## Title

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# Implicit and Explicit Learning of a Covariation Across Visual Search Displays

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## Abstract

The goal of this study was to extend prior reports of implicit learning in visual search (e.g., Chun & Jiang, 1999) by employing eye movement monitoring and reaction time measures to contrast implicit and explicit learning. Towards this end, participants' eye movements were monitored as they performed a visual search task in the 'change blindness' flicker paradigm. In each trial, participants were asked to detect a letter that differed in shape or color across otherwise identical alternating letter arrays. In a subset of trials, for some participants the background luminance covaried with target color (Color rule condition) and for other participants letter thickness covaried with target shape (Shape rule condition). In addition, half of the participants were told of the existence of a covariation (Informed group) and the other half were not notified of this regularity and in a post-experimental interview reported no awareness of this covariation (Uninformed group). In both groups, reaction time data indicated that visual search was facilitated for trials that contained the covariation, and eye movement data showed that participants guided eye movements to potential targets based on the covariation information. Further, Informed participants in the Color rule condition were able to use covariation information to a greater extent than those in the Shape rule condition. In contrast, no differential sensitivity across rule conditions was found for Uninformed participants. Implications to the study of implicit learning in visual search are discussed.

## Introduction

Cognitive psychologists regularly differentiate cognitive processing as being either implicit or explicit in nature. However, there still exists debate in the field over whether these processes are indeed distinct (e.g., Shanks and St. John, 1994). One way to strongly support such a separation would involve demonstrating qualitative differences between these processes (e.g., Cheesman & Merikle, 1986; Dienes & Berry, 1997; Dixon, 1981; Neal & Hesketh, 1997; Reingold & Merikle, 1990; Shevrin & Dickman, 1980; Stadler & Frensch, 1994). As such, the present investigation attempts to make progress towards this goal by extending research demonstrating implicit learning in visual search (e.g., Chun & Jiang, 1999; Chun & Nakayama, 2000; Durgin, 1999; Flowers & Smith, 1998; Miller, 1991). For example, in a study by Chun and Jiang (1999), participants performed a visual search task where they were instructed to look for an object symmetric around the vertical axis. There were two display conditions: in the first condition each of the targets was paired with a distractor set and this pairing was preserved throughout the experiment, and in the second condition the pairings of distractor sets and targets was varied randomly across trials. Chun and Jiang (1999) reported that search efficiency in the consistent pairing condition was significantly better than in the randomized pairing condition. Importantly, an evaluation of participants' awareness of the experimental manipulation indicated that the benefit participants derived from consistent pairing reflected implicit rather than explicit learning. Based on these results Chun and Jiang argued that following implicit learning of the pairing of targets and distractor sets, distractor identity information (i.e., context information) could cue knowledge of target shape information, reducing search time.

In the present study we employed eye movement monitoring as an index of learning in addition to reaction time. Eye movements have been shown to be a tangible trace of perceptual and attentional processes, and represent an ideal indirect measure of processing which can be recorded unobtrusively, concurrent with direct discrimination measures of performance. This may allow for demonstrating dissociations between some aspects of eye movement behavior, such as saccadic selectivity, and overt task performance, such as reaction time. Employing such methodology, this research investigates whether we can learn to make a more efficient visual search based on a covariation that *across* search displays provides target identity information, as well as addressing how awareness of this information affects search performance. In addition, by employing multiple methodologies to empirically investigate implicit and explicit learning, we hope to make progress towards the goal of demonstrating qualitative differences between these processes.

To this end, we exploited a well-established finding in the eye movement and visual search literature that demonstrates a bias in the distribution of saccadic endpoints toward distractors that share stimulus dimensions and features with the target including color, shape, contrast polarity, and size (e.g., Findlay, 1997; Hooge & Erkelens, 1999; Pomplun, Reingold, & Shen, 2001, 2003; Pomplun, Reingold, Shen, & Williams, 2000; Scialfa & Joffe, 1998; Shen & Reingold, 1999; Shen, Reingold, & Pomplun, 2000, 2003; Shen, Reingold, Pomplun, & Williams, 2003; Williams & Reingold, 2001). This finding is typically referred to as saccadic selectivity.

In the present study participants performed a visual search task in the ‘change blindness’ flicker paradigm (Rensink, O'Regan, & Clark, 1997). As shown in Figure 1, participants were asked to detect a letter (target) that differed in color (see Panel A) or shape (see Panel B) across otherwise identical alternating letter arrays. In a subset of trials, there was a covariation embedded in the task that reduced the target to half of the display items. Reaction times for the trials containing the covariation (Covariant trials), were compared to the reaction times obtained for the trials that did not contain covariation information (Random trials). In addition, half of the participants were told of the existence of a covariation (Informed group) and the other half were not notified of this regularity (Uninformed group). Learning of the covariation rule would be expressed by faster reaction times for the Covariant trials than for the Random trials. In addition, learning of the covariation rule would provide target identity information and may be manifested as a bias towards fixating on the letters that have the same shape or color as the target (i.e., saccadic selectivity). Finally, we were also interested in determining if there would be differential search performance across the Informed and Uninformed groups reflecting qualitative differences between implicit and explicit learning.

# Methods

## Participants

Forty-eight participants were paid $20 for their involvement in the two hour experiment: 24 participants searched for the letter that differed in shape and 24 participants searched for the letter that differed in color. Half of the participants in each group were informed of the covariation information (Informed group), while the other half were not (Uninformed group). Participants were tested individually, and all had normal or corrected-to-normal vision.

## Apparatus

The eyetracker employed in this research was the SR Research Ltd. EyeLink system. This system has high spatial resolution (0.005°), and a sampling rate of 250 Hz (4 msec temporal resolution). The EyeLink headband has three cameras, allowing simultaneous tracking of both eyes and of head position for head-motion compensation. By default, only the participant's dominant eye was tracked in our study. The EyeLink system uses an Ethernet link between the eyetracker and display computers for real-time saccade and gaze position data transfer. In the present study the configurable acceleration and velocity thresholds were set to detect saccades of 0.5° or greater.

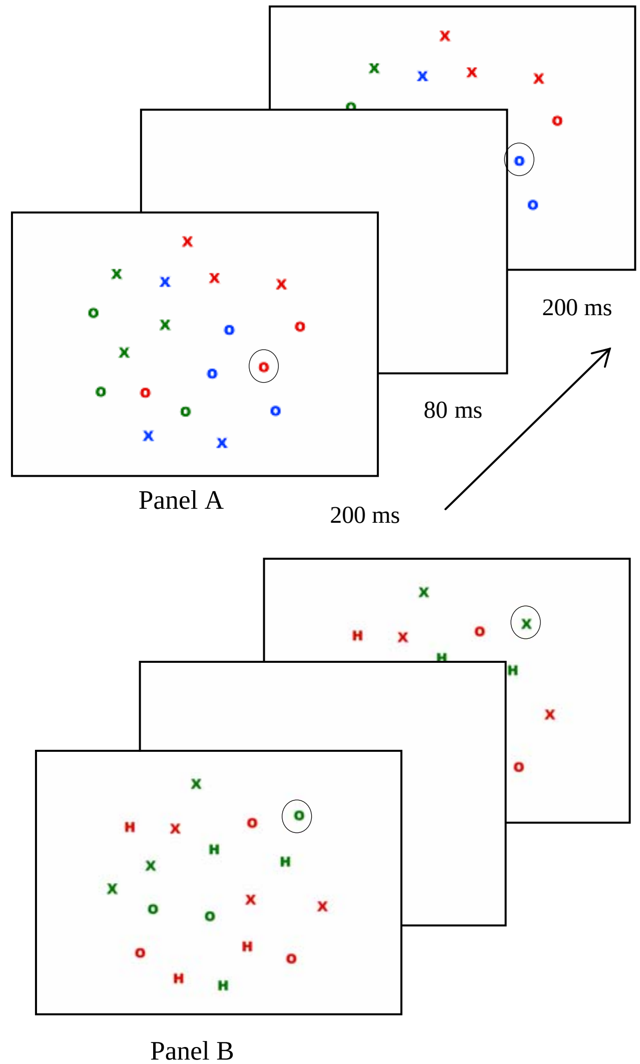


Figure 1: An illustration of the change blindness paradigm. Panel A shows a target changing color, and Panel B shows a target changing shape. The targets are circled for illustration purposes only.

Stimulus displays were presented on two monitors, one for the participant (a 17-inch Viewsonic 17PS) and one for the experimenter. The experimenter monitor was used to give feedback in real-time about the participant’s computed gaze position. This feedback was given in the form of a cursor measuring 1° in diameter which was overlaid on the same image being viewed by the participant. This allowed the experimenter to evaluate system accuracy and to initiate a recalibration if necessary. In general, the average error in the computation of gaze position was less than 0.5° of visual angle.

## Materials and Design

As shown in Figure 1, the change blindness flicker paradigm was used (Rensink et al., 1997). As can be seen, in each trial, the screen flickered between the display and a blank screen (200ms display/80ms blank screen/200ms display). Displays were composed of 18 letters (1 target, 17 distractors) that were arrayed on three invisible concentric rings. On all trials there was an equal number of letters of each color and shape. The radii of the rings were 2.8, 5.6, and 8.3 degrees of visual angle (at a distance of 70 cm). The minimum distance between items was set at 3.5 degrees. Individual letters subtended 0.86 degrees both horizontally and vertically. Colors were matched in luminance and saturation (CIE coordinates: $x$, $y$, red: 0.578, 0.350, green: 0.327, 0.549, blue: 0.170, 0.117 and yellow: 0.446, 0.454). The location of the target and the configuration of the distractor items were randomized for every trial.

As the screen flickered, the participants' task was to detect the letter (target) that differed in color or shape. For trials where the target changed color, half of the displays contained an equal number of X's and O's (X/O displays), and half of the displays contained an equal number of C's and T's (C/T displays). In both cases, an equal number of red, green and blue letters was displayed, one of which was chosen at random to change color. For example, Figure 1, Panel A shows an X/O display where the target (which is circled for illustrative purposes) changes color from red to blue. In this trial the screen would alternate between the display with the red target letter, the blank display, and the display with the blue target letter, until the participant found the target. Alternatively, for trials where the target changed shape, half of the displays contained an equal number of green and red letters (green/red displays), and half of the displays contained an equal number of yellow and blue letters (yellow/blue displays). In both cases, an equal number of X's, O's, and H's was displayed, one of which was chosen at random to change shape. For example, Panel B shows a green/red display where the target changes shape from an O to an X. In this trial the screens would alternate between the given displays until the participant located the target changing shape.

In a subset of each of these types of trials, there was a covariation embedded in the task that reduced the possible target locations to half of the display items. Two covariation rules were used as illustrated in Table 1. In the Shape rule condition, the displays contained either thick letters or thin letters. Letter thickness predicted target shape in the Covariant trials, but not the Random trials. In the example in Table 1, X/O displays correspond to Covariant trials, in which thick letter displays predicted the target to be an X and thin letter displays predicted the target to be an O. In contrast, C/T displays correspond to the Random trials, in which letter thickness did not predict target shape.

In the Color rule condition, the displays contained either a light or a dark background. Background luminance predicted target color in the Covariant trials, but not the Random trials. In the example in Table 1, green/red displays correspond to Covariant trials, in which a light background predicted the target to be green and a dark background predicted the target to be red. In contrast, yellow/blue displays correspond to the Random trials, in which background luminance did not predict target color.

Table 1: An illustration of the covariation rules for the Shape and Color conditions.

| Rule Condition | Display type | Trials: Covariant | Trials: Random |
|---|---|---|---|
| Shape (Fig. 1 Panel A) | Thick Letter | X -> X | C -> C or T -> T |
| | Thin Letter | O -> O | C -> C or T -> T |
| Color (Fig. 1 Panel B) | Light Background | O -> X | O -> X or O -> X |
| | Dark Background | O -> X | O -> X or O -> X |

Each participant performed 624 trials. The order of the stimulus displays was random under the restrictions that there be no more than 4 displays of a given display type or trial type in a row, and that each 48 trial block contained an equal number of trials of each display type and each trial type (Covariant, Random). Mapping of the display types to conditions was counterbalanced across participants.

## Procedure

The experiment was run in a lighted room with a luminance of approximately 30 cd/$m^2$. Before beginning the task, the participants were informed that stimulus displays would consist of letters that would flash intermittently, and that their task was to search for and detect the single letter that was changing shape, for participants in the Color rule condition, or changing color, for participants in the Shape rule condition. Participants were asked to locate the target as quickly as possible and terminate the trial by maintaining fixation on the target. Participants then completed 48 practice trials, followed by 2 blocks of 288 experimental trials. Every 48 trials participants were given a rest break.

At the beginning of each trial, a fixation point was presented in the center of the computer screen in order to correct for drift in gaze position. A button press from the participant initiated the trial and it ended 700 ms after the participant fixated on the target (gaze-controlled response). The time between display onset and the participant's gaze-controlled response was recorded as the response time (RT). In addition, the participant's eye movements, monitored via the EyeLink tracking system, were recorded.

In order to compare explicit and implicit covariant rule learning, following completion of the practice block, half of the 24 participants in the each rule condition were told that there was a 100% covariation between the relevant features in one of the two display types (the Informed group). However, they were not told which display type contained the covariation. The other half of participants were not told anything about this relationship (the Uninformed group). At the end of the experiment a structured questionnaire was given to investigate awareness of the covariation.

## Results

### Reaction Time

For each participant and condition the mean RT was calculated, excluding those trials that were greater than 3 standard deviations from the mean. This resulted in less than 3% of trials being omitted. As Figure 2 reveals, RTs improved over the course of the experiment ($F$ *(2, 88)* = 101, $p$ <.001) and were faster for Covariant than Random trials ($F$ *(1, 44)* = 31.6, $p$ <.001). Importantly, participants improved more over time for Covariant trials than for Random trials, demonstrating a reaction time benefit for learning the covariation, $F$ *(2, 88)* = 3.87, $p$ = .025. Moreover, this RT benefit of Covariant trials over Random trials was significant for both the Informed ($F$ *(1, 22)* = 96.9, $p$ < .001) and Uninformed ($F$ *(1, 22)* = 9.40, $p$ < .01) groups. There were no RT differences for the practice block across trial type ($t$ *(1, 47)* = .82, $p$ > .4).

As can be seen upon further inspection of Figure 2, the instruction manipulation (Informed, Uninformed) affected the degree to which participants benefited from the covariation information. Specifically, there was a greater benefit for the Covariant trials over the Random trials for participants in the Informed group (mean difference = 1010 ms) as compared to participants in the Uninformed group (mean difference = 165 ms), $F$ *(1, 44)* = 53.1, $p$ < .001. Further, Informed participants showed significantly greater RT advantages for Covariant trials than for Random trials in the Color rule condition (mean difference: 1520 ms, SE = 180) when compared to the Shape rule condition (mean difference: 500 ms, SE = 98.0), F (1, 22) = 24.7, p < .001). In contrast, the Uninformed participants showed no differential RT benefit across rule conditions (F (1, 22) < 1, mean difference: 155 ms, SE = 81.2, for the Color rule condition vs. mean difference: 175 ms, SE = 70.8, for the Shape rule condition). These differences manifested themselves as a trial type by instruction by rule condition interaction, $F$ *(1, 44)* = 20.1, $p$ < .001.

### Saccadic Selectivity

Saccadic selectivity was computed by assigning saccadic endpoints to the closest display item and calculating the percentage of saccades directed towards the 7 distractors out of the total of 17 distractors that shared shape with the target in the Shape rule condition or color with the target in the Color rule condition. Accordingly, chance performance on the saccadic selectivity measure (i.e., when all distractors have an equal probability of being fixated) was expected to be 47.06%. Consistent with this, saccadic selectivity was at chance (Mean = 47.06; all $t$*'s (1, 47)* < 1, $p$*'s* > .5) for the Random trials over the course of the experiment. In contrast, as can be seen in Figure 3, while saccadic selectivity did not significantly differ from chance for Covariant trials for the practice block (Mean = 47.06; $t$ *(1, 47*) = 1.24, $p$ > .2), participants' saccadic selectivity increased over time, demonstrating a behavioral consequence for learning of the covariation, $F$ *(2, 88)* = 81.3, $p$ < .001. This bias towards fixating on the letters that had the same shape or color as the target occurred more strongly for the Informed participants ($F$ *(1, 22)* = 27.5, $p$ < .001), than the Uninformed participants ($F$ *(1, 22)* = 10.3, $p$ < .005). Further, Informed participants showed significantly greater saccadic selectivity in the Color rule condition (mean = 75.3%, SE = 1.57) as compared to the Shape rule condition (mean =

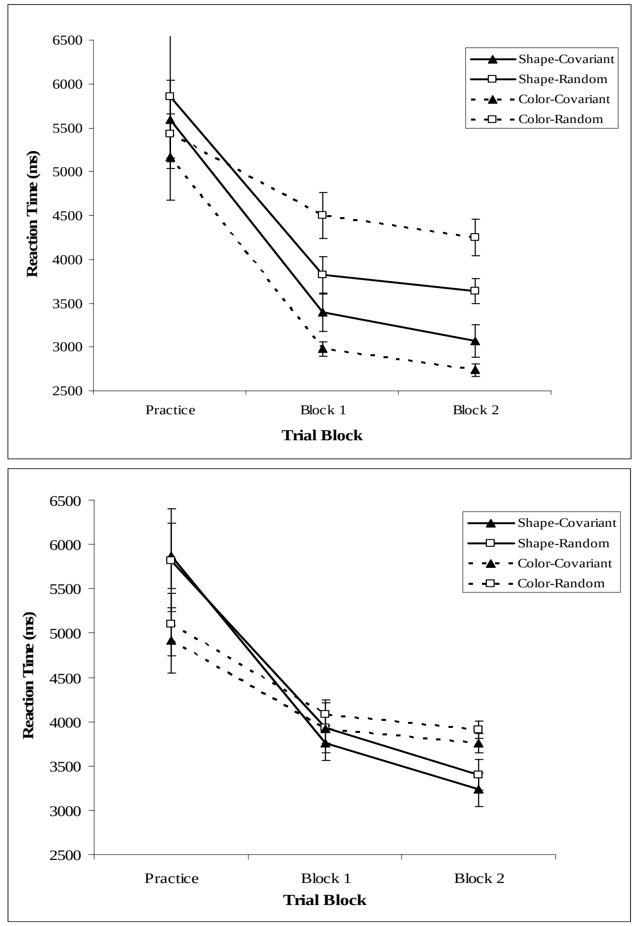


Figure 2: Reaction time by trial Block is shown for both the Covariant and Random trials by rule condition (Shape, Color). The top panel contains the results for the Informed group, and the bottom panel contains the results for the Uninformed group.

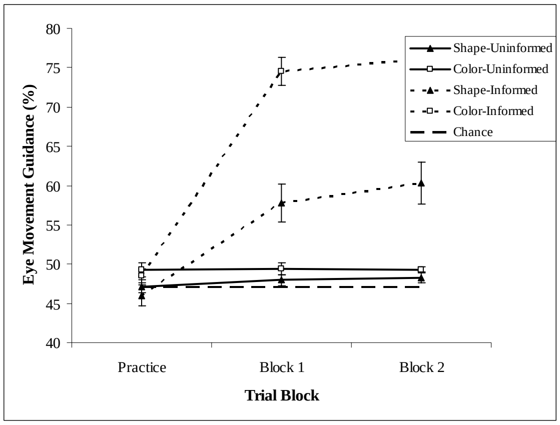


Figure 3: Percent eye-movement guidance by trial Block for the Covariant trials by group (Informed, Uninformed) and rule condition (Shape, Color). Chance guidance is shown by a dashed line at 47.08%. The practice block contains 48 trials, and Blocks 1 and 2 average 288 trials each.

59.1%, SE = 2.43), F (1, 22) = 31.5, p < .001). In contrast, the Uninformed participants showed no differential saccadic selectivity across rule conditions (F (1, 22) = 3.05, p = .095; mean = 49.3%, SE = .482 for the Color rule condition, mean = 48.2%, SE = .476 for the Shape rule condition). These differences manifested themselves as an instruction by rule condition interaction, *F (1, 44)* = 25.71, *p* < .001.

The effectiveness of the instructions was further evaluated by a retrospective report in the form of a structured questionnaire and intensive questioning. It was found that participants in the Uninformed group reported being unaware of the covariation, while those in the Informed group could explain the covariation, consistent with instructions. In fact, most Uninformed participants expressed disbelief when they were told of the covariation, reporting that they thought that letter thickness (for those in the Shape rule condition), or background luminance (for those in the Color rule condition), were irrelevant.

## Discussion

In an attempt to make progress towards the goal of demonstrating qualitative differences between implicit and explicit processing, the present study employed eye movement monitoring as an index of learning, in addition to reaction time, to further explore implicit learning in the context of visual search. It was found that participants can enhance visual search efficiency by utilizing a covariation that provided target identity information, and that such learning occurs even when participants are uninformed and claim to be unaware of this information. Implicit learning was most strongly demonstrated by the response time measure. Specifically, for the Uninformed participants, while the RT measure showed savings for trials containing the covariant rule condition (165ms in both the Shape and Color rule conditions), only a slight saccadic selectivity (1% bias in the Shape rule condition and 2% bias in the Color rule condition) favoring relevant distractors was demonstrated. In contrast, participants who were informed of the covariation rule showed substantial learning of the covariation in the form of a reaction time advantage (500ms in the Shape rule condition and 1520ms in the Color rule condition) and saccadic selectively (12% bias in the Shape rule condition and 28% bias in the Color rule condition). Taken together, saccadic selectivity seems to be one mechanism by which Informed participants made their search more efficient, whereas the weak selectivity displayed by the Uninformed participants suggests that this was not the primary mechanism employed by this group. Future investigation into what other means the Uninformed participants were using to improve search efficiency is warranted. The different picture portrayed by the RT and saccadic selectivity results points to the importance of using multiple concurrent measures of performance in attempting to more conclusively document implicit learning and in attempting to better understand the mechanisms underlying variation in performance associated with the presence or absence of claimed awareness pertaining to the learned covariation.

The present finding of implicit learning in visual search is consistent with previous evidence using other visual search paradigms (e.g., Chun & Jiang, 1999; Chun & Nakayama, 2000; Durgin, 1999; Flowers & Smith, 1998; Miller, 1991). A benefit to our use of the change blindness paradigm was that it allowed us to create a methodology whereby no target-absent trials were needed and where the covariant rule involved a dimension that was seemingly irrelevant to the search task.

Finally, the rule condition (Color, Shape) differentially influenced performance in the Informed and Uninformed groups. Specifically, the Informed participants in the Color rule condition were able to use the covariation information to a greater extent than those in the Shape rule condition, as shown by both the RT and saccadic selectivity results (see Figure 2 and 3, respectively). In contrast, no such differential sensitivity across rule condition was found for the Uninformed participants for either of these measures. We believe that the demonstration of differential search performance across groups and conditions in the present study constitutes progress toward the crucial goal of establishing qualitative differences between implicit and explicit learning in the context of visual search.

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