Effects of Priming on the Deployment of Attention in Visual Search

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Abstract

This study investigates the priming effect in visual search using shape as the priming feature. We program a web-based application that uses Ts as targets and Ls as distractors. We run two separate experiments, each using a different set of targets and distractors, and measure the observer's speed in finding the target on each trial. We also vary the set sizes and scale the dimensions of the images between the experiments. In each experiment, the target can take on two distinct forms: the sharp T and the dotted T in experiment I, and the circular T and the arrow T in experiment II. We show that priming only has a significant effect on the initial deployment of attention and that its effect is not sustained throughout the search task. We propose a transient model of priming where the priming effect is initially strong but rapidly falls off as the search progresses. We also notice that it took the observer longer to respond to the circular and sharp targets which we hypothesized was due to their thickness. The data show a statistically insignificant but comparatively large slope difference between pairs of run (target remains the same) and switch (target changes) functions in each experiment. We attribute this difference to the skinnier objects having a stronger bottom-up salience.

Summary

Visual search describes any task in which an observer must look for a target object among an array of distractor objects. Visual search is guided by factors that are processed before the initial deployment of attention. Priming is one of these factors. It describes the way in which past searches influence the current search task. An object is called "primed" if it shares a property with a target object in the previous search task. In this study, we aim to quantify the priming effect experimentally. We show that the priming effect is initially strong, but falls off before the observer has attended to all of the primed objects. We test this with a task that requires the observer to look for a T (the target) among an array of Ls (the distractors) and declare its orientation. The Ts and Ls can each take on two different shapes in either experiment. In the first experiment, they can take on sharp and dotted shapes and in the second they can be circular or in the shape of an arrow. We hypothesize a transient model for priming in which priming initially has a strong effect that rapidly falls off as the search progresses. We also notice that it takes the observers longer to find the thicker objects than it does the skinnier objects. We attribute this phenomenon to the comparatively greater difficulty in deducing their orientation as well as the skinnier objects popping out of the scene to a larger degree.

1 Introduction

Visual search is a ubiquitous and essential part of many people's daily lives. Visual search tasks range from fast, trivial searches like finding a fork next to a plate, to longer, more complicated tasks like looking for a tumor in a CT scan. Guided search (GS) [1] is a model for visual search based on the following ideas: search is guided by preattentive factors (factors that can be processed without conscious action) and there is a continuum between parallel and serial search tasks. The latter idea is in direct contrast with GS's predecessor, Treisman's Feature Integration Model (FIT) [2], which proposed a dichotomy between parallel and serial search tasks. The GS model purposes that no searches are inherently serial or parallel, but are instead all guided by the features of the stimuli or the scene itself. This key difference between the models allowed GS to resolve a lot of the empirical challenges FIT experienced in searches for conjunctions of two features. GS has been continuously refined since its initial publication and currently exists in its sixth official version, Guided Search 6.0 (GS6) [3]. Guided Search 6.0 introduces an additional three forms of guidance to the two already included in the model. Collectively, they are priming, value, top-down guidance, bottom-up salience, and scene guidance. These five forms of guidance work in concert to create a spatial priority map that guides a search task [4]. Areas of high weight in the priority map correspond to areas in the scene that most strongly draw attention.

Visual priming describes how past searches guide the deployment of attention in the current search task. An object in a search array is called "primed" if it shares a property with a target object in the previous search task. Priming is based on the idea that attending to a feature enhances its processing across the visual field [5]. This effect causes the observer's attention to be guided to stimuli that share the primed feature in subsequent search tasks. In efficient searches, different features can prime the observer independently whereas in less efficient searches priming can be episodic [6]. Despite knowing that priming is an important factor in guiding visual search, little is known about its quantitative effect in general search tasks.

In this paper, we attempt to quantify the priming effect using shape as the primed feature. We create and host a web application that observers can access online. In the task, the user must look for a target with one of two shapes among an array of distractors that varies in size. Through this investigation, we hope to better understand how visual priming influences search tasks when shape is used as the priming feature.

2 Background

Although the guided search model [7] was first published in 1989, research concerning the factors that guide search is relatively new. Until the publication of GS6, only two guiding factors were officially recognized as being part of the model: bottom-up salience and top-down guidance. Bottom-up salience describes how an image may "pop out" of the search display because of one or more salient properties that differentiate it from the stimuli around it [8]. Top-down feature guidance describes how attention is deployed based on the basic, internal representation of the target stored in the searcher's memory (e.g. a red circle). Consequently, research involving the other three factors (priming, value, and scene guidance) is generally in its early stages.

All of the factors present in the model have been accepted as guiding search, but their quantitative effects on reaction time (RT) have yet to be fully understood. Certain features like scene guidance are hard to generalize because they are heavily influenced by the observer's knowledge of the scene and the scene itself. Priming though is a slightly less specific effect that could potentially be generalized to different features of target objects.

2.1 Laboratory Visual Search Tasks

Oftentimes visual search experiments done in a laboratory look very different from real-world search tasks. The stimuli are generally artificial and the target stimulus usually appears at a predefined frequency. Moreover, the duration of search tasks done in a lab is usually very short and the tasks are repeated many times consecutively which is usually not the case in the real world. Notwithstanding, data gathered from these experiments can be generalized to describe real-world tasks; it just has to be applied carefully.

A frequently used laboratory search task requires the observer to look for a T among Ls (TvL tasks). The T (the target) has salient (very noticeable) features that are similar enough to the Ls such that it does not "pop out" of the search display. In other words, the bottom-up guidance in this case is not strong enough to make the task completely trivial. With small set sizes usually ranging from 6 to 18, this task can be performed hundreds of times in short periods making it ideal for efficient data collection.

In TvL tasks, the experimenter must also decide how the observer should notify the program that they have found the T which creates some room for variation between experiments. This always involves indicating a varying property of the T like its color or orientation in some rapid way. How the observer completes the task is very dependent on the experiment itself and more specifically on what is most readily apparent to the observer. A good method of notification should allow the observer to indicate that they have found the target as soon as they recognize it.

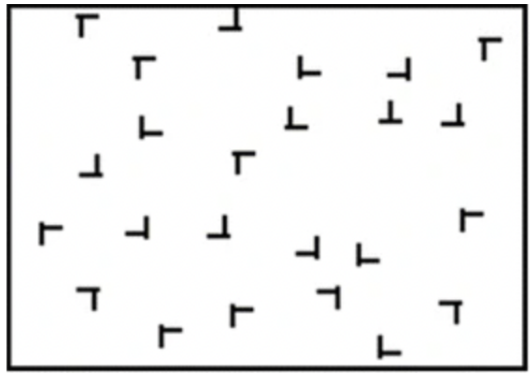


Figure 1: An example TvL search task [9]

2.2 Measuring Guidance

Guidance describes the way in which attention is directed by the features of a scene and the observer's implicit or explicit goals. The features that cause guidance can reduce the time it takes for an observer to find a target item by decreasing the number of deployments of attention to distractor stimuli. This mechanism can also increase the length of the search if it directs the observer's attention to distractor stimuli. The factor or quantity by which guidance impacts the duration of search differs among guiding features and scenes.

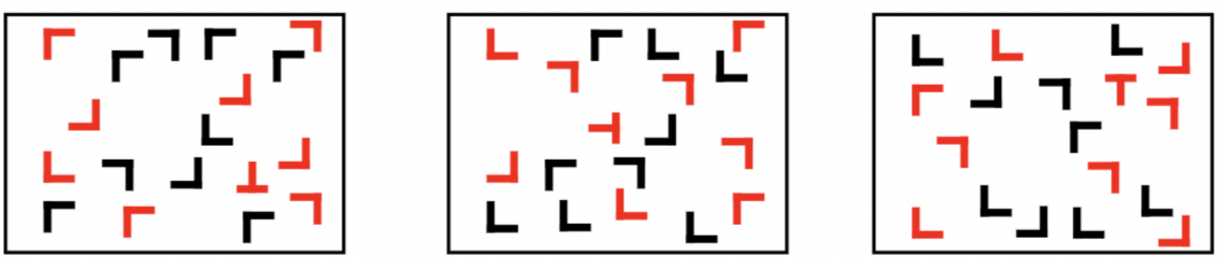


Figure 2: An example of priming in a TvL experiment

The TvL trials (Figure 2) all have a red T as their target as opposed to a black T. This repetition primes the color red in the ensuing iteration of the experiment. The fact that the target has been red for the last three trials acts as a hint to the observer that it may be red again. As a result, the observer will initially deploy their attention to the red stimuli. If the target in the next trial is also red, this will decrease the average RT by reducing the number of deployments of attention to the distractor stimuli. Priming can also have a significant effect on RT when the target is repeated less than three times.

The reduction in RT caused by guidance can be measured as a difference in slope and y-intercept when RT is plotted as a function of set size. A vertical shift in the function between run trials (target remains constant) and switch trials (target is switched) represents an influence on only the first deployment of attention. If the target remains the same and the observer is primed to find it, they will have a greater probability of doing so if they initially attend to a primed object. A change in slope, on the other hand, represents a more sustained effect where the observer continues to look for primed stimuli after the initial deployment of attention. In the case where half of the search display is primed, if this effect is sustained throughout the trial then the slope of the switch function will be double that of the run function.

2.3 Visual Priming

Priming has been accepted as a factor that guides search, but it has not yet been quantified or generalized across different search tasks. We hypothesize two possible effects of priming: the additive effect and the increased slope effect.

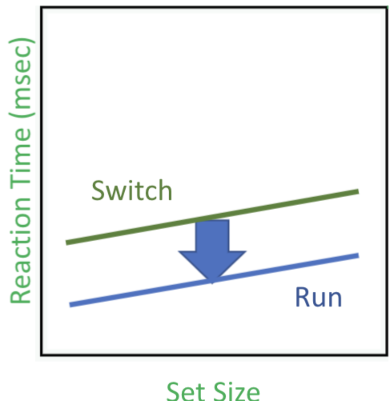


Figure 3: The additive effect

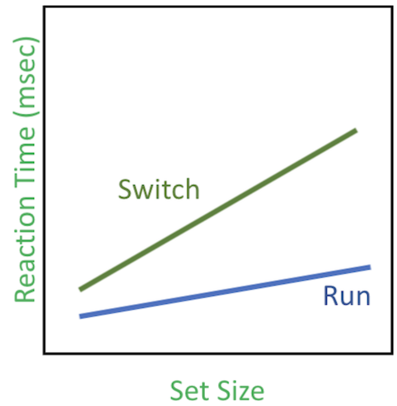


Figure 4: The increased slope effect

The switch function (Figure 3) is greater than the run function by some roughly constant quantity for all inputs. This additive effect is hypothesized to be the result of the priming effect guiding the first deployment of attention. The observer will initially direct their attention to objects with the same salient properties as the previous target object. If the target has not changed (as is in the case of a run) then the observer will be able to find it faster on average resulting in a decrease in RT shown by the vertical shift downwards.

The second switch function (Figure 4) has a slope that is roughly double the slope of the run function. This could occur if priming is sustained past the initial deployment of attention and through the entire trial. In this extreme case, the observer looks through all of the distractor objects before attending to objects with the same salient properties as the target in the current trial.

These hypotheses represent extreme opposite ends of the spectrum in terms of the length of the priming effect's influence. It is possible that results could yield some combination of these hypotheses or some intermediate result.

3 Methods

A web-based experiment was programmed for the purpose of this study with three different categories of trials. The common search task was finding a T (the target stimulus) among an array of Ls (the distractor stimuli). After locating the target object, the observer had to press either the left or right arrow key indicating the orientation of the rotated T. Each experiment type was characterized by a unique salient property of the images. On switch trials, this feature was altered on the target stimulus. The properties chosen were color, size, and shape although only the shape category was used in this study. We ran two separate experiments each with its own set of targets and distractors that both used shape as the priming feature.

3.1 Experiment Design

Two seconds after the start of each experiment and each subsequent trial, a blue square appeared to direct the observer's attention to the center of the screen. These two idle seconds were included to give the observer time to prepare for the next trial. After one second, a search array with a target always present was displayed centered around the blue square. The blue square was displayed in isolation for one second so that the observer had time to fixate on it before the search display appeared. When they appeared, distractors were roughly evenly distributed among their different shapes in each individual trial. Each observer was tasked with completing 10 practice trials and 200 experiment trials in this manner. The users were given instructions previous to the experiment that described how to properly complete the task with examples of labeled T orientations. Left oriented Ts were rotated θ degrees such that $-60° \leqslant \theta \leqslant -30°$ or $120° \leqslant \theta \leqslant 150°$ and right-oriented Ts were rotated α degrees such that $-150° \leqslant \alpha \leqslant -120°$ or $30° \leqslant \alpha \leqslant 60°$.

In both experiments, the target had an equal probability of being one of two shapes. In the first experiment, the shapes were a dotted T and a sharp T, and in the second experiment, the shapes were a circular T and an arrow T. The orientations of both the targets and the distractors were chosen randomly with each stimulus being equally likely to be either oriented left or right. In experiment I, the set size was chosen randomly as either 6, 12, or 18. In experiment II, the set size could be either 4, 7, or 10.

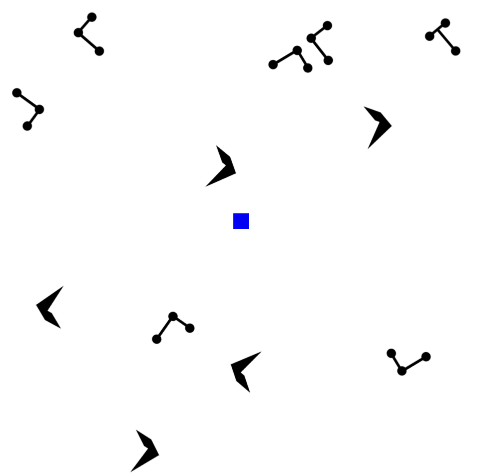


Figure 5: A trial from experiment I

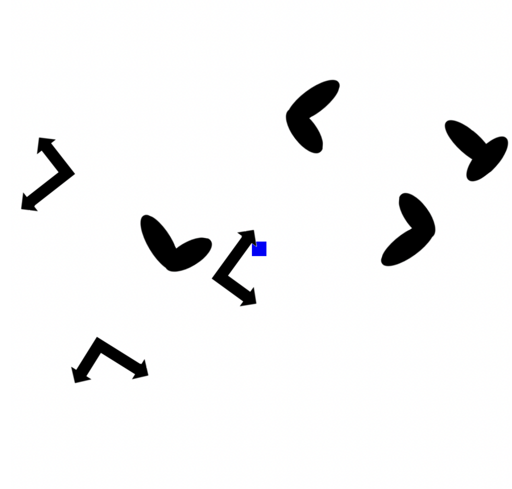


Figure 6: A trial from experiment II

The example trial shown in Figure 5 has a set size of 12 with 11 distractor objects (5 sharp Ls and 6 dotted Ls) and a single target. The target object is a dotted T and is pictured in the upper right corner of the search display. In cases where the set size is 6, there will be 3 sharp Ls and 2 dotted Ls. When the set size is 18, there will be 9 sharp Ls and 8 dotted Ls.

The second image (Figure 8) shows an example trial from experiment II. The set size here is 6, and the target is also in the upper right corner of the search array. The target is inverted, and so the correct response is left. In cases where there is an odd number of distractors, there will be one more circular L than arrow L.

This experiment was posted online as a "Mechanical Turk" experiment and made available to naive observers around the world.

3.2 The Targets and Distractors

Two different target Ts and distractor Ls were used in each experiment. Experiment II had images with dimensions double those of the images in experiment I. The only difference between the targets and the distractors in each respective experiment was the positions of their stems which were translated to produce the shapes of the two letters. The different shapes did not influence the observer's task which was to find the lone T.

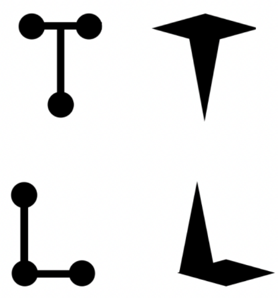


Figure 7: The stimuli in experiment I

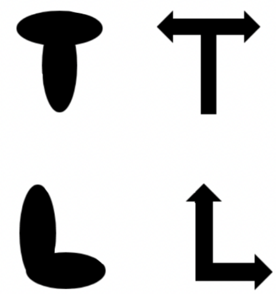


Figure 8: The stimuli in experiment II

The Ts and Ls were individually displayed as 50 x 50 pixel images in experiment I and as 100 x 100 pixel images in experiment II. The empty, white portions of the images were allowed to overlap, but the target always remained on the top and clearly visible. The targets and distractors were all placed randomly in each trial.

The stimuli were designed to be similar so that neither of them would cause overpowering bottom-up salience. If this was the case, it would render the experiment too trivial to properly observe the priming effect. We created the stimuli with different features to test priming with different types of shapes.

4 Results

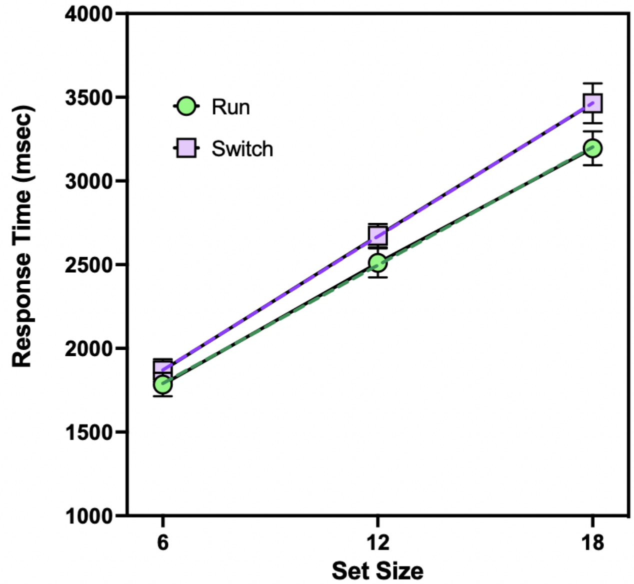
We initially preregistered a plan to collect data from 12 unique observers for each experiment. The resulting data were noisy, so we updated our registration and replicated the same study with a larger sample size (28 observers for the first experiment and 24 observers for the second experiment). Data sets were rejected if they met any of the following criteria:

- The data set was incomplete (less than 200 experiment trials were completed)
- The observer was less than 70% accurate in any one type of trial (e.g. a switch trial with a set size of 6)
- The observer completed less than 80% of the trials correctly

The remaining data were then filtered to exclude practice trials and trials in which the observer made an error. RTs were initially filtered to exclude trials that took longer than 10,000 ms and then the remaining RTs were removed if they were greater than 3 standard deviations from the mean.

4.1 Experiment I

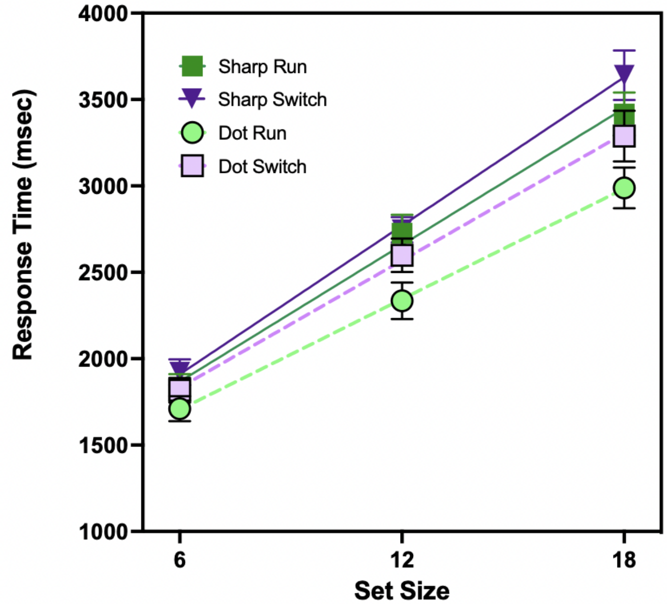
After the second round of data collection, we had a total of 37 partially or fully complete data sets. Filtering the data yielded 28 usable data sets each representing a unique observer. We performed a 3-way ANOVA on the RT data with Set Size, Target Type, and Run/Switch status as the three factors.



	Run	Switch
Slope	117.6	132.9

Figure 9: Average results for the 28 observers in experiment I

The results shown in Figure 9 plot the average RTs for all of the observers on switch and run trials separately. We found a statistically significant main effect between the run and the switch functions (F (0.9233, 24.93) = 31.63, p value < 0.0001) represented by the vertical distance between the regression lines. There was also a main effect in the Set Size (F (1.280, 34.55) = 590.7, p value < 0.0001) represented by the slopes of the lines. The interaction between Set Size and Run/Switch was not significant in these data (p value $>$ 0.05) indicating that the priming effect was not sustained past the initial deployment of attention.



Dot

	Run	Switch
Slope	106.6	122.6

Sharp

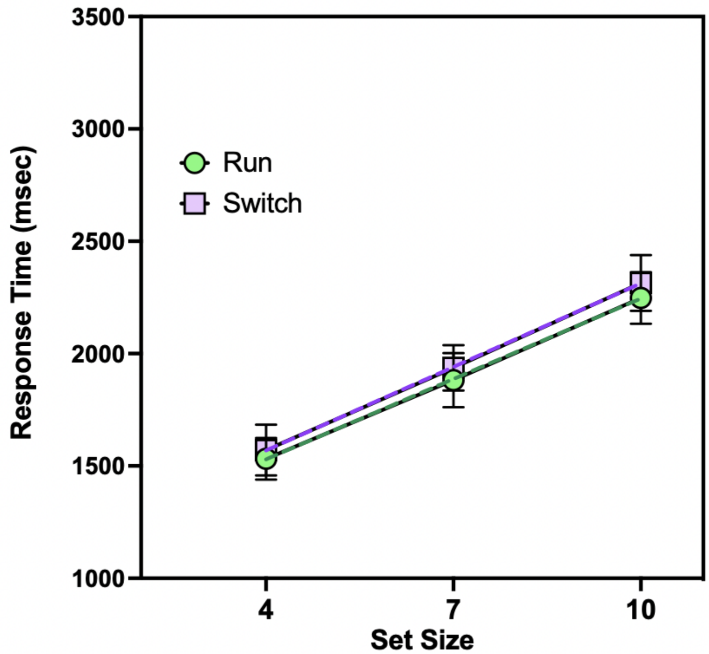
	Run	Switch
Slope	131.8	143.3

Figure 10: Average results for the dotted Ts and the sharp Ts

The results shown in Figure 10 plot the average RTs for all of the observers differentiating between different target shapes. The Target Type factor produced a significant main effect in these data (F (0.7853, 21.20) = 14.51, p value = 0.0019). The interaction of Set Size and Target Type was also significant (F (2, 54) = 3.286, p value = 0.0450). There were greater slope differences between the same functions across images (20.7 ms/item and 25.2 ms/item respectively) than there were between switch and run functions for the same image in both cases (16 ms/item and 11.5 ms/item respectively).

4.2 Experiment II

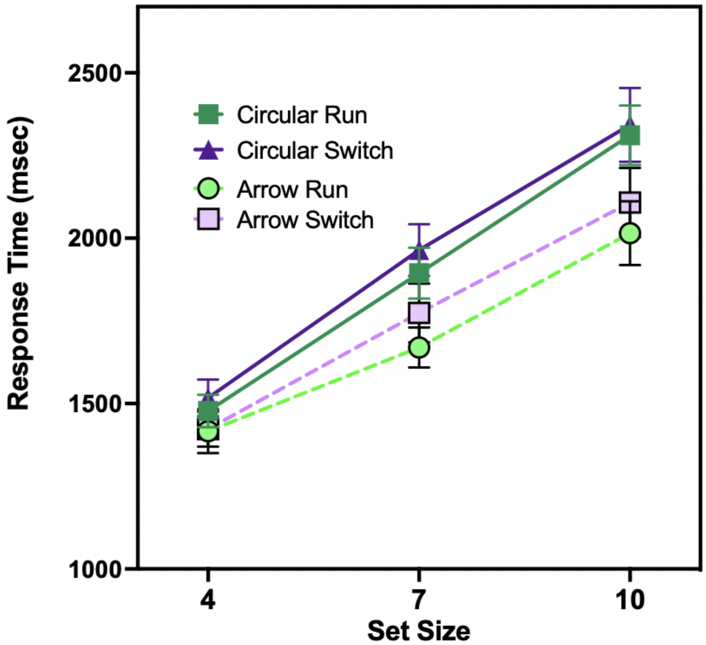
Data collection for the second experiment yielded data sets from 31 unique observers which were filtered down to 23 observers using the same process that was used in the first experiment. We performed an analysis of variance using the same three factors: Set Size, Target Type, and Run/Switch status.



	Run	Switch
Slope	119.3	124.0

Figure 11: Average results for the 23 observers in experiment II

The results (Figure 11) again show a statistically significant main effect between the run and the switch functions ($F(1, 22) = 7.798$, p value $= 0.0106$). There was also a main effect in the Set Size ($F(2, 44) = 145.4$, p value < 0.0001). As was the case in experiment I, the interaction between Set Size and Run/Switch was not significant in these data (p value > 0.05).



Circular

	Run	Switch
Slope	138.9	137.6

Arrow

	Run	Switch
Slope	99.78	114.2

Figure 12: Average results for the circular Ts and the arrow Ts

Figure 12 shows that the additive effect is apparent when the RTs for different shapes are graphed independently of one another against set size. The Target Type again produces a significant main effect in these data ($F(1, 22) = 18.67$, p value $= 0.0003$). The interaction between Set Size and Target Type was also significant ($F\ (2, 44) = 3.604$, p value $= 0.0355$). The other interactions were not significant (p value > 0.05) in the data from this experiment.

5 Discussion

Our data support the claim that the priming effect is apparent when shape is used as the priming feature. The results from both of the experiments provide evidence for the additive effect of priming. We suggest a transient model in which the priming effect is initially strong, but wears off before many of the stimuli have been attended to.

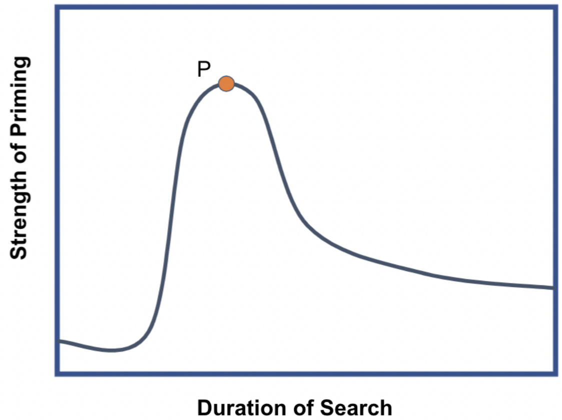


Figure 13: Transient model for priming

The vertex (point P) of the graph (Figure 13) represents the point where priming overtakes stronger forms of guidance and becomes the primary mechanism for guiding search. The graph shows the effect rapidly falling off after the initial deployment of attention as was shown in the data.

The stimuli-specific results showed a significant difference between the two pairs of functions in both experiments. The functions representing RTs for circular and sharp Ts were both greater than their respective counterparts in each experiment. We propose that this is the result of it being more difficult to determine the orientation of thicker targets. The circular and sharp Ts both have thicker stems which allow for lines covering a larger range of angles to be drawn inside their shapes. We hypothesize that condensing information about these lines into a single response about the target's orientation requires greater processing and thus takes more time to complete.

The differences in slopes between the same functions across different stimuli were also significant in each experiment. We propose that this effect is the result of a stronger bottom-up salience from the dotted and arrow Ts than the circular and sharp Ts. We hypothesize that this bottom-up salience was initially stronger than the guidance due to priming in both experiments resulting in the observer's attention being drawn to these stimuli at the start of each trial. In switch trials, this would effectively increase the set size resulting in the increased slopes shown in the data. We hypothesize that it was the skinnier nature of the dotted and arrow Ts that produced the stronger bottom-up salience effect. This is likely the only shared property of the images that could be processed in the preattentive stage of the search to produce this guidance.

This clear evidence for priming could have many consequences in real-world search tasks. Radiologists, for example, look through many X-rays for a wide range of abnormalities. Does finding a certain irregularity in a previous X-ray decrease the likelihood that an entirely different irregularity will be found in an ensuing X-ray? If this is the case and the decrease is significant, then there may observable health issues being left untreated due to primed radiologists not seeing them.

6 Future Work

We propose an extension of this experiment using other shapes and set sizes to better understand the relationship between priming and shape. Our data showed that skinnier figures may produce more bottom-up salience, but we would like to confirm this with a larger, more focused experiment that would give us more statistical power. We also propose a study that investigates how the priming effect is related to the number of target repetitions. This study should switch the target with a smaller probability to produce longer strings of repeated targets. It would also be interesting to study the priming effect in scenes that more closely resemble the real world. Using more realistic scenes may allow the data to overcome a lot of the shortcomings of laboratory search tasks and make the results more easily applicable.

The web application designed for this experiment already has functionality built-in to test the priming effect with size and color as salient properties. We hope to run further Mechanical Turk experiments with these alternate features and combine the results with those of this study. This would allow for a better understanding of how priming changes when different features are primed and it could lead to a more general understanding of the priming effect.

7 Conclusion

In conclusion, we showed that priming has observable effects in search tasks that use shape as the priming feature. In both experiments, the priming effect only guided the first deployment of attention after it became the strongest guiding factor. This was shown by the significant additive effect in the data. We proposed a transient model of priming to explain this phenomenon in which the priming effect has a brief, immediate impact on visual search.

We also hypothesized that the dotted and arrow Ts have a stronger bottom-up salience than the sharp and circular Ts. This hypothesis was based on the significantly different slopes between the different images in each of the trials. We would like to test the idea of thinner figures causing stronger bottom-up salience with a larger study using a greater variety of images. Lastly, we concluded that it took longer to respond to the thicker targets because it took more time to deduce their orientation.

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