Set-Size Effects in Visual Search Tasks

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Abstract. Set-size effects have always been fundamental factors to be studied in visual search tasks. The existence of set-size effects has been proven in most visual search tasks. However, some exceptions did not demonstrate significant set-size effects. Results of several experiments indicated that altering the shape of stimuli presented might cause the set-size effects to diminish. Thus, the goal of this study is to investigate the set-size effects in a specific visual search task with polygons as stimuli. For brevity, polygon search tasks will be used. An experiment using hexagons and pentagons as stimuli was designed and carried out to investigate the set-size effects in polygon search tasks in depth. The result showed that the mean reaction time of participants increased slowly for larger set sizes, suggesting that set-size effects exist in polygon search tasks. However, the correlation between the mean reaction time and the set size declined compared to that in simple visual search tasks, which led to the conclusion that polygon search tasks might be affected by factors other than set sizes.

Keywords: Visual search tasks · Polygons · Set-size effects · Selective attention

1 Introduction

Most people have played a game called Spot the difference. It can be regarded as a visual search task since the task of finding a target among distractors is generally referred to as a visual search. When doing a visual search task, people will probably discover that they can find the targets quicker if they can easily discriminate them from their surroundings. Thus, discriminability has become a common manipulated variable in visual search tasks. In addition, a vast majority of the behavioral studies of visual search measure the mean reaction time, which is a significant index of the effect of manipulated variables. Palmer and Mclean measured the mean reaction time as a function of discriminability while requesting volunteers to keep error levels around 10% [1]. Their findings indicated a negative correlation between the mean reaction time and discriminability, with the mean reaction time increasing as a function of decreasing discriminability [1]. Many previous search studies have similarly proven the relationship between mean reaction time and set size: when discriminability was high, mean reaction time increased slowly with set

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size, whereas it increased significantly more rapidly when discriminability was low [1]. From the perspective of neuroscience, encoding precision in visual working memory decreases with the number of encoded items [2]. The set-size effects were identified as the cause of the association between mean reaction time and set size. Numerous studies have been conducted since then to either generalize the set-size effects to more visual search tasks or demonstrate a correlation between mean reaction time, discriminability, and set size.

1.1 Feature Integration Theory

A lot of researchers have proposed their models and theories based on their experiments and findings. One of the most influential theories was the feature integration theory. According to the now-classic feature integration theory, a two-stage visual process determines search performance. The first stage of processing, known as preattentive, was assumed to occur before the effect of attention. It consisted of maps with different features—dimensions including color, orientation, motion, and spatial frequency. These feature maps were hypothesized to correspond to neurons that are selective for a narrow range of values in each of these dimensions. This stage's elements worked in parallel, allowing for simultaneous processing across the display, resulting in search durations that were independent of the number of objects in the display. If the first stage failed to isolate the target, a second limited-capacity serial stage was necessary, which concentrated attention on single objects or groups of things one at a time. This serial stage was assumed to account for increasing search durations as the number of components in the display increased [1]. Feature integration theory has become an important reference to consider when performing paradigms such as visual search, texture segregation, identification, and localization because it provided a new set of criteria for distinguishing separable from integral features as well as a new rationale for predicting which tasks will show attention limits and which will not [3].

1.2 Unlimited and Limited Capacity Model

Models with unlimited and limited capacity were compared by Palmer and Mclean [4]. They also determined that the unlimited-capacity model is reasonable for visual search and that when the model's component processes are imperfect, the model provides plausible predictions [4]. Their research established a novel experimental approach for evaluating the reaction to stimuli of varying luminance. Volunteers were asked "yes or no" questions during the testing procedure. After completing the experiment, mathematical and statistical data were collected to analyze the mean reaction time and determine the relationship between the mean reaction time and different set sizes. To further evaluate the data, the researchers also employed Roger Ratcliff's diffusion model, which was a model that transformed behavioral data into components of cognitive processing and offered extensive explanations of behavior in two-choice discriminating tests [5]. Because answering "yes or no" questions did not involve any ability, their experimental technique enabled participants to readily join the experiment. It also made data collection and analysis easier for researchers. It might, however, generate erroneous and inaccurate results since participants could answer the question even if they were unable to identify whether the target stimulus was on the screen. Furthermore, they did not specify their sample size in their study, implying that their findings were based on calculations rather than actual data. Additionally, their experiment involved the use of high-resolution equipment; otherwise, the results might not be reliable.

1.3 Attentional Effects

Palmer demonstrated a relationship between set-size effects, contrast increment, and correct rate, as well as a relationship between search duration and contrast increment. The experiments' primary breakthrough is the use of the stimulative interference effect between the target and the distractors. During the experiments, the cueing paradigm was used to isolate attentional processes. The result of the cueing conditions was identical to the corresponding display-set-size conditions since selective attention is the main cause of cueing effects under the same stimuli. To control the discriminability, they also employed threshold measurements. It ensured that the results of all these distinct types of search accuracy trials were compatible with those of classic visual search paradigms. Simultaneously, the results of these experiments were found to be consistent with the predictions of the unlimited-capacity hypothesis's independent channel model. It demonstrated that the unlimited-capacity perception hypothesis was accurate, whereas the limited-capacity perception hypothesis was inaccurate. However, the set-size effects would be lessened for higher threshold criteria. Finally, they compared the effects of set size on both accuracy and mean reaction time. The finding was that the larger the contrast increment, the smaller the set-size effects and the accurate rate increased; the smaller the contrast increment, the larger the set-size effects and the accurate rate decreased. Caroline Barras and Dirk Kerzel derived a similar result, that in the high-similarity circumstance, the mean reaction time was longer than in the low-similarity case. The former circumstance's rate of rising in mean reaction time is substantially faster than the latter situation [6]. The study, however, failed to establish a detailed unlimited-capacity perception model for predicting search time. Ultimately, the common bottleneck hypothesis was investigated in the experiments in terms of its effects on accuracy and the mean reaction time. However, it was uncertain whether the results of special cases in which the bottleneck hypothesis was tested differed from those of the common bottleneck hypothesis [7].

1.4 Aim of the Present Paper

Other research investigated the effects of set size in visual search tasks using letters and app icons, but no polygons were used as targets or distractors [8, 9]. Palmer also claimed that in conjunction tasks, rotational Ts and Ls tasks, and spatial tasks, significant set-size effects might not exist [7]. Thus, this study intends to design a polygon search task to demonstrate correlations between set size, reaction time, and discriminability. It's also necessary to investigate whether there is a type of search task that consistently has substantial set-size effects. The set-size effects are expected to be amplified if the stimuli are changed to polygons.

2 Method

2.1 Participants

The experiment involved 26 participants (8 males) with an average age of 16.65 years old, and it was carried out entirely online using TeamViewer. WeChat and QQ were used to recruit all of the participants. Participants were assured that they understood what they were supposed to do in the experiment and that they had no technical problems that would have influenced the outcome. They were asked to consent to data collection before the trial began. After finishing the experiment, each participant was paid ¥5 for their participation. The experiment took approximately 4–5 min.

2.2 Materials

The experiment mainly consisted of five routines, which were intCode, instruct, fixation, trial, and finish word in sequence. The first four routines were kept operating two times by a loop called trials. A hexagon and eight black pentagons were set as the target stimulus and the distractors. The target stimulus would be either red or black to simulate different discriminability. There were two manipulated variables in this experiment: one was the color of the target stimuli presented, which was controlled by the target color, and the other was the number of distractors shown on the screen, which was controlled by opacity. When the value of opacity is 1, it means that the distractor is visible to participants; when the value of opacity is 0, it means that the distractor is invisible to participants. For example, when the target's color is black and the opacity of eight distractors is 1, participants will see both a black hexagon and eight pentagons on the screen. Therefore, the method can control the number of distractors presented efficiently.

Two code components were added to the intCode and trial routines to improve the experiment's reliability and validity. The code in intCode was used to determine if participants had finished all eighteen trials in the loop. The code halted the experiment and restarted it from the instruction routine if participants had already finished a loop. The instruction routine was set to continue the experiment only if participants pressed the mouse button. The interval between loops was set to restore participants' attention, increasing the experiment's reliability. The code in the trial routine was used to randomize all stimuli on the screen, increasing the experiment's validity.

2.3 Procedures

The experiment began with a brief explanation. Participants were instructed to click the hexagon as quickly as possible but then just tapped the screen to start. A fixation triangle would be displayed in the middle of the screen for 0.5 s after the first tapping, followed by a trial with a hexagon and some pentagons. Before the next trial began, the fixation triangle would be displayed again for 0.5 s after the participants clicked the hexagon on the screen. The target stimulus was a hexagon, while the distractors were 0 to 8 pentagons in each trial. On the screen, they were both positioned randomly. Participants were allowed to take breaks after completing 18 trials before tapping the screen to begin the following loop.

There were 18 experimental conditions (2 target colors * 9 set sizes). There were 18 trials in each loop, with one experimental condition in each trial. Because the loop would be activated twice, the experiment included a total of 36 trials.

2.4 Data Analysis

The data was analyzed using OriginPro 2021 64-bit and Microsoft Excel. The mean reaction time for each participant was computed when discriminability was the manipulated variable and set size was the manipulated variable, respectively. Figure 1 shows the overall mean of participants' mean reaction times under various discriminability conditions. Error bars were calculated and presented in Fig. 1. Figures 2A and 2B show the overall mean of participants' mean reaction times under different set size conditions when discriminability was high and low, respectively.

3 Results

3.1 Discriminability

According to Fig. 1, when the hexagon had the same color as the pentagons, the mean reaction time was higher than that when the hexagon had different colors from the pentagons.

3.2 Set Size

According to Fig. 2A, when the hexagon had the same color as the pentagons, which was of low discriminability, the mean reaction time increased as the set size increased. According to Fig. 2B, when the hexagon had different colors from the pentagons, which was of high discriminability, reaction time increased slowly as the set size increased. To compare the exact effect of set size, the slope of trend lines was calculated based on

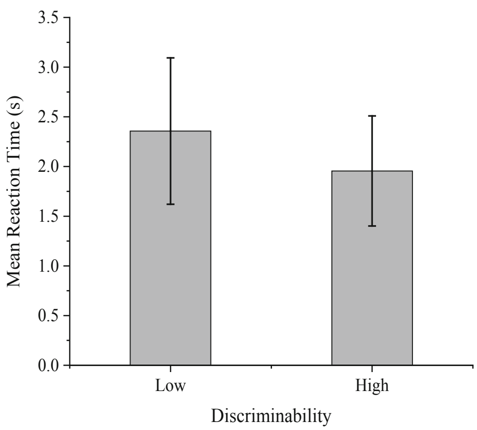

Fig. 1. RTs of participants under different discriminability

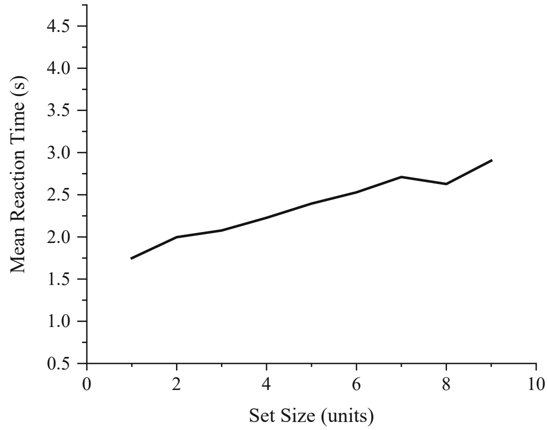

Fig. 2A. RTs as a function of Set Size under low discriminability

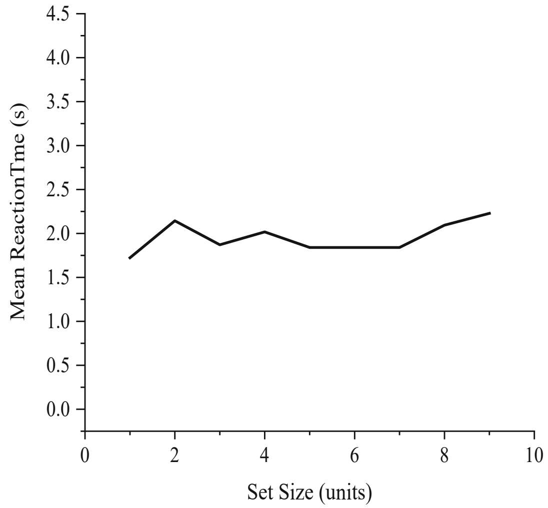

Fig. 2B. RTs as a function of Set Size under high discriminability

Fig. 2A and Fig. 2B. The slope of the trendline in Fig. 2A was 0.13, and the slope of the trend line in Fig. 2B was 0.03. The slope of the trend line in Fig. 2A was much higher than that in Fig. 2B.

4 Discussion

The experiment is aimed at examining to what extent the set size affects the mean reaction time of participants in the visual search task that uses polygons as its stimuli. The results of the experiment proved that the mean reaction time would increase for either larger set sizes or lower discriminability. Polygons are made up of features that have separable dimensions (shape and color) as well as local elements or sections of figures (lines, curves, etc. in letters) [3]. In terms of the discriminability and the set size, participants were likely to spend more time recognizing the target when the discriminability of the target was low or when the set size was large. This finding was also reported by a previous study [9]. However, the slope of the trend line for simple visual search tasks, which is used to represent the intensity of the set-size effects, was around 0.25. That number was much higher than the slope of the trend line derived from the polygon search task. The difference in the slopes of the trend lines indicates that the data derived from the experiment cannot verify the hypothesis that the set-size effects will be amplified when doing polygon search tasks. That leads to the question of why the result of the experiment is not consistent with the hypothesis.

It is noteworthy that the data of some particular trials fluctuated widely, which indicates that there might be confounding variables that had not been considered. Since the process of every trial was observed, some counterintuitive behaviors of participants were also noted. It was observed that when participants were doing trials in which the hexagon had the same color as the pentagons, several participants would check all polygons presented on the screen until they found the right one if they did not find the hexagon at first glance. Additionally, participants were likely to keep using the method in more trials, leading to the fact that they would spend more time checking every polygon, even if the hexagon had different colors from the pentagons. That caused the reaction time to increase in trials in which the reaction time should be lower. This phenomenon was attributed to the fact that participants had different levels of obsessive-compulsive tendencies. Participants with a high obsessive-compulsive tendency had less processing flexibility and preferred focused processing over parallel processing when compared to those with a low obsessive-compulsive tendency [10]. Thus, there were two different search modes generated from randomly changing colors. It was assumed that every participant would set a priority in a short period before they started to search for the hexagon, and the participants would have to choose between searching for the hexagon and searching for the polygon that had different colors from other polygons. On the one hand, if the participants had high obsessive-compulsive tendencies, they would only use focused processing. The priority of searching for the hexagon was higher than that of searching for the polygon that had different colors from other polygons, leading participants to spend more time checking the shape of every polygon. On the other hand, if the participants had low obsessive-compulsive tendencies, they were more likely to process flexibly. In other words, participants using parallel processing would set the priority of searching for the polygon that had different colors from other polygons higher than that of searching for the hexagon. If the colors were the same, they would next use focused processing to check the shape of every polygon until they found the right one. Thus, participants may spend less time checking the color of every polygon.

The difference between the two searching modes might act as a confounding variable when the participants did not use these searching modes properly in the corresponding trials. This confounding variable can be eliminated by dividing participants randomly into two groups. One group will do the original experiment, while the other group will do the experiment that has only one fixed color for the hexagon, which can be either red or black. Therefore, the effect of different searching modes may be eliminated, leading to an increase in the accuracy of the results. In addition, according to the experimental settings, the participants can move from one trial to another only after clicking the hexagon. According to the diffusion decision model, however, there was a nondecision interval during which the muscle' s reaction time accumulated until it reached the response threshold [5]. As a result, the range of reaction times of various participants may vary, implying that reaction times may not accurately reflect the participants' ability to choose the hexagon as quickly as possible. Furthermore, some uncertainty factors known as diffusion may influence the participants' drift. Specifically, participants may prefer to check the shape of each polygon (drift), but unknown factors may make participants spend time keeping drift or prioritize checking the color of each polygon. Participants will think about which approach to employ to finish the next trial, but before they make their final decision, the next trial may get started straight away. However, according to the research, increasing the size of the boundary of the time between trials can improve drift stability by offering people sufficient time to make a decision [5]. As a result, we decided to address this problem by setting a 5-s interval between trials. Some outliers can be extracted from the data in this way, thus enhancing the experiment's reliability and validity.

Last but not least, there are far more females among our participants than males. Although no exact evidence was found to indicate a relationship between the participants' gender and their performance, it may be desirable to have a reasonable combination of female and male participants.

5 Conclusion

Visual search is a common task in everyday life. People may have to search through a great number of distractions to find what they're looking for. People will have to devote more time to recognizing objects with low discriminability. Since attention is a limited resource, people may gradually become fatigued. As a result, determining the most appropriate set size and the discriminability of objects that people interact with daily can help individuals enhance efficiency and avoid wasting attention resources. Variable set sizes and discriminability can have an impact on people's ability to monitor road hazards and informational signs while driving. According to the overall results of our polygon search task, the set-size effects were diminished when the stimuli were presented in the form of polygons, and the effect of object discriminability was significant. Since most items can be regarded as polygons, this can lead to certain application advancements in people's everyday lives. Additionally, corporations can add additional polygonal components to their logos to attract customers and increase the brand's distinctiveness.

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