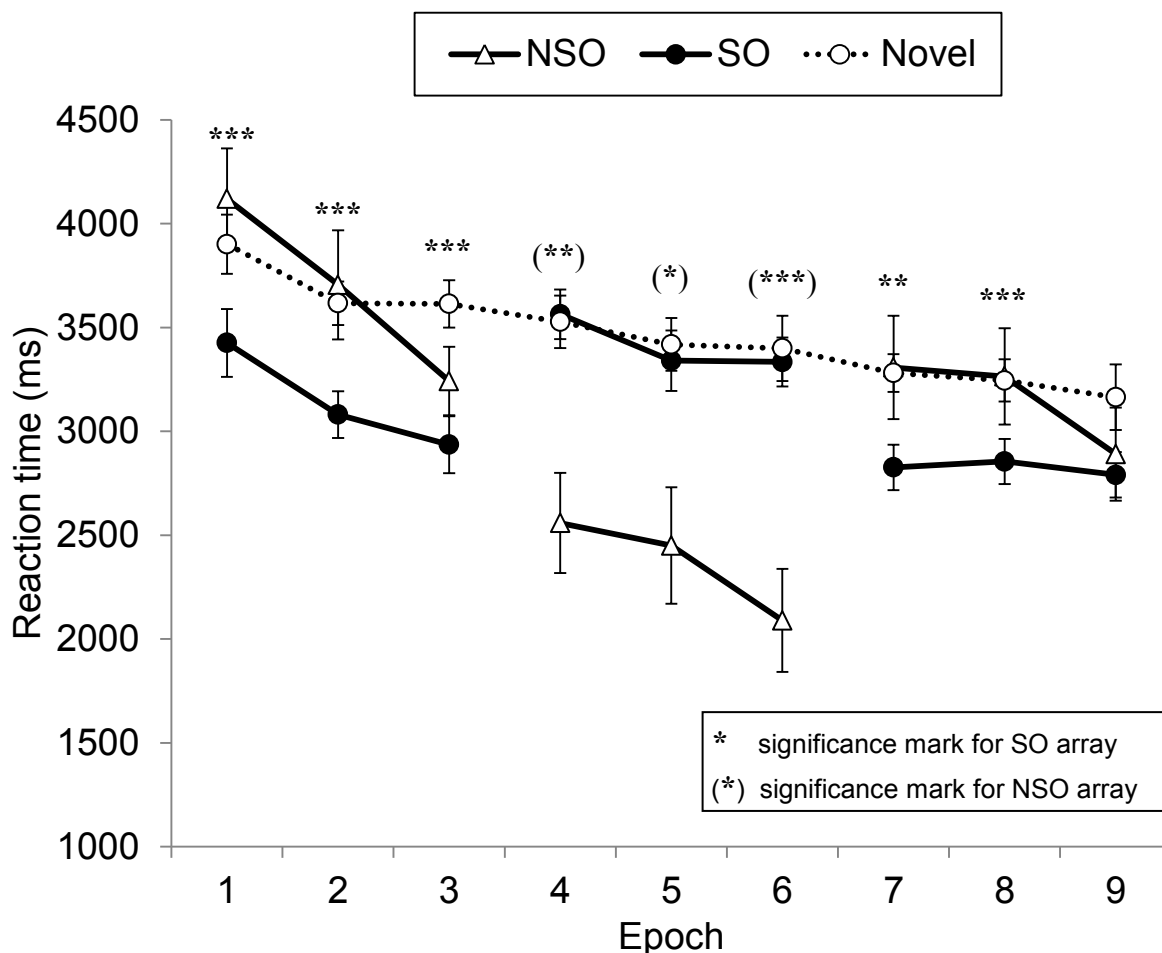


Figure 5. Mean reaction time (RTs; in ms with associated standard errors) across epochs (Novel vs. SO vs. NSO array). Epochs 1-3 represents phase A₁; epochs 4-6 represents phase B and epochs 7-9 represents phase A₂. Unfilled circles, filled circle, and unfilled triangle respectively represent novel, SO, and NSO arrays. Error bars represent the standard error of the mean. Pairwise comparisons between RTs for SO and novel arrays and NSO and novel array were computed for each epoch. Asterisk represents significant contextual cueing effect for SO array. The asterisk in brackets represents significant contextual cueing effect for NSO array. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. (Bonferroni-corrected significance level: $p < 0.0167$).

Since the SO arrays are the major repeated arrays, it's much reliable to analysis the SO arrays to clarify the mechanism of lack of behavioral cost. For the SO arrays, significant interactions between array and epoch was yielded for epochs 3 and 4 ($F_{(1,17)} = 27.372$, $p < 0.001$), and epochs 6 and 7 ($F_{(1,15)} = 15.106$, $p = 0.001$), which suggests the RT for SO and novel arrays were influenced by both swap and return differently.

Pairwise comparisons showed, from epoch 3 to 4, the RT for SO arrays changed from significantly faster (678ms) ($p < 0.001$) to not significantly slower (36ms) than novel array. From epoch 6 to 7, the RT changed from not significantly faster (65ms) to significantly faster (455ms) than novel array after target return to the original location ($p = 0.007$). No significant RT differences were found when comparing epoch 3 and epoch 7. This confirms the only the original target locations for SO arrays were learned.

Same conclusion was made by the NSO arrays. Significant interactions between array and epoch was also yielded for epochs 3 and 4 ($F_{(1, 15)} = 7.316$, $p = 0.016$), and epochs 6 and 7 ($F_{(1, 15)} = 10.606$, $p = 0.005$), which suggests the RT for NSO and novel arrays were also influenced by both swap and return differently. In contrast to SO array, from epoch 3 to 4, the RT for NSO array changed from not significantly faster (372ms) to significantly faster (969ms) ($p = 0.009$) than novel array. From epoch 6 to 7, the RT changed from significantly faster (1311ms) ($p < 0.001$) to not significantly slower (26ms) than novel array after return. No significant RT differences were found when comparing epoch 3 and epoch 7. This also confirms the only the original target locations for SO arrays were learned.

The following eye movement analysis is based on the major repeated arrays-SO arrays.

Mean number of fixations required to find the target. Figure 6 shows the mean number of fixations required to find the target for novel and SO arrays. Significant interactions between array (SO, novel) and epoch (epochs 3, 4; epochs 6, 7) were found after both swap and return ($F_{(1, 17)} = 26.802$, $p < 0.001$; $F_{(1, 17)} = 9.201$, $p = 0.008$). Significant main effects of epoch but not array were also found after swap and return ($F_{(1,$

$t_{(17)} = 10.660, p = 0.005; F_{(1, 17)} = 4.973, p = 0.040$). With manipulation of swap, paired t-tests showed the number of fixations for the SO array changed from less ($t_{(17)} = -5.124, p < 0.001$) to more ($t_{(17)} = 2.370, p = 0.030$) than novel arrays, and keeping this significance throughout the rest of phase B (epoch 5: ($t_{(17)} = 2.496, p = 0.023$); epoch 6: ($t_{(17)} = 2.891, p = 0.010$)). After return, this number became significantly less than novel ($t_{(17)} = -2.366, p = 0.030$) and not significantly different from epoch 3.

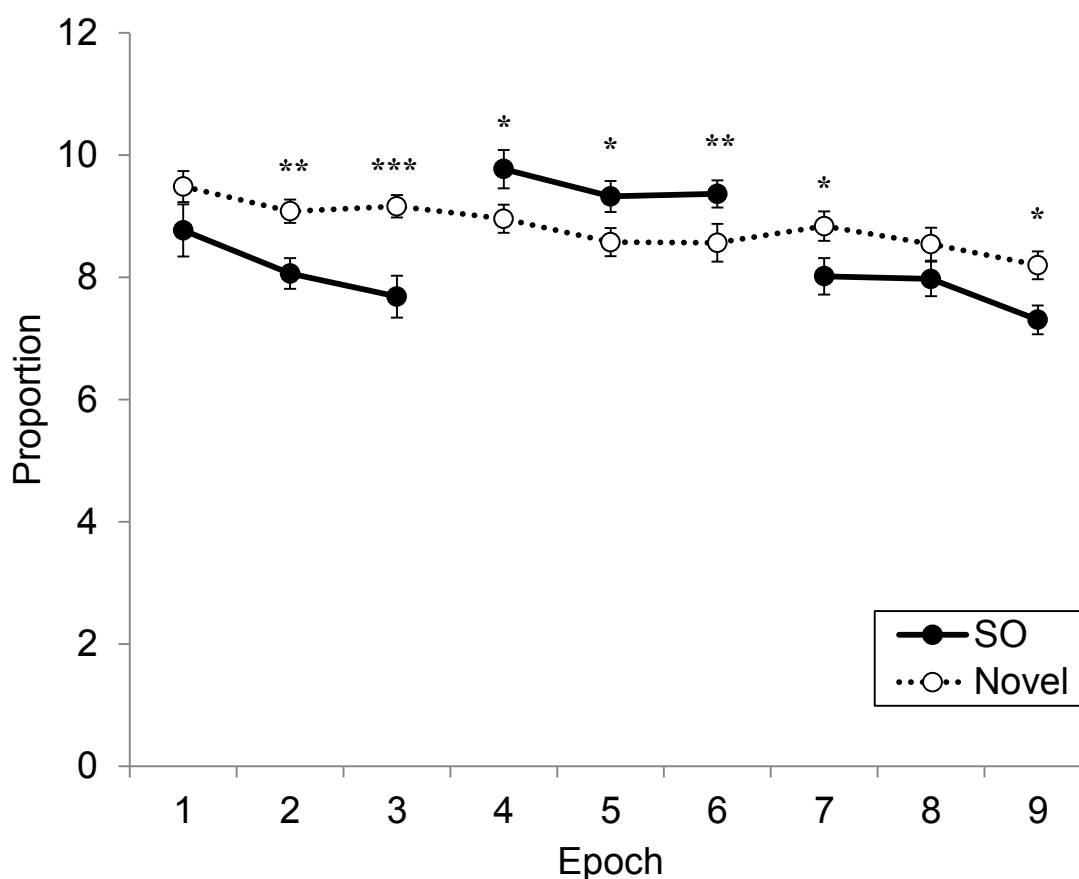


Figure 6. Mean number of fixations required to find targets (SO array). Epochs 1-3 represents phase A₁; epochs 4-6 represents phase B and epochs 7-9 represents phase A₂. Unfilled circles and filled circle respectively represent novel and SO arrays. Error bars represent the standard error of the mean. Paired t-tests between number of fixation for SO and Novel array were conducted for each epoch. Asterisk represents significant contextual cueing effect. * $p < 0.05$; ** $p < 0.01$.

Proportion of trials searching the diagonal quadrant to the target quadrant. Figure 7 shows the proportion changes of trials searching the proportion of trials searching the diagonal quadrant to the target quadrant across epochs for SO array. A significant increase from 63.92% to 73.87% after swap ($t_{(17)} = -3.774$, $p = 0.002$) for this proportion. Then during the phase B, the proportion kept increasing from 63.92% to 83.20%. In contrast, after targets returned to the original locations, the proportion significantly decreased from 83.20% to 64.99% ($t_{(17)} = 2.137$, $p = 0.040$). No significant difference was found between epoch 3 and epoch 7. It suggests participants still searched the original target quadrant after the target swapped and this behavior lasted for the whole swap phase.

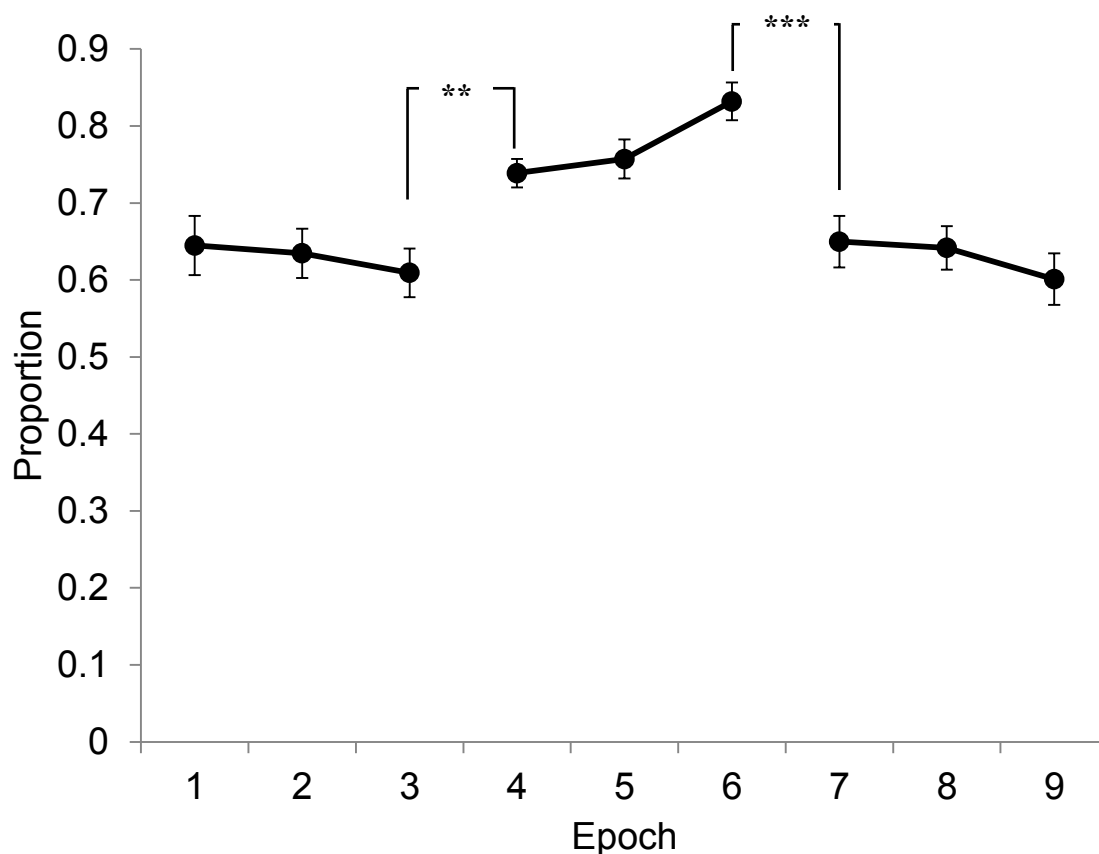


Figure 7. Proportion of trials searching the diagonal quadrant to the target quadrant for SO arrays. Epochs 1-3 represents phase A₁; epochs 4-6 represents phase B and epochs 7-

9 represents phase A₂. Filled circle represent SO arrays. Error bars represent the standard error of the mean. Paired t-tests between proportions for epoch 3 and 4, and epoch 6 and 7 were conducted. Asterisk represents significant difference between two epochs. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Proportion of trials in which the target was found by the first saccade. Figure 8 shows the proportion change of the SO trials in which the target was found by the first saccade across epochs for the SO array. The proportion significantly decreased from 15.07% to 8.21% after the swap ($t_{(17)} = 2.488$, $p = 0.024$). Then during the phase B, the proportion kept decreasing from 8.21% to 4.22%. In contrast, after targets returned to the original locations, the proportion significantly increased from 8.21% to 15.12% ($t_{(17)} = -3.641$, $p = 0.002$). No significant difference was found between epoch 3 and epoch 7. It suggests the swap manipulation did interfere with the accuracy of initial fixation and eyes still kept fixating directly at the target locations after the swap phase.

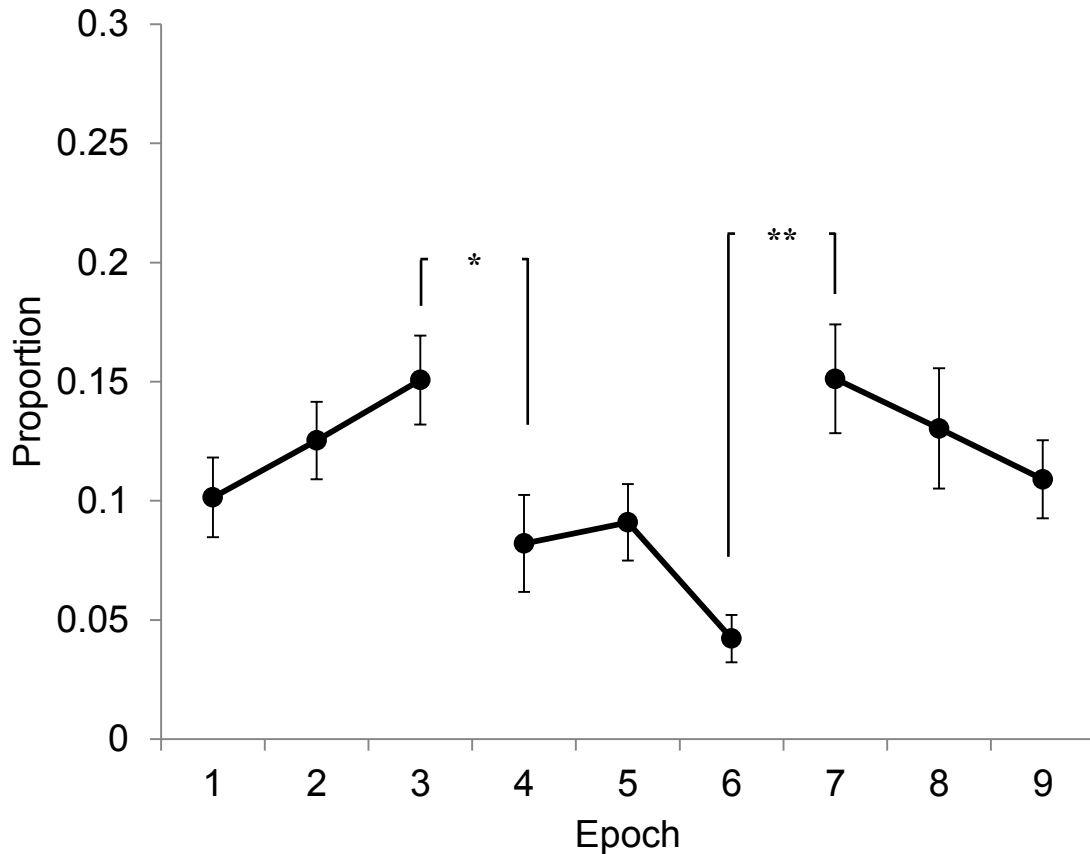


Figure 8. Proportion of trials in which target was found by the first saccade in SO arrays. Epochs 1-3 represents phase A₁; epochs 4-6 represents phase B and epochs 7-9 represents phase A₂. Filled circle represent SO arrays. Error bars represent the standard error of the mean. Paired t-tests between proportions for epoch 3 and 4, and epoch 6 and 7 were conducted. Asterisk represents significant difference between two epochs. * $p < 0.05$; ** $p < 0.01$.

Discussion

The present study replicates the previous findings wherein a behavioral cost is observed after a target swapped with a diagonal distractor, but no such cost is observed when the target return to the initial location (Hanson & Greene, 2011; see also Conci et al., 2011; Makovski & Jiang, 2010). RT data showed two effects of great interest: 1) No significant contextual cueing effect was observed until the last epoch of the swap phase (B); 2) when the target returns to its initial location (A₂), facilitation returned

immediately to previously observed levels (end of phase A_1). Analysis of RT and eye-movement data showed the mechanism of both effects is proactive interference. During phase B, participants continued to prioritize their search to the original target location for most arrays. This accounts for behavioral cost after the swap and immediate facilitation after the return. Thus, no evidence was found to support the flexibility of implicit learning.

It is well established that implicit expectation of target location directs one's gaze quickly to the target location with minimal searching in other locations; this leads to such things as faster searching time, fewer fixation and higher accuracy of initial fixation (e.g., Peterson and Kramer, 2001). Fundamental to this study is the method of dividing the repeated context arrays into those where new target locations were not learned (searched original target location during the last epoch of swap phase (B); SO) and those where new target locations were learned (did not search original target location during the last epoch of swap phase (B); NSO) arrays, then see whether in the last epoch of the learning phase (A_1) the original target location for SO/NSO arrays were learned or not. If the original target location was learned in the learning phase (A_1) and the new target location was not learned in the swap phase (B), this would suggest that proactive interference took place. In this study, at the end of the swap phase (B), if a given new target location was learned, the eyes should prioritize the location around the new target without searching the original target location which was in the diagonal quadrant. That is, the search strategy during the last epoch of phase B was used to sort arrays into the SO and NSO categories used for analysis of all learning epochs.

Proactive interference was observed for most arrays: in only around 2 out of 12 repeated arrays, participants found the new target without searching the original target quadrants during the last epoch of phase B and were accordingly categorized as NSO arrays; the other 10 repeated arrays were categorized as SO arrays. Interestingly, for the NSO arrays, the target was successfully learned in phase B, but their original target locations in phase A₁ were not. Thus proactive interference was not evident in these arrays during phase B only because no prior learning in phase A₁ had taken place. Additionally, for NSO arrays, the target location was not learned in phase A₂. Similarly, the new target locations in phase B for SO array were not successfully learned but the original target locations were successfully learned. The absence of a behavior difference between epoch 3 and epoch 7 for both arrays also confirmed this. It appears that for any given array, only one target location can be learned, sometimes in phase A₁ and sometimes in phase B.

The current findings confirm the hypothesis that contextual cueing is essentially limited to one-target learning (Zellin, von Mühlennen, Müller, & Conci, 2013). Once the target location is learned, it interferes with subsequent learning for a long period (Jungé, Scholl, & Chun, 2007; Zellin, et al., 2013). The existence of proactive interference caused by initial learning seems to protect initial learning (A₁ and A₂) and prevents the updating of the new contextual cue learning, this suggests the learning in this task cannot flexibly adapt to the new context-target association. Initial learning (phase A₁) supports an immediate resumption of facilitation in the return phase (phase A₂), because no adaption to the new context was observed during the entire swap phase (B) for SO array.

A more detailed examination of RT and eye-movement data during different phases of the task provides support for the hypothesis that only a single target location may be learned. As expected, by the third block, a reliable contextual cueing effect was observed, which is consistent with previous reports of early contextual cueing effect (Conci & von Muhlenen, 2009; Martina, von Mühlenen, Müller, & Conci, 2013).

Immediately after the swap, an abrupt increase of RT suggests proactive interference, and several measures of eye-movement demonstrate a search priority for the original target location: 1) in this phase, proportion of trials searching the diagonal quadrant to the target quadrant confirmed the eyes continue to search the original target location; 2) similarly, the initial saccade was unlikely to locate the target.

During the swap phase (B) the RT data show that learning proceeds but not to the extent observed in phase A_1 , only reaching significance by the last epoch of the phase. However, eye-movement data, particularly the SO-NSO categorization, demonstrate that this is driven entirely by the small proportion of arrays wherein no learning occurred during the initial learning phase (A_1). For the majority of arrays (SO) eye-movement demonstrates that initial learning perseverated and prevented learning the new target location as evidenced by the proportion of trials searching the original location and the location of the initial saccade.

In the return phase (A_2), the priority of the original target search led to an immediate facilitation. Moreover, that no difference in RT was detected between epoch 3 and epoch 7 suggested the initial learning was sustained over the entire swap phase (B). Eye-movement further revealed that the proportion of trials spent searching the diagonal

quadrant compared to the target quadrant and that detecting the target by initial saccade were all sustained during the swap phase (B).

For the NSO arrays, the contextual cueing effects were only observed in swap phase (B) but not initial (A_1) or return phases (A_2). That is, for NSO arrays, only the new target location in the swap phase (B) was learned. After target returned to its initial location (A_2), the RT performance of NSO array returned to levels observed in the initial phase (A_1) where performance no learning had occurred (NSO arrays did not differ from novel arrays in either phase A_1 or phase A_2). These findings provide no evidence for flexibility in this relational learning task.

These findings do not contradict but support previous studies that showed the multiple target locations learning when targets are simultaneously presented in the same contexts (Conci, Sun, & Müller, 2011) or new target locations subsequently presented in repeated contexts (Zellin & Conci, 2011). Because both target locations were predicted during the learning phase, only transient interruption was observed. Moreover, in these studies, the targets were relocated to empty locations while other distractor locations were invariable. This manipulation made it easier for participants to relearn the new contextual cues than in present study (Makovski & Jiang, 2010). However, some reports of quick adaptation to global changes were reported (Chun & Jiang, 1998; Jiang & Wagner, 2004; Brockmole & Henderson, 2006). Together, with the present findings, it appears that the capacity for flexibility in the contextual cueing task depends largely on the particulars of the task demands.

For further support of this finding, an ABAB task should be conducted. That is, after the target returns to the original target location, the target would swap with the same

distractor again in an addition phase. If the behavioral changes replicate the phenomena after the first return, it will support the view that contextual cue learning is inflexible. Another concern is that participants may require more time to update the initial learning, so longer swap phase may be applied to further study.

Conclusion. Initial RT results demonstrated immediate facilitation when target returned to initial location. However, the present results demonstrate that the mechanism for this is likely because participants prioritize their search to the initial location resulting in a failure to learn a new location in the B phase. The analysis of eye movement data for this task provided a much clearer picture of performance. The behavioral cost in Phase B was found to be caused in large part by proactive interference from learning in Phase A₁. The mechanism for the immediate recovery after the return was likewise largely explainable as perseveration of learning from phase A₁, which sustained throughout phase B. The present study shows no evidence that participants can learn two targets locations that were subsequently presented in the same context within the limited time available to them. It may be that with more learning trials, they could acquire additional target locations, but fatigue limits the amount of time participants can spend on this task in one sitting. No evidence was found to support the flexibility of contextual cue learning. While flexibility has been proposed as a defining feature of both declarative (explicit) memory and relational memory, the present study provides converging evidence that flexibility may have more to do with task demands than memory type.

Reference

- Barclay, J. R., Bransford, J. D., Franks, J. J., McCarrell, N. S., & Nitsch, K. (1974). Comprehension and semantic flexibility. *Journal of Verbal Learning and Verbal Behavior, 13*, 471-481.
- Beesley, T., & Le Pelley, M. E. (2010). The effect of predictive past on the learning of sub-sequence contingencies. *Quarterly Journal of Experimental Psychology, 63*, 108–135
- Blumenfeld, R. S., Parks, C. M., Yonelinas, A. P., & Ranganath, C. (2011). Putting the pieces together: The role of dorsolateral prefrontal cortex in relational memory encoding. *Journal of Cognitive Neuroscience, 23*(1), 257-265.
- Bobrow, S. A., & Easton, R. D. (1972). A confirmation that relational organization facilitates memory. *Psychonomic Science, 29*(4), 256-257.
- Bo, J., Jenet, S., Seidler, R.D. (2011). Working memory capacity correlates with implicit serial reaction time task performance. *Exp. Brain Res. 214*, 73–81.
- Brady, T. F., & Chun, M. M. (2007). Spatial constraints on learning in visual search: Modeling contextual cueing. *Journal of Experimental Psychology: Human Perception and Performance, 33*(4), 798-815.
- Brockmole, J. R., & Henderson, J. M. (2006). Recognition and attention guidance during contextual cueing in real-world scenes: Evidence from eye movements. *Quarterly Journal of Experimental Psychology, 59*, 1177–1187.

- Tomiczek, C. Burke, D. (2008). Is implicit learning perceptually inflexible? New evidence using a simple cued reaction-time task. *Learning and Motivation, 39*, 95–113
- Chun, M. M., & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology, 36*(1), 28-71.
- Chun, M. M., & Jiang, Y. (2003). Implicit, long-term spatial contextual memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(2), 224-234.
- Chun, M. M., & Phelps, E. A. (1999). Memory deficits for implicit contextual information in amnesic subjects with hippocampal damage. *Nat. Neurosci. 2*:844–847.
- Clark, R. E., & Squire, L. R. (1998). Classical conditioning and brain systems: The role of awareness. *Science, 280*(5360), 77-81.
- Cohen, N. J., Eichenbaum, H., Deacedo, B. S., & Corkin, S. (1985). Different memory systems underlying acquisition of procedural and declarative knowledge. *Annals of the New York Academy of Sciences, 444*, 54-71.
- Cohen, N. J., & Eichenbaum, H. (1993). *Memory, amnesia, and the hippocampal system*. Cambridge, MA: MIT Press.
- Cohen, N. J., Poldrack, R. A. & Eichenbaum, H. (1997). Memory for items and memory for relations in the procedural/declarative memory framework. *Memory, 5*, 131-178.

- Conci, M., Sun, L., & Müller, H. J. (2011). Contextual remapping in visual search after predictable target location changes. *Psychological Research, 75*, 279–289
- Conci, Markus., & Mühlennen. (2011). Limitations of perceptual segmentation on contextual cueing in visual search. *Visual Cognition, 19*(2), 203-233.
- Conci, M., Zellin, M., & Müller, H. J. (2012). Whatever after next? Adaptive predictions based on short and long-term memory in visual search. *Frontiers in Psychology, 3*, 409
- Dale, R., Duran, N. D., & Morehead, J. R. (2012). Prediction during statistical learning, and the implications for the implicit/explicit divide. *Advances in Cognitive Psychology, 8*, 196–209
- Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review, 96*, 433-458.
- Eichenbaum, H. (1997). Declarative memory: Insights from cognitive neurobiology. *Annual Review of Psychology, 48*, 547-572. doi:10.1146/annurev.psych.48.1.547
- Eichenbaum, H., Yonelinas, A.P. & Ranganath, C. (2007). The medial Temporal Lob and Recognition Memory. *Annual Review Neuroscience, 2007*, 30: 123-152.
- Fernandez-Duque, D., & Thornton, I. M. (2003). Explicit mechanisms do not account for implicit localization and identification of change: An empirical reply to Mitroff et al. (2002) *Journal of Experimental Psychology: Human Perception and Performance, 29*(5), 846–858.

- Friederici, A. D., Steinhauer, K., & Frisch, S. (1999). Lexical integration: Sequential effects of syntactic and semantic information". *Memory & Cognition* 27 (3): 438–453.
- Geyer, T., Shi, Z., & Müller, H. J. (2010). Contextual cueing in multiconjunction visual search is dependent on color- and configuration-based intertrial contingencies. *Journal of Experimental Psychology: Human Perception and Performance*, 36(3), 515-532.
- Graf, P. & Schacter, D.L. (1985). Implicit and explicit memory for new associations in normal and amnesic subjects. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 11, 501-518.
- Greene, A. J. (2007). Human hippocampal-dependent tasks: Is awareness necessary or sufficient? *Hippocampus*, 17(6), 429-433.
- Greene, A. J., Gross, W. L., Elsinger, C. L., & Rao, S. M. (2007). Hippocampal differentiation without recognition: An fMRI analysis of the contextual cueing task. *Learning & Memory*, 14(8), 548-553.
- Greene, A. J., Spellman, B., Dusek, J. A., Eichenbaum, H. B., & Levy, W. B. (2001). Relational learning with and without awareness: Transitive inference using nonverbal stimuli in humans. *Memory & Cognition*, 29(6), 893-902.
- Gross, W. L., & Greene, A. J. (2007). Analogical inference: The role of awareness in abstract learning. *Memory*, 15(8), 838-844.

- Hannula, D. E., & Greene, A. J. (2012). The hippocampus reevaluated in unconscious learning and memory: At a tipping point? *Frontiers in Human Neuroscience*, 6(80)
- Hannula, D.E. & Ranganath, C. (2009). The eyes have it: Hippocampal activity predicts expression of memory in eye movements. *Neuron*, 63, 592-599.
- Hanson, R. J. & GREENE, A. J. (2011, November). *Implicit flexibility and rapid adaptation of relational memories using visual search*. Poster presented at the annual meeting of the Society for Neuroscience, Washington, D.C.
- Henke, K. (2010). A model for memory systems based on processing modes rather than consciousness. *Nature Reviews Neuroscience*, 11(7), 523-532.
- Hollingworth, A., Williams, C. C., & Henderson, J. M. (2001). To see and remember: Visually specific information is retained in memory from previously attended objects in natural scenes. *Psychonomic Bulletin & Review*, 8, 761-768.
- Huang, L. (2006). Contextual cueing based on spatial arrangement of color. *Perception & Psychophysics*, 68(5), 792-799.
- Hunt, R. R., & Einstein, G. O. (1981). Relational and item-specific information in memory. *Journal of Verbal Learning & Verbal Behavior*, 20(5), 497-514.
- Jiang, Y., & Chun, M. M. (2001). Selective attention modulates implicit learning. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, 54A(4), 1105-1124.

Jiang, Y., Chun, M. M., Olson, I. R. (2004). Perceptual grouping in change detection.

Perception & Psychophysics, 66, 446-453.

Jiang, Y., Song, J., & Rigas, A. (2005). High-capacity spatial contextual memory.

Psychonomic Bulletin & Review, 12(3), 524-529.

Jiang, Y. V., Swallow, K. M., Rosenbaum, G. M., & Herzig, C. (2013). Rapid acquisition

but slow extinction of an attentional bias in space. *Journal of Experimental*

Psychology: Human Perception & Performance, 39, 87–99

Jungé, J. A., Scholl, B. J., & Chun, M. M. (2007). How is spatial context learning

integrated over signal versus noise? A primacy effect in contextual cueing. *Visual*

Cognition, 15, 1–11.

Koen, J. D., & Yonelinas, A. P. (2010). Memory variability is due to the contribution of

recollection and familiarity, not to encoding variability. *Journal of Experimental*

Psychology: Learning, Memory, and Cognition, 36, 1536-1542.

Kounios, J., & Holcomb, P. J. (1992). Structure and process in semantic memory:

Evidence from event-related brain potentials and reaction times. *Journal of*

Experimental Psychology: General, 121(4), 459-479.

Kunar, M. A., & Wolfe, J. M. (2011). Target absent trials in configural contextual cuing.

Attention, Perception, & Psychophysics, 73, 2077–2091

Leo, P. D., & Greene, A. J. (2008). Is awareness necessary for true inference? *Memory &*

Cognition, 36(6), 1079-1086.

- Makovski, T., & Jiang, Y. V. (2010). Contextual cost: When a visual-search target is not where it should be. *Quarterly Journal of Experimental Psychology*, *63*(2), 216-225.
- Manginelli, A. A., & Pollmann, S. (2009). Misleading contextual cues: How do they affect visual search? *Psychological Research*, *73*(2), 212-221.
- Manns, J. R., & Eichenbaum, H. (2006). Evolution of declarative memory. *Hippocampus*, *16*(9), 795-808.
- Mathews, R. C., Buss, R. R., Stanley, W. B., Blanchard-Fields, F., Cho, J. R., & Druhan, B. (1989). Role of implicit and explicit processes in learning from examples: A synergistic effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*, 1083-1100.
- Neider, M. B., & Zelinsky, G. J. (2006). Scene context guides eye movements during visual search. *Vision Research*, *46*(5), 614–621.
- Olson, I. R., & Chun, M. M. (2002). Perceptual constraints on implicit learning of spatial context. *Visual Cognition*, *9*(3), 273-302.
- Ostreicher, M. L., Moses, S. N., Rosenbaum, R. S., & Ryan, J. D. (2010). Prior experience supports new learning of relations in aging. *The Journals of Gerontology: Series B: Psychological Sciences and Social Sciences*, *65B*(1), 32-41.
- Pashler, H., & Baylis, G. C. (1991). Procedural learning: I. locus of practice effects in speeded choice tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(1), 20-32.

- Peterson, M. S., & Kramer, A. F. (2001). Attentional Guidance of the eyes by contextual information and abrupt onsets. *Perception & Psychophysics*, *63*(7), 1239-1249
- Postman, L. (1951). The generalization gradient in recognition memory. *Journal of Experimental Psychology*, *42*(4), 231-235.
- Reber, A. S. (1969). Transfer of syntactic structure in synthetic languages. *Journal of Experimental Psychology*, *81*, 93-133.
- Reber, P. J., Knowlton, B. J., & Squire, L. R (1996). Dissociable properties of memory systems: Differences in the flexibility of declarative and nondeclarative knowledge. *Behavioral Neuroscience*, *110*,861-871.
- Reber, T.P., Luechinger, R., Boesiger, P., & Henke, K. (2012). Unconscious relational inference recruits the hippocampus. *Journal of Neurosci*,*32*, 6138-6148
- Reder, L. M., Weber, K., Shang, J., & Vanyukov, P. M. (2003). The adaptive character of the attentional system: Statistical sensitivity in a target localization task. *Journal of Experimental Psychology: Human Perception & Performance*, *29*, 631-649
- Roediger, H. L., & Blaxton, T.A. (1987). Effects of varying modality, surface features, and retention interval on priming in word-fragment completion. *Memory and Cognition*, *15*, 379-388.
- Ryan, J.D, Althoff, R., Whitlow, S., & Cohen, N. (2000). Amnesia is a deficit in relationalmemory. *Psychological Science*, *11*, 454-461.

- Ryan, J.D. & Cohen. N.J. 2004. Processing and short-term retention of relational information in amnesia. *Neuropsychologia* 42, 497-511.
- Schacter, D. L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 13, 501-518.
- Schacter, D. L, Bowers J., & Booker, J. (1989). Intention, awareness, and implicit memory: The retrieval intentionality criterion. *Implicit memory: Theoretical issues*. 47-65.
- Schmidt, R. A. (1988). *Motor control and learning: A behavioral emphasis*. Illinois: Human Kinetics Publishers, Inc.
- Shimamura, A. P. (1986). Priming effects in Amnesia: Evidence for a dissociable memory function. *The Quarterly Journal of Experimental Psychology*, 38A, 619–644
- Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs: General and Applied*, 74(11), 1-29.
- Squire, L. R. (1998). Memory systems. *Comptes Rendus De l'Academie Des Sciences.Serie III, Sciences De La Vie*, 321(2-3), 153-156.
- Squire, L. R., & Zola, S. M. (1998). Episodic memory, semantic memory, and amnesia. *Hippocampus*, 8(3), 205-211.
- Stadler, M. A. (1997). Distinguishing implicit and explicit learning. *Psychonomic Bulletin & Review*, 4, 56-62.

- Thornton, I. M. & Fernandez-Duque, D. (2002). Converging evidence for the detection of change without awareness. In J. Hyönä, D. P. Munoz, W. Heide, and R. Radach (Eds.), *The brain's eye: Neurobiological and clinical aspects of oculomotor research: Progress in brain research*. 140, 99-118. Amsterdam: Elsevier.
- Tulving, E., Schacter, D. L., & Stark, H. A. (1982). Priming Effects in Word Fragment Completion are independent of Recognition Memory. *Journal of Experimental Psychology: Learning, Memory and Cognition* 8 (4). 103-109.
- Tulving, E., & Markowitsch, H. J. (1998). Episodic and declarative memory: Role of the hippocampus. *Hippocampus*, 8(3), 198-204.
- Tulving, E., & S. (1990). Priming and human memory systems. *Science*, 247, 301-306.
- Tulving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review*, 80, 352-373.
- Tulving, E. (1985). How many memory systems are there? *American Psychologist*, 40(4), 385-398.
- Turk-Browne, N., Scholl, B. J., Johnson, M. K., & Chun, M. M. (2010). Implicit perceptual anticipation triggered by statistical learning. *The Journal of Neuroscience*, 30, 11177–11187.
- van Asselen, M., & Castelo-Branco, M. (2009). The role of peripheral vision in implicit contextual cuing. *Attention, Perception, & Psychophysics*, 71, 76–81.

- Voss, J. L., Baym, C. L., & Paller, K. A. (2008). Accurate forced-choice recognition without awareness of memory retrieval. *Learning & Memory, 15*(6), 454-459.
- Voss, J. L., Lucas, H. D., & Paller, K. A. (2010). Conceptual priming and familiarity: Different expression of memory during recognition testing with distinct neurophysiological correlates. *Journal of Cognitive Neuroscience, 22*(11), 2638-2651.
- Voss, J. L., & Paller, K. A. (2008). Brain substrates of implicit and explicit memory: The importance of concurrently acquired neural signals of both memory groups. *Neuropsychologia, 46*(13), 3021-3029.
- Willingham, D. B. (1997). Implicit and explicit memory do not differ in flexibility: Comment on Dienes & Berry, 1997. *Psychonomic Bulletin and Review, 4*, 587-591.
- Yonelinas, A. P. (2001). Components of episodic memory: The contribution of recollection and familiarity. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 356*(1413), 1363-1374.
- Zellin, M., Conci, M., von Mühlenen, A., & Müller, H. J. (2013). Here today, gone tomorrow: Memory adaptation in contextual cueing. *PLoS One, 8*(3), e59466,
- Zellin, M., von Mühlenen, A., Müller, H. & Conci, M.(2013). Statistical learning in the past modulates contextual cueing in the future. *Journal of Vision, 13*(3), 1-14.

Zurif, E.B., Swinney, D., Prather, P., Solomon, J., & Bushell, C. (1993). An on-line analysis of syntactic processing in broca's and wernicke's aphasia. *Brain and Language*, 45(3): 448–464.