Categorical Contextual Cueing in Visual Search

By

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ABSTRACT

Previous research has shown that people can implicitly learn repeated visual contexts and use this information when locating relevant items. For example, when people are presented with repeated spatial configurations of distractor items or distractor identities in visual search, they become faster to find target stimuli in these repeated contexts over time (Chun and Jiang, 1998; 1999). Given that people learn these repeated distractor configurations and identities, might they also implicitly encode semantic information about distractors, if this information is predictive of the target location? We investigated this question with a series of visual search experiments using real-world stimuli within a *contextual cueing* paradigm (Chun and Jiang, 1998). Specifically, we tested whether participants could learn, through experience, that the target images they are searching for are always located near specific categories of distractors, such as food items or animals. We also varied the spatial consistency of target locations, in order to rule out implicit learning of repeated target locations. Results suggest that participants implicitly learned the target-predictive categories of distractors and used this information during search, although these results failed to reach significance. This lack of significance may have been due the relative simplicity of the search task, however, and several new experiments are proposed to further investigate whether repeated category information can benefit search.

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When trying to visually locate a specific object in everyday life, we typically rely on meaningful contextual associations between objects to guide our attention. For example, when looking for a bicycle in a street scene, you would most likely scour the street, sidewalks and bike racks, where a bicycle is most likely to occur, rather than the tops of trees or the sky (Biederman, 1972; Biederman, Mezzanotte & Rabinowitz, 1982). Prior experience informs this search effort: Bicycles are typically associated with particular items or locations, such as bike racks and sidewalks, but not others, such as trees and the sky. In the current study, we explored the mechanisms by which people might learn these contextual associations, by testing whether they can learn to associate target stimuli to particular semantic contexts in a series of visual search tasks. In other words, can participants learn, over a series of trials, that the target item will always appear near items from the categories "fruit" or "sports equipment" and use this semantic information during search?

Spatial and Object-Based Contextual Cueing

Previous findings have shown that in the absence of such semantic associations, people can implicitly learn consistent spatial associations between stimuli to inform search. Chun and Jiang (1998) developed the *contextual cueing paradigm* in which participants were given a series of visual search trials with repeated spatial layouts of distractors. They were instructed to detect a target object (a rotated T) among many distractor objects (Ls). On a set of critical trials, distractors were arranged into specific, invariant spatial configurations within which the target location was held constant. On these trials, the entire search display, or the global context, reliably predicted the target location. These repeated, target-predictive trials were embedded within several blocks of non-predictive trials containing randomly-generated distractor configurations, and participants became reliably faster at detecting targets on repeated trials. Furthermore, a post-experiment surprise recognition test showed that participants could not explicitly identify repeated distractor configurations above chance levels, indicating that the contextual learning was implicit in nature. Similar contextual cueing effects were found for a relatively small number of repeated, target-predictive trials when participants had to search through a large number of non-predictive trials and over many days (Jiang, Song & Rigas, 2005). Contextual cueing was also stable after predictive configurations were rescaled, preserving the shape of the overall distractor configuration (Jiang & Wagner, 2004), and, in another study, contextual cueing was observed for previously unattended, repeated predictive configurations when attention was subsequently directed to those configurations, further demonstrating the implicit nature of spatial contextual cueing (Jiang & Leung, 2005).

In addition to showing this contextual cueing effect with consistent spatial configurations of distractors and targets, Chun and Jiang (1999) demonstrated implicit cueing of target and distractor identities, independent of spatial configuration. They presented a visual search task containing artificial stimuli. Participants were instructed to detect a target shape that was symmetric around the vertical axis, among a background of distractor shapes that were also symmetric and tilted away from the vertical axis. On critical trials, specific target shapes were consistently paired with repeated configurations of distractor sets consisting of specific shapes. On all trials, however, the spatial location of distractors and the target were randomized, so that spatial location was not confounded with target and distractor identities. Participants became faster at locating targets that occurred within repeated distractor sets over time, and a recognition test again revealed that they could not explicitly identify these target-distractor pairings above chance. These results demonstrate contextual cueing with object pairings in the absence of spatial consistency.

Overall, these findings demonstrate that people implicitly learn consistent spatial and object associations between simple stimuli, and that these associations facilitate search performance. Hout and Goldinger (2010) demonstrated similar search facilitation through repeated contexts, using real-world stimuli. They presented participants with a series of visual search experiments, each containing one of four distractor configurations that repeated across trials: (1) a fixed set of distractor identities repeating in fixed locations, (2) fixed distractor locations and fixed sets of distractor identities, but the distractors were randomly assigned to each of the fixed locations across trials, (3) random locations with fixed distractor identities, and (4) fixed locations with random distractor identities. Results showed reliable effects of learning evidenced in faster target detection across repeated trials in all configurations. However, the cueing benefit was greatest when object identities were tied to consistent spatial locations, and least when random objects occupied consistent locations. Furthermore, a post-search surprise recognition test revealed that subjects incidentally learned distractor identities at levels greater than chance. These results indicate that subjects incidentally learn distractor identities and use this information in search, and that the learning benefit from repeated objects outweighs that of repeated spatial locations, although both types of information are informative (see also Endo and Takeda, 2004, and Hout and Goldinger, 2012).

Semantic Contextual Cueing

Given that search performance benefits from both consistent spatial layouts and object identity information over repeated exposures, could people also benefit from repeated semantic information, independently of spatial and identity information? Goujon, Didierjean, and Marmèche (2007) tested this hypothesis using simple digit stimuli—on critical trials, distractor digits' property of "oddness" or "evenness" was predictive of the target location. They presented participants with a visual search task in which target-predictive displays were comprised of either odd or even numbers, and control trials contained a mix of both. On predictive trials with odd-numbered distractors, the target number was always localized to a particular side of the search display, while on trials containing even-numbered distractors, the target was located on the opposite side of the display. Participants became faster to detect targets on predictive trials than control trials, demonstrating that they learned these contextual associations between distractor meaning and target location. Similar results were obtained by Goujon, Didierjean, and Marmèche (2009) using verbal stimuli, when distractor words belonging to specific categories (e.g., "mammals" or "fruits/vegetables") were predictive of the target location. Taken together, these findings demonstrate that people can implicitly learn semantic information about verbally-presented distractors during search.

The Present Investigation

While Goujon, et al. (2007; 2009) showed that categorical information about verbal distractors becomes active and can reliably cue the target location, we sought to further investigate whether semantic contextual cueing also occurs when categories of distractors are presented as images. In order to test this hypothesis, we conducted several experiments using real-world stimuli in which the target image always occurred within a quadrant containing semantically-related distractors. For example, on predictive displays, the target image would always occur within the quadrant containing items from the category “animals.” For half of the participants, the spatial location of this predictive quadrant was randomly assigned, in order to eliminate spatial cueing as a possible explanation for any observed contextual cueing effect.

Experiment 1A presented these predictive displays while holding distractor identities constant. Consequently, any contextual cueing effects observed in 1A could be the result of participants learning distractor identities, or a combination of categorical cueing and this item-specific cueing. In order to further test whether potential contextual effects are semantic in nature, Experiment 1B presented the same conditions as 1A, while varying the identities of distractors from trial-to-trial, preserving distractor categories. Therefore, finding contextual cueing effects in 1B would strongly suggest that participants can use categorical information to cue target locations.

Experiments 1A and 1B also presented verbal target cues to participants, in order to make search difficult enough so that participants would sufficiently look at distractors. For example, the word “stroller” would be presented instead of a picture of the target stroller. Here, the absence of a target template to hold in memory during search should require greater inspection of distractors in order to rule them out as targets, providing optimal conditions for categorical information about these distractors to become active. For comparison, Experiment 1C presented the same conditions as 1A, but with image target cues. If we found contextual cueing effects in 1A but not in 1C, this would show that participants need adequate time looking at distractors for semantic information to become available to cue them to the target location.

The control experiments 2A and 2B eliminated this potential semantic cueing, by eliminating coherent categorical grouping among distractors. The same analogous conditions were presented as in experiments 1A and 1B (consistent distractor identities and varied identities, respectively), but items from all categories were intermixed within each quadrant of the display. Consequently, no categorical contextual cueing effects should emerge in these control experiments.

Overall, Experiment 1B provides the strongest test of our predictions, because this experiment isolates semantic information about distractors as being the single attribute that is predictive of target location. Finding contextual cueing effects in the condition of 1B where spatial locations of distractors are varied would provide the best evidence for search facilitation through category learning.

Experiment 1

Our first experiment examined whether participants could implicitly learn when targets consistently occurred near specific categories of distractors and use this information to quickly detect targets. We conducted three sub-experiments: In Experiment 1A, all exemplars of distractors remained consistent throughout the experiment. However, finding contextual cueing effects in Experiment 1A could indicate a combination of learning both distractor categories and identities. In order to isolate implicit learning of distractor categories from the learning of distractor identities, Experiment 1B eliminated consistent distractor identities by presenting distractors that were randomly selected from larger lists of exemplars on each trial. To decrease the chance of participants using template-matching strategies in which they might simply hold the target template in visual memory and use this memory template to efficiently guide search, Experiments 1A and 1B presented verbal target cues (i.e., the words “dollar bill” when a dollar bill was the target). For comparison, Experiment 1C presented participants with image target cues, where an exact image of the target was shown to participants before a given trial. (See Figures 1 and 2 for conditions in Experiment 1).

In order to determine whether contextual cueing was the result of learning repeated target locations or learning target-predictive distractor categories, we presented participants with conditions in which (1) the location of each distractor category, including the target-predictive category, were held fixed to a particular quadrant throughout the experiment, or (2) randomly assigned to different quadrants from trial-to-trial, eliminating consistent spatial cueing. These fixed and random quadrant assignments were presented in all sub-experiments.

Method

Participants

One-hundred and fifty students from Arizona State University participated in Experiment 1 for partial course credit (50, 49, and 51 participants in Experiments 1A, 1B, and 1C, respectively). All experiments in this study were approved by the university’s Institutional Review Board and all participants gave informed consent to participate (see Appendix A).

Design

We manipulated two within-subjects variables, which included (1) predictiveness (predictive displays with categorical cueing of target location, versus non-predictive displays with no categorical cueing), and (2) epoch (four blocks of 70 trials each). The variable configuration (fixed versus random) was manipulated between-subjects. Our dependent variable was search time on correct trials.

Apparatus and Stimuli

All data were collected on up to 11 computers simultaneously with identical hardware and software profiles. These computers consisted of Dell Optiplex 380 PCs at 3.06 GHz and 3.21 GB RAM, in 1366 x 768 resolution on Dell E1912H 18.5” monitors at a 60 Hz refresh rate, with the display controlled by an Intel G41 Express chipset, each running Windows XP. All experiments were presented using E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2012). All stimuli consisted of real-world objects converted to grayscale and resized to 2.9° visual angle (centered) from a viewing distance of 60 cm. Stimuli were selected from a combination of the Massive Memory database (Brady, Konkle, Alvarez, & Oliva, 2008; Konkle, Brady, Alvarez, & Oliva, 2010; cvcl.mit.edu/MM/stimuli.html.) and a Google image search. Eight superordinate-level categories were selected (Rosch, 1975; Rosch, Mervis, Gray, Johnson & Boyles-Braem, 1976), consisting of animals, food, clothing, furniture, tools, musical instruments, vehicles, and sports equipment. Each category consisted of eight types of items, with six exemplars of each type (e.g., six tigers, six dogs, and six elephants within the category “animals”) while target items were selected such that they did not fall into any of the distractor categories. See Tables 1 and 2 for distractor and target stimuli.

Procedure

Each participant was first assigned to either the fixed or random spatial configuration condition, which was counterbalanced by subject number. In the fixed configuration condition, spatial consistency of each distractor category was held relatively consistent: The four predictive and four non-predictive categories were randomly assigned to occur within specific quadrants, and these quadrant assignments remained constant throughout the experiment (although the absolute location of distractors within a quadrant was randomized). For example, animals, food, clothing, and furniture might occur within quadrants one through four, respectively, on all predictive trials, while tools, musical instruments, motorized vehicles, and sports equipment would occur within quadrants one through four on all non-predictive trials. The random configuration version of the experiment was identical to the fixed configuration version, except that each distractor category within the predictive and non-predictive displays was randomly assigned to a quadrant from trial-to-trial.

The specific categories assigned to predictive and non-predictive displays was random for each participant, and one of the four categories that comprised predictive displays was randomly selected to be predictive of the target location throughout the experiment (e.g., the target would always occur in the same quadrant as animals). Predictive and non-predictive trials were randomly intermixed for each participant.

In Experiment 1A, all distractor stimuli were initially randomly selected from larger lists of exemplars from the outset, and each distractor remained fixed throughout the experiment. For example, the same tiger, dog, and elephant from the category “animals” would be presented on all trials where animals occur. In order to eliminate item-specific cueing, in Experiment 1B, all stimuli were randomly sampled from larger lists of six exemplars each from trial-to-trial, such that the tiger, dog, and elephant on trial *n* might be a different tiger, dog, and elephant on trial *n* + 1. Experiment 1C was identical to 1A, except that participants were shown image target cues. In all experiments, only one exemplar of the items comprising a given category was present on each trial (e.g., the quadrant containing the category "animals" would contain one tiger, one dog, one elephant, and so forth). Each quadrant contained eight distractors, for a set size of 32 on all trials, and the target image was presented in place of one of the distractor images on every trial.

At the beginning of each trial, participants were initially shown the name of this search target in Experiments 1A and 1B, and an image of the target in Experiment 1C. They then performed a speeded search among the distractors, and pressed the space bar once the target was located. All of the stimuli were then converted into digits (1 through 32) when the space bar was pressed. On a subsequent screen, participants made a two-alternative forced choice between the correct number that replaced the target location and a random foil, and were given feedback on their decisions. All participants completed eight practice trials at the beginning of the experiment and were given a one-minute rest period between each block (epoch) of 70 trials. See Figure 3 for the progression of events in a trial.

In order to determine whether any potential learning of distractor displays was implicit or explicit, all participants were given a post-experiment surprise recognition test in all experiments. Each participant was shown one display containing distractors from target-predictive trials, and one display containing distractors from non-predictive trials.

Each of these displays contained the numbers one through four in the center of each quadrant, and participants were instructed to choose the most likely general location of the target, if it were present (no target was presented in these displays). Following each display, participants were instructed to type the reason for choosing a paticular quadrant, on a subsequent screen, and they were instructed to type “I guessed” if they guessed the target location in the recognition test.

Results

Four participants were excluded from analysis for Experiment 1A: one for being a non-native English speaker, two for having low accuracies (< 2.5 standard deviations) and one for having slow search times (> 2.5 standard deviations), leaving a total of 46 participants retained with an average search accuracy of .97. Two participants were excluded from Experiment 1B: one for low accuracy and one for slow search times, leaving a total of 47 participants retained, with an average accuracy of .98. Four participants were excluded from 1C: three for having low accuracy, and one for having slow search times, leaving a total of 47 participants retained, with an average accuracy of .98.

For all experiments, we conducted mixed-model ANOVAs that included the variables epoch, predictiveness, and configuration. In order to examine the effect of categorical cueing within the fixed and random configurations, we also conducted separate ANOVAs looking at epoch and predictiveness within these configuration conditions. All inferential tests reported use multivariate values, to correct for violations of the statistical assumption of sphericity.

Experiment 1A: Single-exemplar distractors: In the full analysis, we found a main effect of epoch, $F(3, 42) = 78.04$, $p < .001$, $\eta_p^2 = .85$, indicating that participants became faster searchers over time. We also found a main effect of predictiveness, $F(1, 44) = 50.80$, $p < .001$, $\eta_p^2 = .54$, indicating generally faster search on predictive than on non-predictive displays. There was also a main effect of configuration, $F(1, 44) = 9.16$, $p = .004$, $\eta_p^2 = .17$, and a Predictiveness × Configuration interaction, $F(1, 44) = 18.58$, $p < .001$, $\eta_p^2 = .30$. As Figure 4 indicates, participants became faster on predictive than on non-predictive displays, but this benefit of target-predictive displays was greater when distractor configurations were fixed. There was also a marginal Epoch × Predictiveness × Configuration interaction, $F(3, 42) = 2.29$, $p = .09$, $\eta_p^2 = .14$. The Epoch × Configuration and Epoch × Predictiveness interaction were not significant (both *F*s < 1).

Looking at epoch and predictiveness within the fixed configuration condition alone, we observed a significant main effect of epoch, $F(3, 21) = 30.26$, $p < .001$, $\eta_p^2 = .81$, again indicating that participants became faster searchers over time, and a main effect of predictiveness, $F(1, 23) = 130.54$, $p < .001$, $\eta_p^2 = .85$, indicating faster search on predictive than in non-predictive displays. The interaction was not significant ($F < 2$). Eighteen out of the 24 participants (.75) in the fixed configuration group selected the correct, target-predictive quadrant in the follow-up recognition test, and 11 of these 18 gave reasons that indicted they were aware of spatial cueing; e.g., "That's where I would look the majority of the time," but none indicated that they were aware of categorical cueing.

Within the random configuration condition, we again found a main effect of epoch, $F(3, 19) = 56.96$, $p < .001$, $\eta_p^2 = .90$, and a marginal Epoch × Predictiveness interaction, $F(3, 19) = 2.91$, $p = .061$, $\eta_p^2 = .32$, suggesting that search was initially faster on predictive than on non-predictive displays, but this effect of cueing decreased over time (Figure 4). There was no main effect of predictiveness, $F(1, 21)$, = 2.50, $p = .129$. Seven out of 22 participants (.32) selected the target-predictive quadrant in the recognition test, but none were aware of categorical cueing.

Experiment 1B: Multiple-exemplar distractors: In the full analysis, there were main effects of epoch, $F(3, 43) = 70.08$, $p < .001$, $\eta_p^2 = .83$, and predictiveness, $F(1, 45) = 20.87$, $p < .001$, $\eta_p^2 = .32$, indicating faster search over time and on predictive displays. There was also a main effect of configuration, $F(1, 45) = 6.27$, $p = .016$, $\eta_p^2 = .12$, and a Predictiveness × Configuration interaction, $F(1, 45) = 5.96$, $p = .019$, $\eta_p^2 = .12$, indicating that participants benefitted from contextual cueing in predictive displays primarily in the fixed configuration condition (Figure 5). The Epoch × Predictiveness interaction was marginal, $F(3, 43) = 2.32$, $p = .088$, $\eta_p^2 = .14$, and the remaining Epoch × Configuration and Epoch × Predictiveness × Configuration interactions were not significant (both Fs < 2).

Within the fixed configuration group, we found main effects of epoch, $F(3, 22) = 39.72$, $p < .001$, $\eta_p^2 = .84$, and predictiveness, $F(1, 24) = 22.05$, $p < .001$, $\eta_p^2 = .48$, and an Epoch × Predictiveness interaction, $F(3, 22) = 3.24$, $p = .042$, $\eta_p^2 = .31$. Fourteen out of 25 participants (.56) in the fixed configuration group selected the target-predictive quadrant, and eight of these participants indicated explicit awareness of spatial cueing in the recognition test. One of these eight participants indicated a possible awareness of categorical cueing (“I saw many other sports-related objects”).

In the random configuration group, we found a significant main effect of epoch $F(3, 19) = 35.32$, $p < .001$, $\eta_p^2 = .85$, but no significant effect of predictiveness, $F(1, 21) = 2.72$, $p = .114$, and no interaction ($F < 1$). Nine out of the 22 participants (.41) selected the correct target quadrant, and one of these participants indicated a potential awareness of categorical cueing (“Household/random objects”).

Experiment 1C: Single-exemplar distractors, with image target cues: In the overall analysis, we found significant effects of epoch, $F(3, 43) = 19.76$ $p < .001$, $\eta_p^2 = .58$, predictiveness, $F(1, 45) = 42.33$, $p < .001$, $\eta_p^2 = .49$, and configuration, $F(1, 45) = 22.69$, $p < .001$, $\eta_p^2 = .34$. We also observed a Predictiveness × Configuration interaction, $F(1, 45) = 45.63$, $p < .001$, $\eta_p^2 = .50$, indicating that participants only benefitted from predictive displays when distractor configurations were fixed (Figure 6). Marginal interactions include Epoch × Configuration, $F(3, 43) = 2.44$, $p = .077$, $\eta_p^2 = .15$, and Epoch × Predictiveness, $F(3, 43) = 2.41$, $p = .080$, $\eta_p^2 = .14$. The three-way interaction was not significant ($F < 2$).

In the fixed configuration condition, we found significant effects of epoch, $F(3, 22) = 16.15$, $p < .001$, $\eta_p^2 = .69$, and predictiveness, $F(1, 24) = 108.16$, $p < .001$, $\eta_p^2 = .82$, but no interaction ($F < 1$). Thirteen out of 25 participants (.52) selected the correct, target-predictive quadrant in the recognition test, and nine of these were aware of spatial cueing. None indicated that they were aware of categorical cueing.

In the random configuration condition, there was a main effect of epoch, $F(3, 19) = 6.07$, $p = .004$, $\eta_p^2 = .49$, but no effect of predictiveness, $F(1, 21) = .025$, $p = .875$, and no interaction ($F < 2$). Only three out of 22 participants (.14) selected the target-predictive quadrant in the final memory test, and none were explicitly aware of categorical cueing.

Discussion

In Experiment 1, we presented paticipants with a visual search task in which each display was comprised of several categories of distractors, each clustered together in each quadrant, and one of these categories was predictive of the target location. Experiments 1A and 1B presented verbal target cues, while 1C presented image cues. In Experiments 1A and 1C, each distractor exemplar was held constant throughout the experiment, while 1B presented varied exemplars on each trial.

In fixed displays, where the locations of each distractor category were held constant in particular quadrants, participants were faster to find the target on predictive displays than on non-predictive displays. This learning was evident early in all sub-experiments, indicating a rapid learning of predictive displays. However, given that spatial locations of each distractor category, including the target-predictive category, were held relatively constant, any effect of categorical cueing cannot be dissociated from spatial cueing in fixed displays. Also, object-specific cueing cannot be separated from category-based cueing in Experiments 1A and 1C, because distractor identities were held constant in these experiments.

Finding similar contextual cueing effects in random displays, however, would provide support that participants were learning categorical information about distractors and using this to locate targets, independently of learning consistent target spatial locations. With random distractor configurations, participants were generally faster to find targets in predictive displays than in non-predictive displays in Experiments 1A and 1B, although these effects were weak or nonsignificant. No contextual cueing was evident in the random condition of Experiment 1C, where search times were also generally faster than in 1A (1499 ms versus 2183 ms, respectively). These results likely indicate that participants need adequate time to inspect distractors in order for semantic information to become available (i.e., distractors' category membership).

Despite the lack of significant effects in the random configuration conditions of Experiments 1A and 1B, the means for predictive and non-predictive displays were in the predicted direction—search times were faster in predictive than in non-predictive displays. Although finding this trend in Experiment 1B suggests that people were learning the predictive distractor category when exemplars comprising this category were varied, the possibility still exists that they were learning individual distractor identities, given that only six possible exemplars of each image could be presented. In order to rule out the learning of distractor identities as an explanation for this trend, we conducted two additional control experiments in which we eliminated coherent distractor categories.

Experiment 2

In order to determine if the mean differences between the predictive and non-predictive displays observed in Experiments 1A and 1B were the result of categorical contextual cueing, we conducted two additional experiments that eliminated consistent categorical grouping of distractors. Experiments 2A and 2B were identical to 1A and 1B, except that distractors from all categories were intermixed within each quadrant. In the fixed spatial configuration conditions of Experiment 2, finding a pattern of mean differences between predictive and non-predictive displays similar to Experiments 1A and 1B would indicate spatial contextual cueing. Within the random spatial configuration condition, spatial cueing and categorical cueing effects should be absent. Item-specific cueing effects have the greatest likelihood of emerging in Experiment 2A, where only one exemplar of each distractor was presented throughout.

Method

Participants

Ninety-seven students at Arizona State University took part in Experiment 2 (48 in 2A and 49 in 2B). All participants gave informed consent, and this experiment was approved by the Arizona State University Institutional Review Board.

Procedure

All stimuli presented in Experiments 2A and 2B were identical to those presented in Experiment 1, and only verbal target cues were presented in these experiments. In order to eliminate coherent category grouping, each quadrant contained items from all distractor categories. For example, a dog, a screwdriver, and a table from the categories "animals," "tools," and "furniture" might occur together within quadrant 1, while a cat, a hammer, and a chair might occur in quadrant 2. As in Experiment 1, distractor exemplars were held constant on each trial in Experiment 2A, and randomly sampled from larger lists of exemplars in Experiment 2B to decrease the possibility of item-specific contextual cueing (see Figures 7 and 8 for the conditions in Experiment 2).

Results

One participant was excluded from the analyses in Experiment 2A for having low accuracy (< 2.5 standard deviations), for a total of 47 participants retained. The average accuracy for retained participants in Experiment 2A was .97. Two participants were excluded from Experiment 2B, one for being a non-native English speaker and one for having low accuracy, for a total of 47 participants retained. Average search accuracy was .97 in Experiment 2B.

In addition to the analyses conducted within each sub-experiment, several analyses were conducted in order to compare the experimental (Experiment 1) to the control (Experiment 2) conditions: Experiment 1A to Experiment 2A (fixed distractor exemplars), and Experiment 1B to Experiment 2B (varied distractors). These analyses were conducted separately for fixed and random spatial configurations. Finding a Predictiveness × Experiment interaction within these analyses would indicate differential effects of cueing in the experimental and control conditions.

Experiment 2A: Single-exemplar distractors: Within the full analysis, main effects include epoch, $F(3, 43) = 74.99$, $p < .001$, $\eta_p^2 = .84$, predictiveness, $F(1, 45) = 43.40$, $p < .001$, $\eta_p^2 = .49$, and configuration, $F(1, 45) = 7.41$, $p = .009$, $\eta_p^2 = .14$. There was also a significant Predictiveness × Configuration interaction, $F(1, 45) = 36.74$, $p < .001$, $\eta_p^2 = .45$. As Figure 9 indicates, participants became faster on predictive displays, but only when distractor configurations were spatially fixed. None of the remaining interactions (Epoch × Configuration, Epoch × Predictiveness, and Epoch × Predictiveness × Configuration) were significant (all *F*s < 2).

Within fixed distractor configurations, we observed main effects of epoch, $F(3, 22) = 45.81$, $p < .001$, $\eta_p^2 = .86$, and predictiveness, $F(1, 24) = 55.61$, $p < .001$, $\eta_p^2 = .70$, but no interaction ($F < 1$). Eleven out of 25 participants (.44) selected the correct target-predictive quadrant in the post-experiment recognition test, and all of these 11 participants indicated that they were aware of spatial cueing.

With random configurations, we found a main effect of epoch, $F(3, 19) = 27.97$, $p < .001$, $\eta_p^2 = .82$, and an Epoch × Predictiveness interaction, $F(3, 19) = 3.49$, $p = .036$, $\eta_p^2 = .36$, but no main effect of predictiveness, $F(1, 21) = .337$, $p = .568$. Although the interaction is significant, Figure 9 indicates that this effect is not interpretable, given that the means for predictive and non-predictive trials are largely overlapping. Only four out of 22 participants (.18) selected the correct target-predictive quadrant in the follow-up test. None indicated that they were aware that the target occurred near the same distractors in predictive displays (i.e., explicit object-based cueing).

Comparison: Experiments 1A and 2A: In the analysis comparing the fixed configuration conditions within each experiment, we observed main effects of epoch, $F(3, 45) = 78.62$, $p < .001$, $\eta_p^2 = .84$, predictiveness, $F(1, 47) = 156.87$, $p < .001$, $\eta_p^2 = .77$, and experiment, $F(1, 47) = 14.02$, $p < .001$, $\eta_p^2 = .23$. None of the interactions were significant (all *F*s < 2), indicating that effects of cueing were equivalent across experiments.

In the analysis comparing each experiment's random configuration condition, we observed main effects of epoch, $F(3, 40) = 73.84$, $p < .001$, $\eta_p^2 = .84$, and experiment, $F(1, 42) = 13.42$, $p = .001$, $\eta_p^2 = .24$. The main effect of predictiveness was not significant, $F(1, 42) = 2.83$, $p = .100$, and none of the interactions were significant (all *F*s < 3), indicating a lack of significant cueing either when distractors were categorically grouped (Experiment 1A) or intermixed (Experiment 2A).

Experiment 2B: Multiple-exemplar distractors: In the full analysis, we found main effects of epoch, $F(3, 43) = 64.32$, $p < .001$, $\eta_p^2 = .82$, predictiveness, $F(1, 45) = 41.34$, $p < .001$, $\eta_p^2 = .48$, and a marginal effect of configuration, $F(1, 45) = 3.71$, $p < .060$, $\eta_p^2 = .08$. There was also a Predictiveness × Configuration interaction, $F(1, 45) = 45.02$, $p < .001$, $\eta_p^2 = .50$, indicating faster search on predictive displays, within fixed, but not random, configurations (Figure 10). None of the remaining interactions were significant (all *F*s < 3).

In the fixed distractor configuration condition, we found main effects of epoch, $F(3, 20) = 44.41$, $p < .001$, $\eta_p^2 = .87$, and predictiveness, $F(1, 22) = 85.85$, $p < .001$, $\eta_p^2 = .80$, but no interaction ($F < 2$). Eleven out of 23 participants (.48) selected the correct target-predictive quadrant in the follow-up test, and seven of these participants indicated that they were aware of spatial cueing.

Within random configurations, we found a main effect of epoch, $F(3, 21) = 21.71$, $p < .001$, $\eta_p^2 = .76$, but no effect of predictiveness, $F(1, 23) =.04$, $p = .844$, and no interaction ($F < 1$). Six out of 24 participants (.25) selected the correct target-predictive quadrant in the memory test. One participant indicated remembering specific distractors from the experiment (“I just remember some items from that location”).

Comparison: Experiments 1B and 2B: In fixed configurations, we found significant main effects of epoch, $F(3, 44) = 80.05$, $p < .001$, $\eta_p^2 = .85$, predictiveness, $F(1, 46) = 74.89$, $p < .001$, $\eta_p^2 = .62$, and experiment, $F(1, 46) = 10.86$, $p = .002$, $\eta_p^2 = .19$, and a marginal Epoch × Predictiveness interaction, $F(3, 44) = 2.80$, $p = .051$, $\eta_p^2 = .16$. None of the remaining interactions were significant (all *F*s < 1), indicating that effects of cueing were equivalent in each experiment.

In random configurations, there were main effects of epoch, $F(3, 42) = 53.75$, $p < .001$, $\eta_p^2 = .79$, and experiment, $F(1, 44) = 9.46$, $p = .004$, $\eta_p^2 = .18$, but no significant main effect of predictiveness, $F(1, 44) = 1.57$, $p = .217$, $\eta_p^2 = .03$, and no interactions (all *F*s < 3). These results indicate a lack of significant cueing effects in either experimental (Experiment 1B) or control (Experiment 2B) conditions.

Discussion

In Experiment 2, we presented participants with identical conditions as Experiment 1, except that we eliminated coherent categorical grouping of distractors in the search display. In Experiment 2A, the same exemplars of distractors were held constant throughout the experiment, and in Experiment 2B, distractor exemplars were randomly sampled from larger lists on each trial.

Not surprisingly, participants were faster to find the target on predictive trials than on non-predictive trials within the spatially-fixed condition of both experiments. Given that distractors were no longer coherently grouped into categories with each quadrant, this effect was a result of spatial cueing, as indicated by several participants in the post-experiment surprise recognition tests. Such contextual cueing effects were absent when participants were presented with random configurations of distractors in both 2A and 2B, which suggests that participants were not encoding specific distractor identities and using this information to locate targets (i.e., object-specific cueing). Although we failed to find significant differences between the experimental and control conditions (Experiments 1 and 2, respectively) in random configurations, the absence of object-specific cueing in the control experiments 2A and 2B strongly suggests that the potential cueing effects observed in Experiments 1A and 1B were a result of participants learning the predictive categories of distractors, and not a result of implicit learning of specific exemplars (e.g., Chun & Jiang, 1999).

General Discussion

Previous research has shown that people can implicitly encode repeated visual contexts and benefit from this information during search. This contextual cueing occurs when repeated distractor images and spatial configurations (Chun & Jiang; 1998, 1999) are predictive of the target location. Goujon, et al. (2007; 2009) also showed that when distractors are verbally presented, semantic information (i.e., category membership) can cue participants to the target location. We sought to further investigate this effect of categorical cueing by presenting participants with visual search displays in which specific categories of distractors were consistently predictive of target locations.

In Experiment 1A, we presented participants with these predictive displays, while holding distractor identities constant. Results showed reliable contextual cueing effects when the spatial location of the predictive category was held relatively constant, and a marginal effect of cueing when category locations were random. In the condition where spatial locations of distractors were constant, these results could indicate a combination of spatial, categorical, and object-based cueing. When spatial locations of distractors were varied, however, only categorical and object-based cueing could be the cause of this cueing effect—i.e., participants could have implicitly learned both distractor categories and their identities and used this information to guide search. No such cueing effects were observed with random spatial configurations in Experiment 1C, however, which was identical to 1A, except that image target cues were presented instead of verbal target cues. This absence of potential categorical or distractor-specific cueing in 1C was likely due to the ease of the search task, given that participants were shown the exact target before each trial.

Because the contextual cueing effects observed with random distractor configurations in Experiment 1A could have been partially a result of implicit learning of distractor identities, we sought to isolate categorical cueing from any distractor-specific cueing in Experiment 1B. In this experiment, we varied the exemplars that comprised each distractor category from trial-to-trial. We observed a similar pattern of results as those from Experiment 1A: Spatial cueing occurred when distractor locations were held constant. With random distractor category configurations, we observed a predicted pattern of mean differences—target detection times were faster on trials with target-predictive categories than on control trials—although these differences failed to reach significance. No such mean differences between predictive and non-predictive trials were observed with random spatial configurations in the two control experiments, 2A and 2B, indicating that the possible cueing effects observed in 1A and 1B were likely due to participants learning specific categories of distractors, and not using repeated exemplars to cue them to the target location.

Speeded Search and the Availability of Semantic Information

One possible interpretation of the weak categorical cueing effects in Experiments 1A and 1B is that the search task was too easy for semantic contextual cueing to fully emerge. In these critical experiments, the means for predictive and non-predictive trials were in the predicted direction (i.e., participants were faster on predictive than non-predictive trials). In contrast, there were obviously no cueing effects in 1C (Figure 6), but search times were also generally faster, indicating that participants were likely using a strategy of holding the image target cue in memory and using this visual representation to rapidly locate the target in each search display.

Given this potential search strategy and such rapid search times, time spent fixating distractors was likely limited, decreasing the time for potential categorical information about distractors to become available. Using the visual world paradigm, Huettig and McQueen (2007) demonstrated the substantial time required for semantic information about images to become active enough to draw fixations. They tracked the eye movements of participants as they freely viewed displays containing four images, each occupying a quadrant of the screen. During viewing, participants also heard spoken sentences containing a target word. Of these images, one was semantically similar to the target word, one was phonologically similar, and one was similarly-shaped to the object described by the target word, in addition to a control image. The probability of fixating items that were semantically similar to the target (e.g., an image of a boat if "paddle" was the spoken target word) increased relative to phonological competitors and control images approximaely 600 ms after the onset of the target word. These results suggest that in our experiments, semantic information about distractors, including category membership, only became available after sufficient viewing time. Consequently, future experiments will include conditions that require extensive search through distractors by increasing search difficulty. These experiments will present multiple-target search (i.e., search for any one of three possible targets), and static noise will be added in place of a plain white background, in order to decrease target salience.

The Role of Global and Local Information in Contextual Cueing

Although limited distractor viewing time is a likely explanation for the weak observed contextual cueing effects, another possible explanation for these results concerns the spatial contexts within which we presented predictive displays. Within fixed distractor configurations, the global context of each display was held constant throughout all experiments—each category of distractors remained in the same respective quadrant. In this condition, the local context within which the target always appeared also remained constant, because target locations were confined to spatially-fixed predictive categories of distractors. With random spatial configurations, however, only the local categorical context where targets occurred (the predictive distractor category) remained constant, because each distractor category was assigned to a random quadrant location on every trial. Although the local predictive context was constant in this condition, the degraded global context of these displays may explain why contextual cueing effects were weak with varied distractor configurations, if category learning is strongly dependent on consistent global context.

Previous findings are equivocal on whether global or local context plays a greater role in contextual cueing, depending on the nature of the stimuli presented. For instance, Olson and Chun (2002) found that local elements are most important to driving spatial contextual cueing in a series of experiments. They presented participants with repeated displays in which either (1) the configurations of distractor Ls located in the same hemifield as the target T were held constant (short-distance cueing), but long-distance distractor Ls (in the opposite hemifield) were spatially randomized, or (2) long-distance distractor configurations were consistent but short-distance configurations were randomized (long-distance cueing). Contextual cueing was robust when short-distance configurations were repeated, but long-distance contextual cueing only emerged when there were no intervening elements from short-distance random configurations in the space between the target and the long-distance predictive configurations. Brady and Chun (2007) also found local context to be important to contextual cueing, but only when the absolute location of these locally predictive elements remained constant within the display. They presented repeated configurations similar to ours, in which predictive spatial contexts were confined to a quadrant of the display. On critical repeated trials, they presented a target T and a small, fixed group of several distractor Ls together within a particular quadrant, with all other quadrants containing random configurations of distractors. Participants learned these repeated local contexts when the target-predictive quadrant remained fixed throughout predictive trials, but not when the predictive quadrant location was randomized. Taken together, these findings suggest that with simple, semantically-neutral stimuli, local context strongly contributes to contextual cueing, if this context is fixed to a particular location within repeated displays.

Alternatively, findings from scene perception research demonstrate that global context is most important to target localization when stimuli contain meaningful information. In his classic scene perception study, Biederman (1972) demonstrated that even when local context is held spatially constant, people are more accurate at detecting targets within this local context if global context is intact. He presented participants with real-world scenes that were either intact or jumbled, with each containing a critical target object (e.g., a bicycle). The location of critical objects within their local contexts was preserved across intact and jumbled scenes, however. Participants were more accurate at detecting these target objects in preserved than jumbled scenes, despite the consistent local target contexts and locations in both conditions. These results suggest that global context is crucial for target localization in scenes. More recently, Brockmole, Castelhano, and Henderson (2009) supported this finding by varying whether local or global contexts were repeated within scenes. In one condition, the global context (e.g., a library scene) remained constant throughout repeated trials but the local context (e.g., a coffee table) where a target letter was consistently located was varied during a transfer task—the specific coffee table was changed. In another condition, the global context varied while the local context remained constant (e.g., the library was changed to a living room scene, but each scene contained the same table). Participants were faster to find targets within repeated global contexts over time than in repeated local contexts, suggesting that global context is most relevant when searching through scenes.

Overall, these findings demonstrate that local context plays a greater role in contextual cueing when repeated displays contain little semantic information, while global context plays a greater role when stimuli are meaningful (e.g., scenes). In order to examine the role that global context learning played in our results, future extensions of our study will include a condition analogous to that of Biederman (1972) in which we vary the global context of predictive displays while holding local context spatially constant. Specifically, on predictive displays, the target-predictive category will be fixed to a particular quadrant throughout the experiment, while the additional categories will be randomly assigned to the remaining three quadrants on each trial. Search performance in this condition can then be compared to another condition where the entire global context is held constant (i.e., fixed displays), in order to determine the importance of learning global versus local context in categorical cueing. If global information plays an important role with meaningful stimuli, as Biederman (1972) and Brockmole, et al. (2009) suggest, we would expect greater contextual cueing in our experiment when global context is consistent.

Conclusions

In conclusion, our experiments demonstrate the possibility that people can learn repeated semantic information about background items and use this information when it reliably predicts target locations. Future experiments will need to be conducted in order to verify this effect of categorical contextual cueing, and to examine the degree to which people rely on local and global information when searching through meaningful stimuli.

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Table 1

Categories of Distractor Stimuli

Animals	Clothing	Food	Furniture	Musical Instruments	Sports Equipment	Tools	Vehicles
bear	coat	doughnut	bed	banjo	golf bag	axe	boat
cat	dress	burger	bench	bugle	baseball bat	power drill	bus
dog	glove	burrito	cabinet	drum	football	hammer	car
elephant	hat	cake	chair	cymbals	baseball glove	pliers	helicopter
horse	pants	French fries	desk	guitar	hockey net	handsaw	motorcycle
mouse	robe	hot dog	sofa	saxophone	hockey puck	shovel	plane
pig	shirt	ice cream	stool	piano	tennis racket	tape measure	train
tiger	shoe	pizza	table	xylophone	soccer ball	wrench	truck

Note. *Each distractor item was represented by six exemplars.*

Table 2

Target Stimuli

alien	carpet	dome	funnel	lock	satellite
anchor	cart	domino	furnace	log	satellite dish
baby	ceiling fan	door knocker	gift box	loudspeaker	scoop
backpack	cell phone	doorbell	glasses	lunch tray	scroll
barrel	chain	drain	globe	microscope	skull
barricade	cheese grater	dumpster	grenade	mixer	slide
beaker	clothes dryer	duster	grill	muffler	snowflake
bible	clothespin	dustpan	hair brush	nunchucks	soap bottle
bird feeder	cooking pan	dynamite	hair dryer	nutcracker	spoon
birdbath	crossbow	earrings	handbag	packing foam	spray bottle
blanket	crucifix	easel	handcuffs	painting	staircase
bone	curtains	electric burner	hanger	paper bag	stapler
boomerang	cutting board	electricity meter	joystick	parking meter	stroller
box	dancer	faucet	jukebox	party favor	swing set
bracelet	dentures	feather	key	pencil sharpener	teapot
briefcase	deodorant	fence	keyboard	perfume	telephone dial
broom	detergent	file folder	keychain	pillow	thermometer
bucket	devil	film	kite	pool	thumbtack
buckle	diamond	fish tank	ladle	propeller	toy wagon
button	dishwasher	flashbulb	lamp	record player	trophy
cactus	diskette	flask	lantern	refrigerator	washboard
calculator	dog collar	flower	laptop	remote control	webcam
candle	doll	fort	light switch	retainer	wheelchair
canteen	dollar bill	fountain	lighter	ribbon	wig
carousel	dollhouse	fryer	lip balm	rubber stamp	witch

Figure 1. Conditions in Experiments 1A and 1C. Only four items are presented within each quadrant for illustrative purposes; each quadrant contained eight items in the experiment. The dashed lines dividing each quadrant are also presented for illustrative purposes and were not visible to participants.

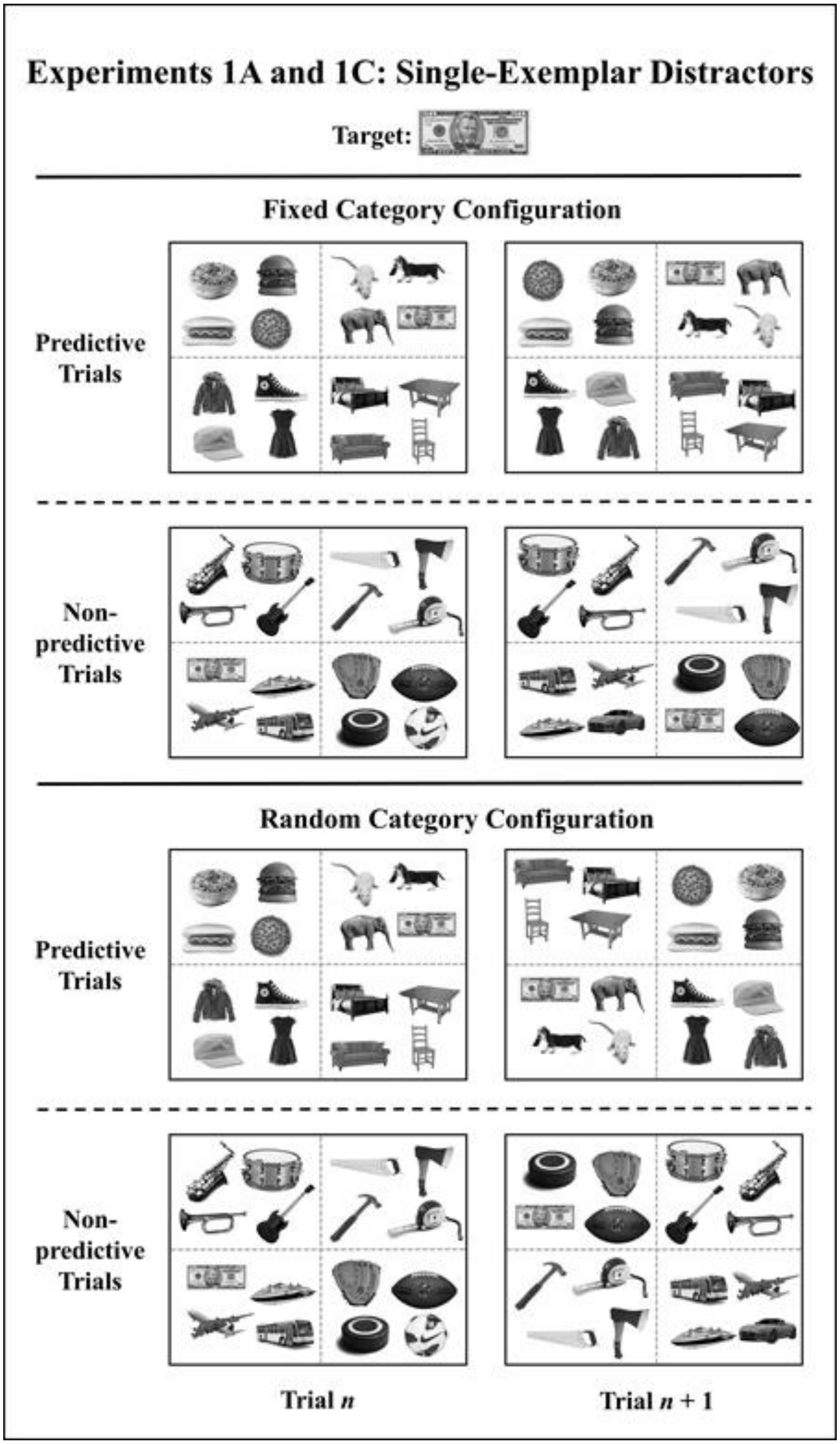


Figure 2. Conditions in Experiment 1B.

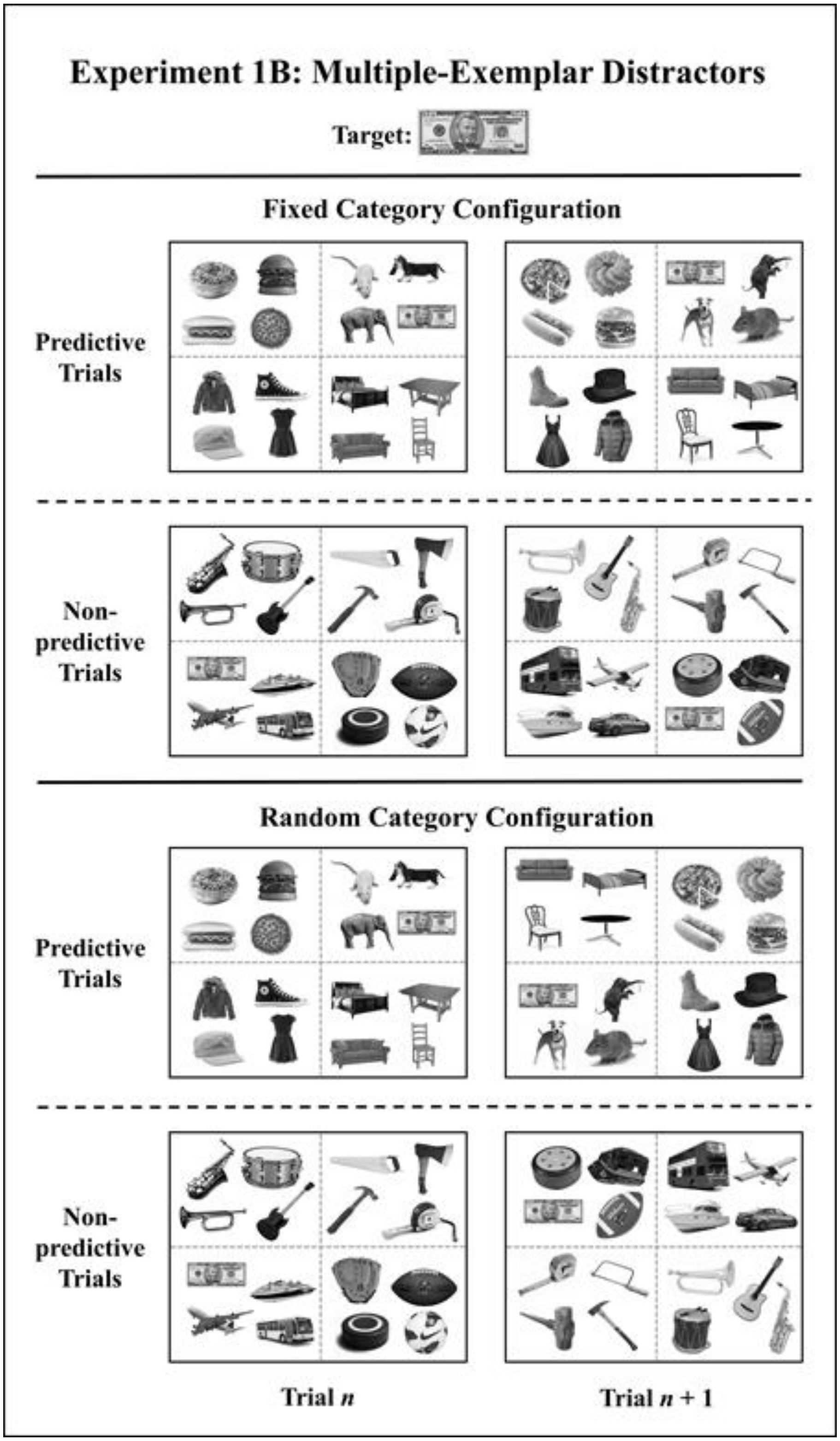


Figure 3. Sequence of events in each trial.

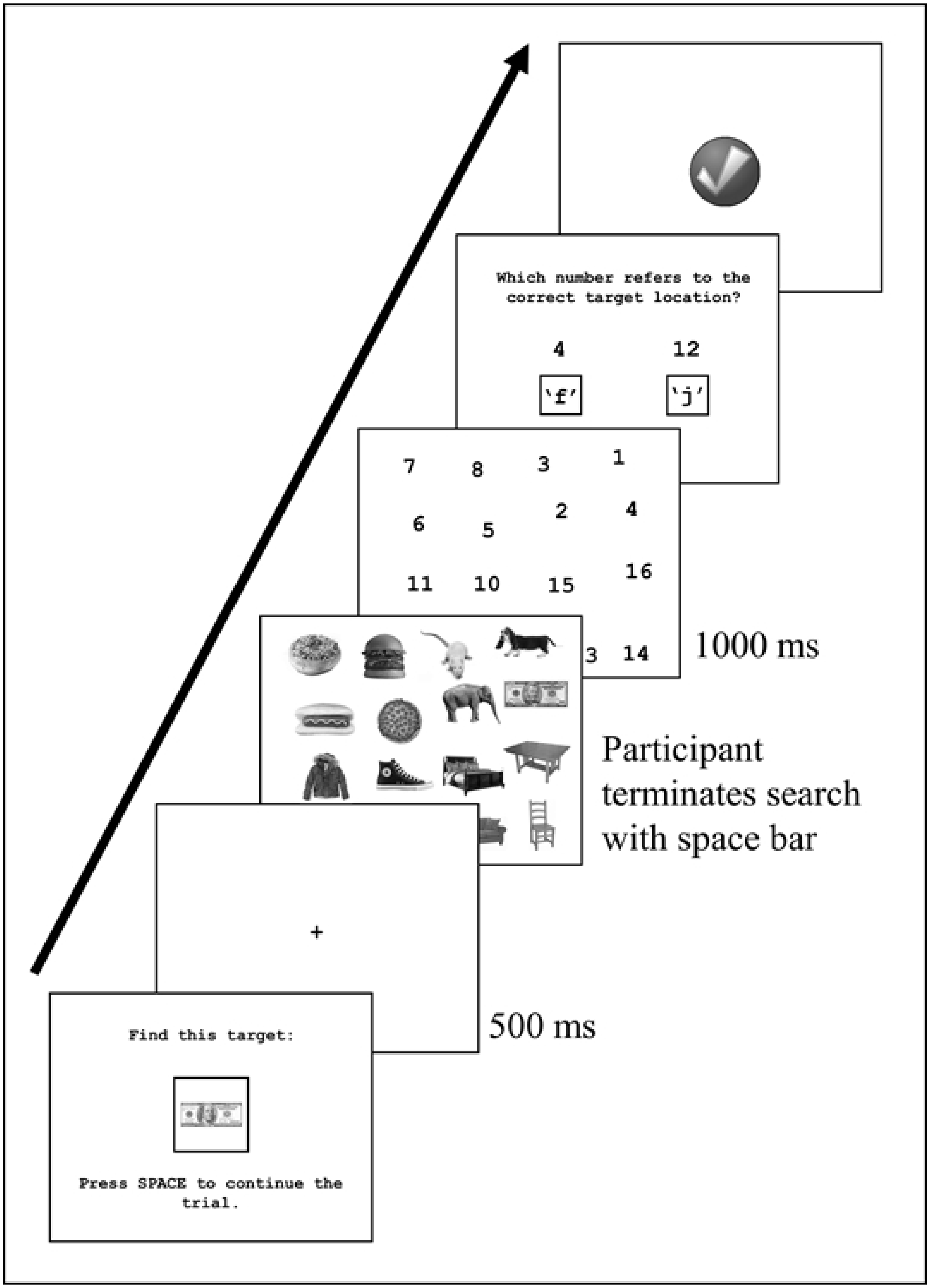


Figure 4. Search time for fixed and random configurations, as a function of predictiveness and epoch in Experiment 1A, which presented categorically-predictive displays. Each distractor item was represented by a single exemplar on all trials.

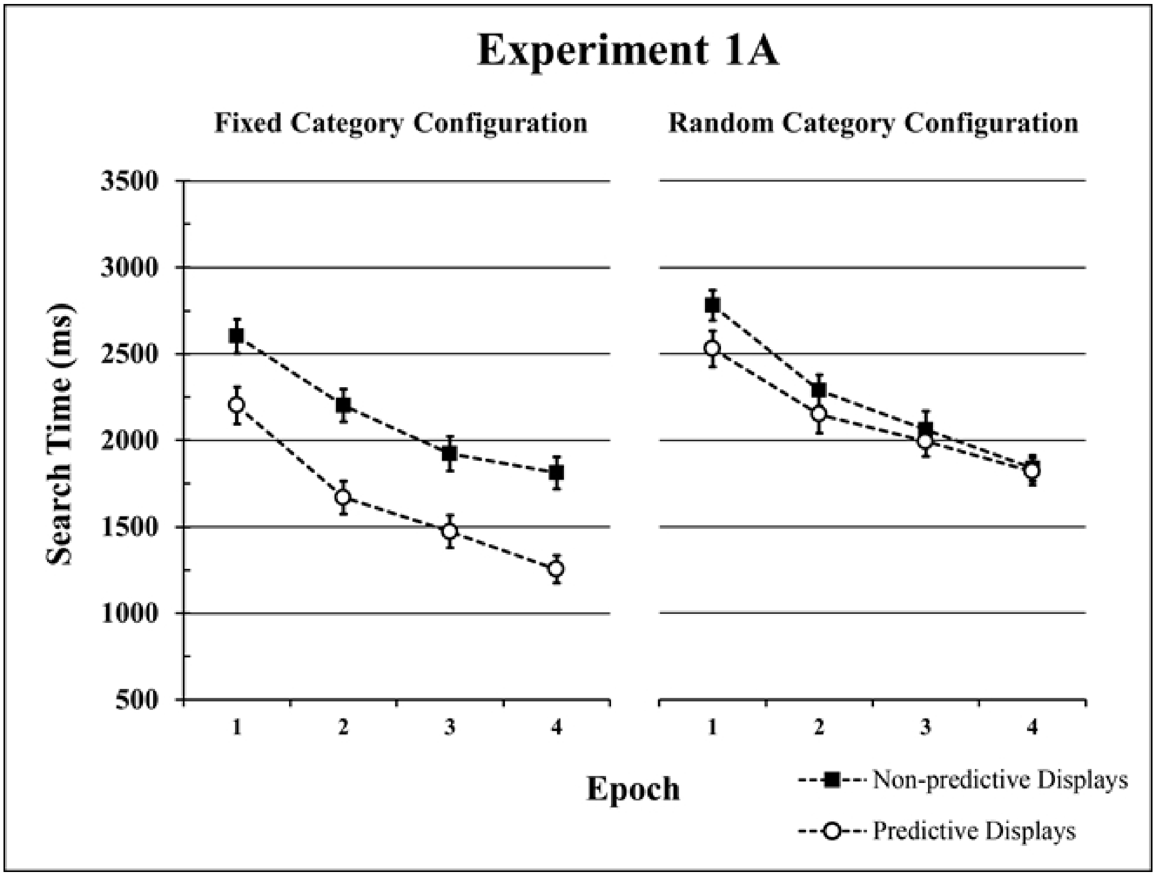


Figure 5. Search time for fixed and random configurations, as a function of predictiveness and epoch in Experiment 1B, which presented categorically-predictive displays. Each distractor was represented by one of six randomly-sampled exemplars on each trial.

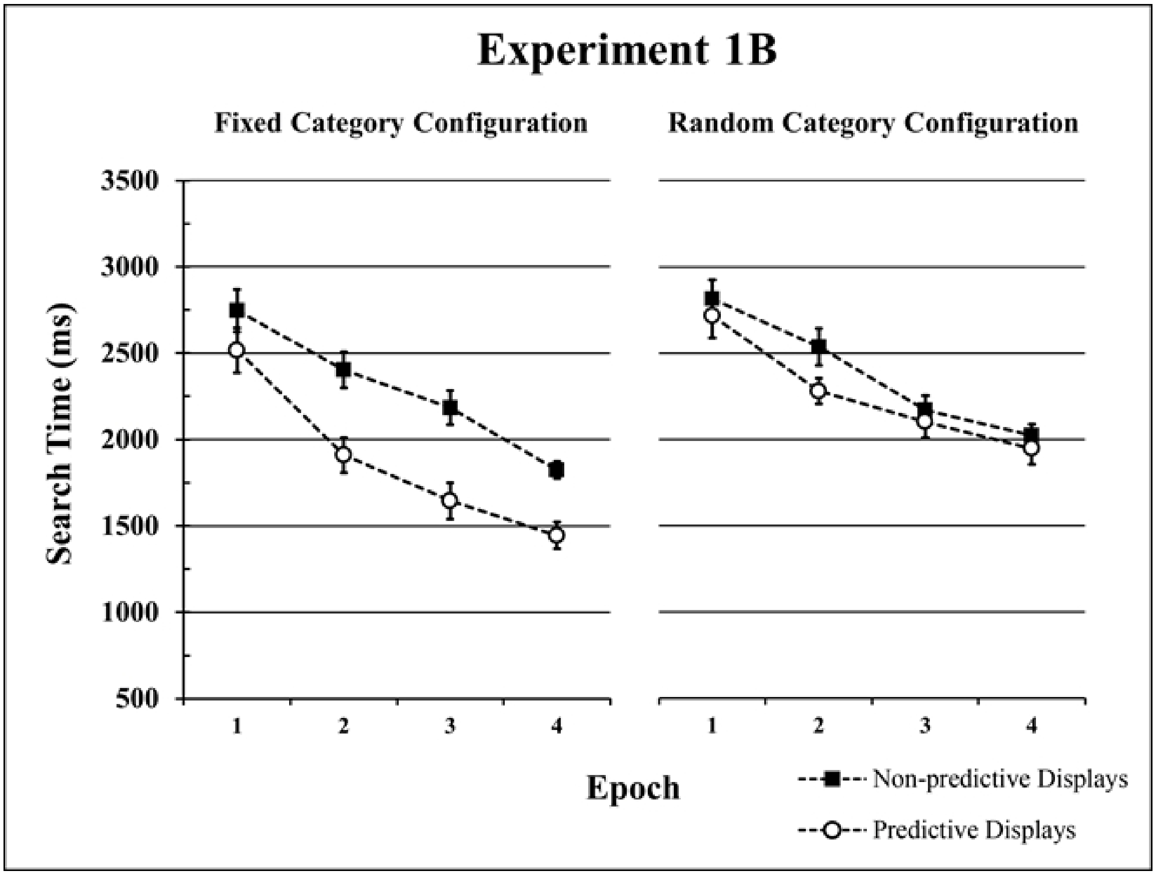


Figure 6. Search time for fixed and random configurations, as a function of predictiveness and epoch in Experiment 1C, which presented categorically-predictive displays with fixed exemplars representing each distractor item. Note that image target cues were presented instead of verbal cues at the beginning of each search trial.

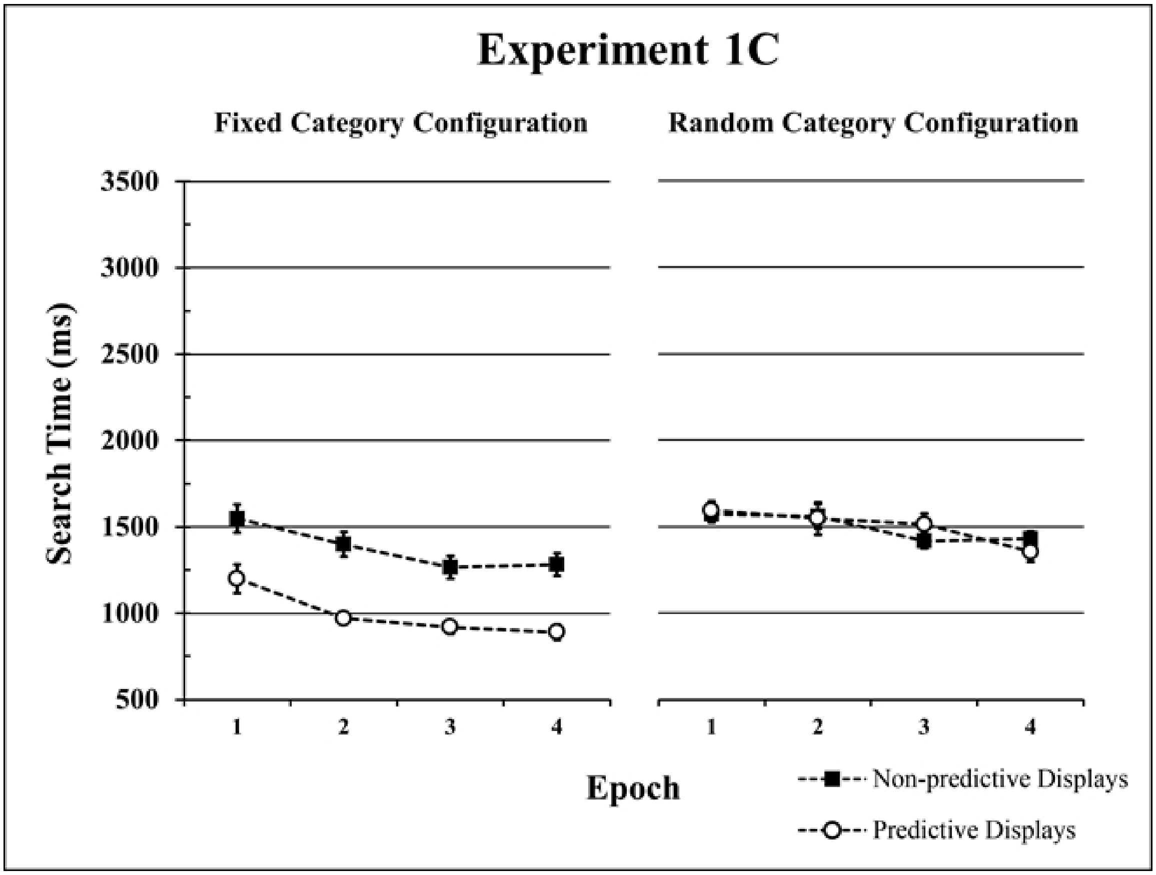


Figure 7. Conditions in Experiment 2A.

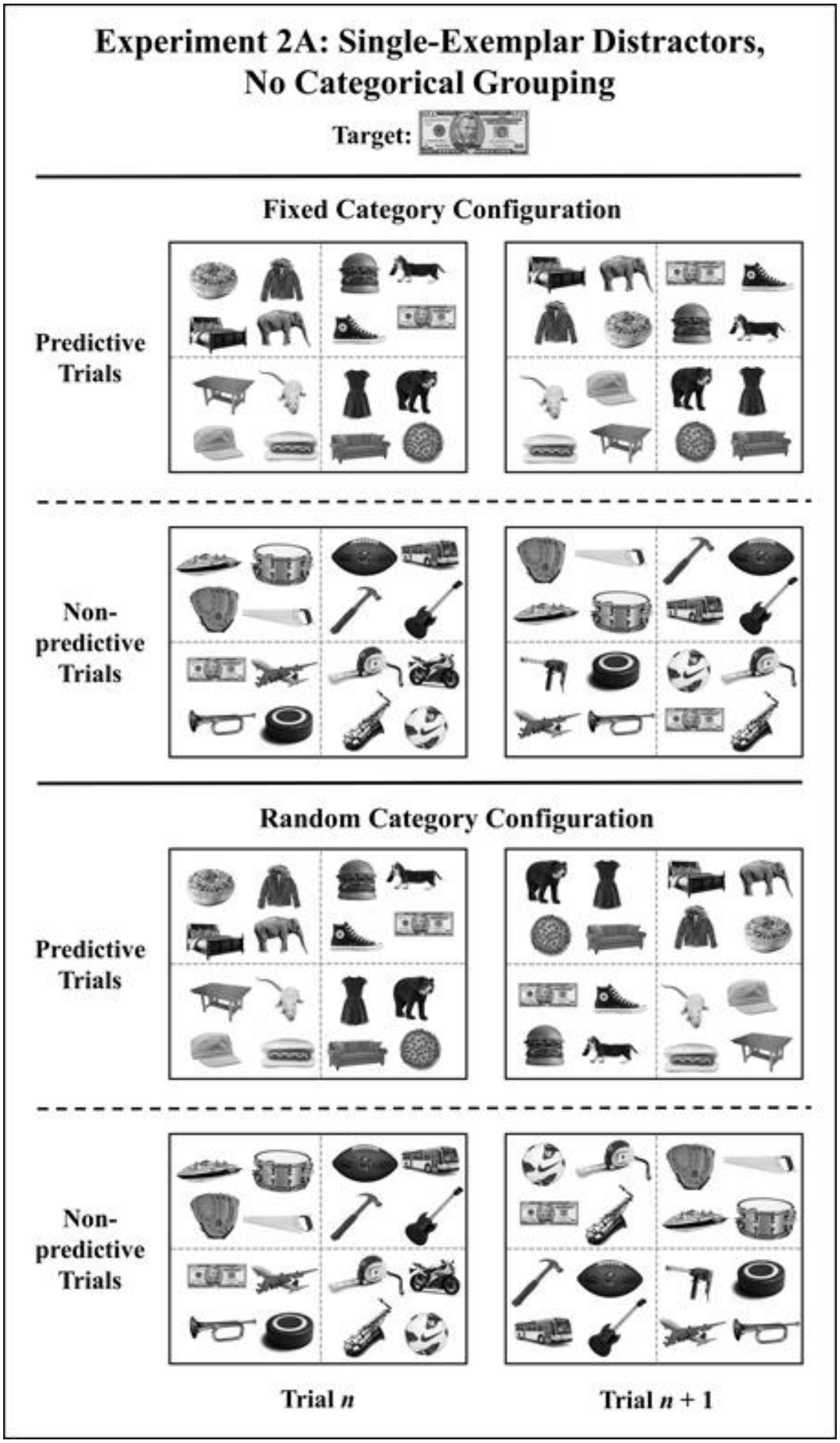


Figure 8. Conditions in Experiment 2B.

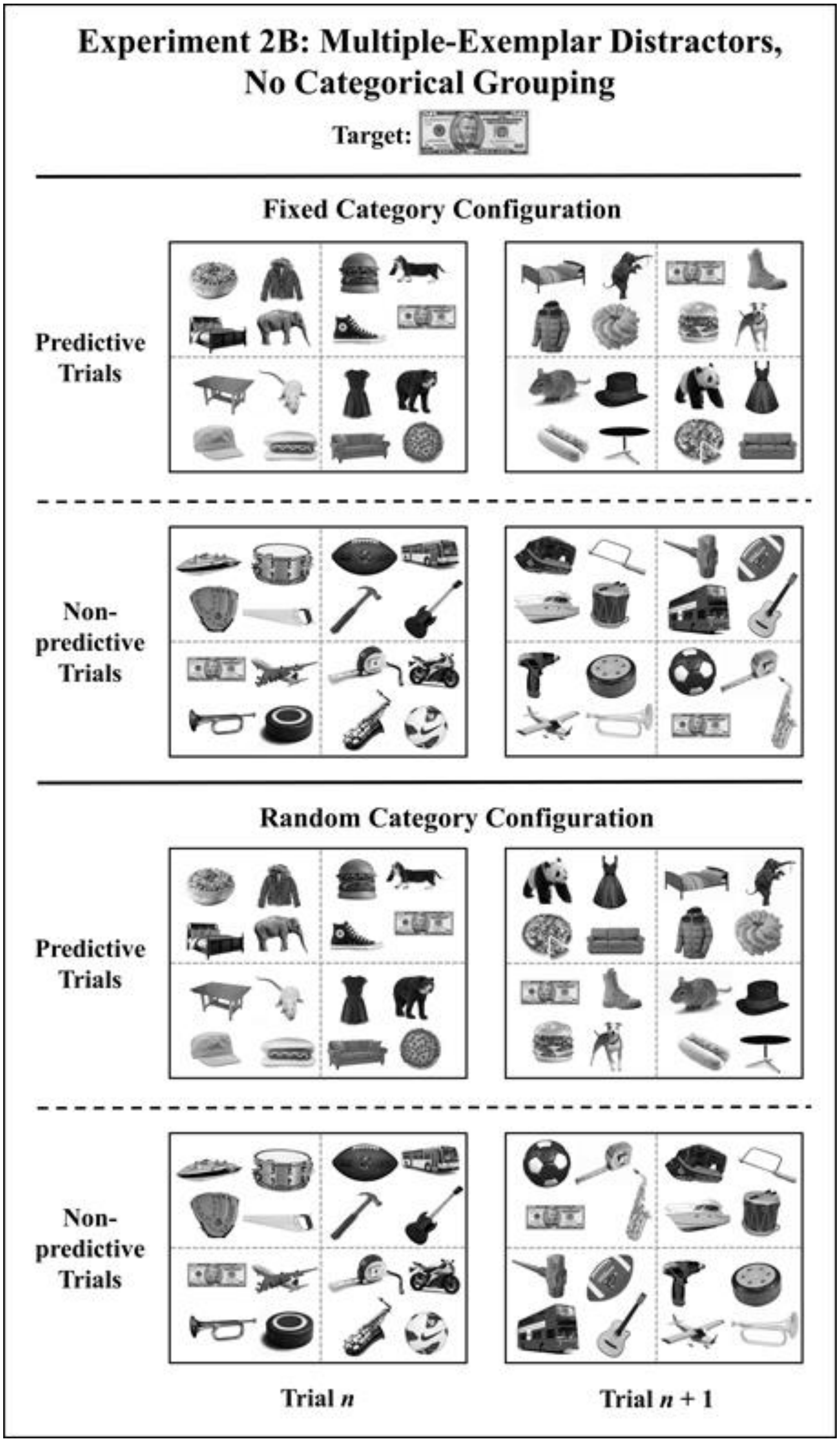


Figure 9. Search time for fixed and random configurations, as a function of predictiveness and epoch in Experiment 2A. Coherent distractor categories were eliminated in this experiment, and each distractor was represented by a single exemplar on all trials.

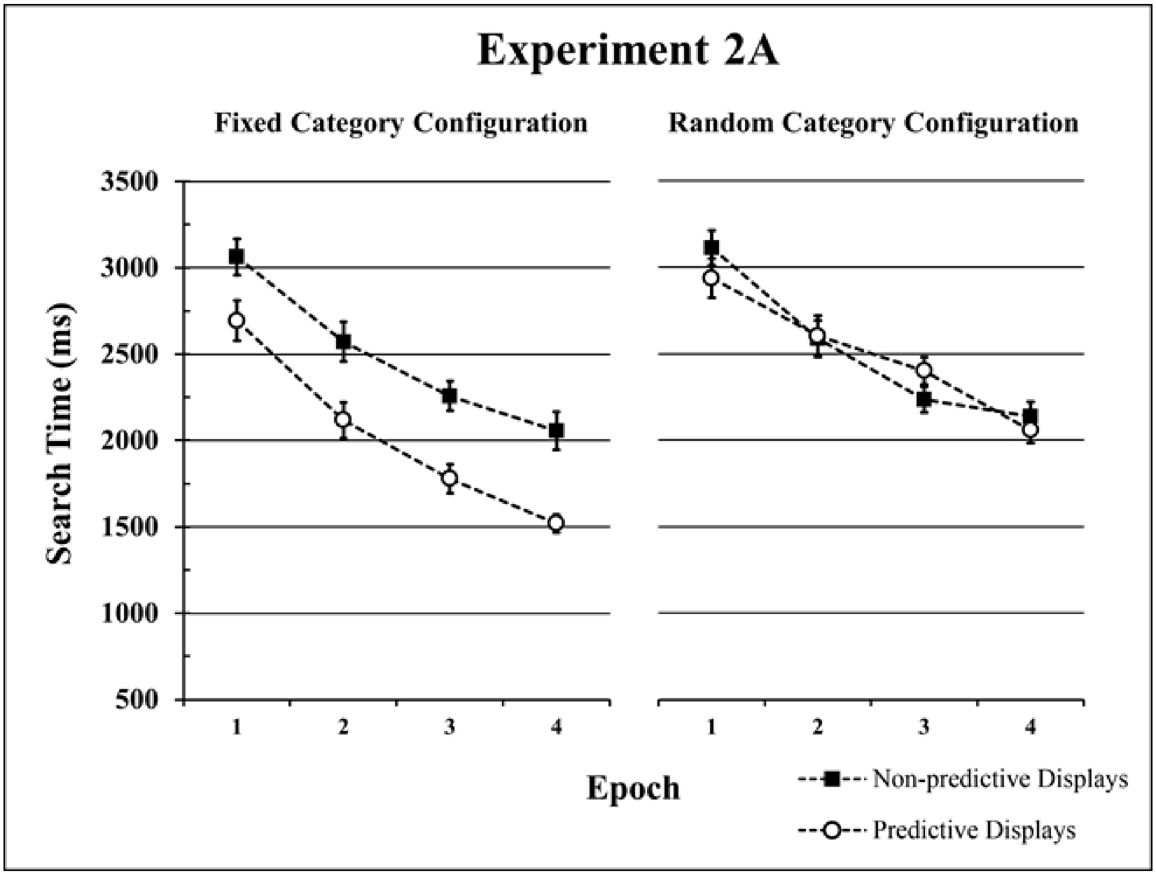
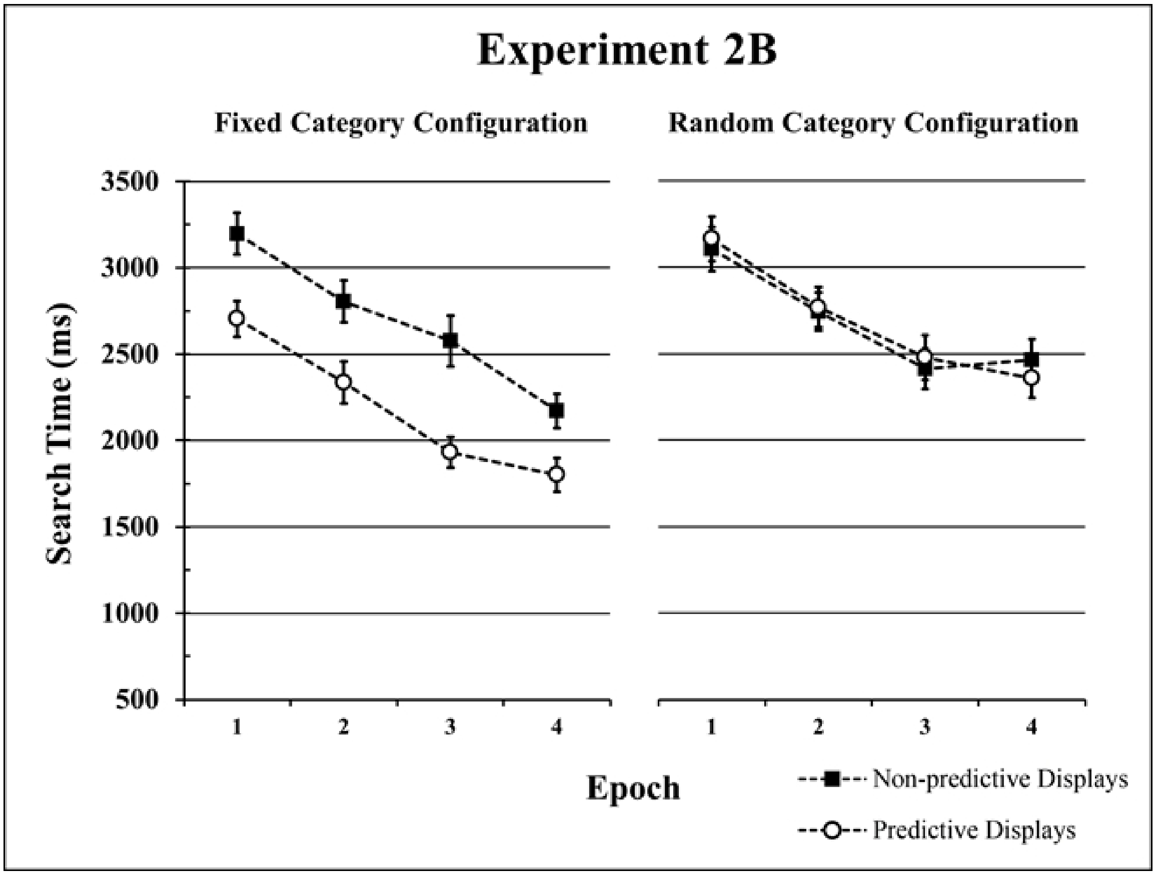


Figure 10. Search time for fixed and random configurations, as a function of predictiveness and epoch in Experiment 2B. Coherent distractor categories were eliminated in this experiment, and each distractor was represented by a randomly-sampled exemplar on each trial.



APPENDIX A

ASU INSTITUTIONAL REVIEW BOARD HUMAN SUBJECTS APPROVAL

Knowledge Enterprise Development

Office of Research Integrity and Assurance

To:	Stephen Goldinger Psychology
From:	Mark Roosa, Chair Soc Beh IRB
Date:	01/14/2013
Committee Action:	**Exemption Granted**
IRB Action Date:	01/14/2013
IRB Protocol #:	1301008689
Study Title:	Attention and Object Representation

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(2) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.