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Perceptual similarity in visual search for multiple targets

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ABSTRACT

Visual search for multiple targets can cause errors called subsequent search misses (SSM) – a decrease in accuracy at detecting a second target after a first target has been found. One of the possible explanations of SSM errors is perceptual set. After the first target has been found, the subjects become biased to find perceptually similar targets, therefore they are more likely to find perceptually similar targets and less likely to find the targets that are perceptually dissimilar. This study investigated the role of perceptual similarity in SSM errors. The search array in each trial consisted of 20 stimuli (ellipses and crosses, black and white, small and big, oriented horizontally and vertically), which could contain one, two or no targets. In case of two targets, the targets could have two, three or four shared features (in the last case the targets were identical). The error rate decreased with increasing the similarity between the targets. These results state the role of perceptual similarity and have implications for the perceptual set theory.

1. Introduction

Visual search is a perceptual task of searching for targets among distractors. This task is very important for everyday activity, especially in some jobs (i.e. radiology and baggage-screening). A typical visual search task implies searching for one target among multiple distractors. Nevertheless, real-life visual search often implies searching for multiple targets. For example, a radiological scan can contain multiple anomalies, and the radiologist's task is to find all of them. The search for multiple targets can cause errors called subsequent search misses (SSM) – a decrease in accuracy at detecting a second target after a first target has been found (e.g. Adamo, Cain, & Mitroff, 2013). This phenomenon is also known as satisfaction of search (e.g. Fleck, Samei, & Mitroff, 2010) and was first observed in radiology studies.

In radiology, second target misses were principally explained as the prematurely ending of search. After finding the first anomaly, the subject becomes "satisfied" with this result and doesn't search for any other anomalies (Tuddenham, 1962). Therefore this phenomenon has been called satisfaction of search. Nevertheless the results of later studies both in radiology (Berbaum et al., 1991) and in cognitive psychology (Fleck et al., 2010) revealed that the subject's "satisfaction" of finding the first target is not the main factor leading to second target omission. For that reason this phenomenon was renamed to subsequent search misses (Adamo et al., 2013).

Another possible explanation for SSM errors is a resource depletion account (Cain & Mitroff, 2013). This explanation suggests that the first target consumes valuable cognitive recourses (e.g. working memory) leaving fewer resources available during subsequent search and thereby preventing finding the second target. To this end, the SSM effect can be the spatial analogue of attentional blink which is observed in rapid serial visual presentation paradigm (Raymond, Shapiro, & Arnell, 1992). Attentional blink causes a decrease in accuracy when a second target appears 200 to 500 ms after a first target is detected. Thus, both SSM effect and attentional blink involve the failure to detect the second target after the first target was detected. Moreover, eye-tracking data of visual search task revealed that the SSM effect has the same time frame as attentional blink (Adamo et al., 2013). In addition, the increase of visual clutter (the number of items present within the vicinity of a target), imposing an additional load on attention reduces the detection of a second target (Adamo, Cain, & Mitroff, 2015).

A third possible explanation of SSM errors refers to "perceptual bias". According to perceptual set theory, after the first target is found, the subject becomes biased to find perceptual similar targets. The subject is more likely to find perceptually similar targets and less likely to find the targets that are perceptually dissimilar. For example, after a radiologist finds a broken bone, he is more likely to find another broken bone than a tumor (Berbaum et al., 1991). The possible underlying mechanisms of perceptual set can refer to perceptual priming or guidance. In both cases, finding a first target leads to the threshold reduction for other perceptually similar targets (Kristjánsson & Campana, 2010).

This idea is consistent with the findings from standard visual search tasks with one target. For example, distracters have more impact on visual search efficiency when they are perceptually similar to the target

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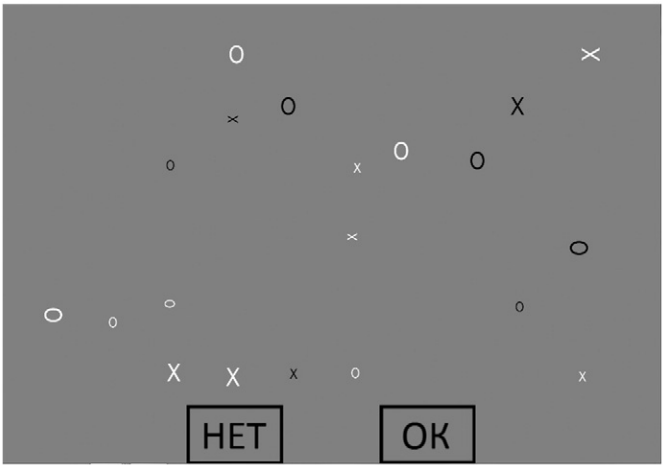

Fig. 1. An example of experimental trial. The target is defined by features – black, horizontal. There are two targets with two shared features. The button "HET" means "NO".

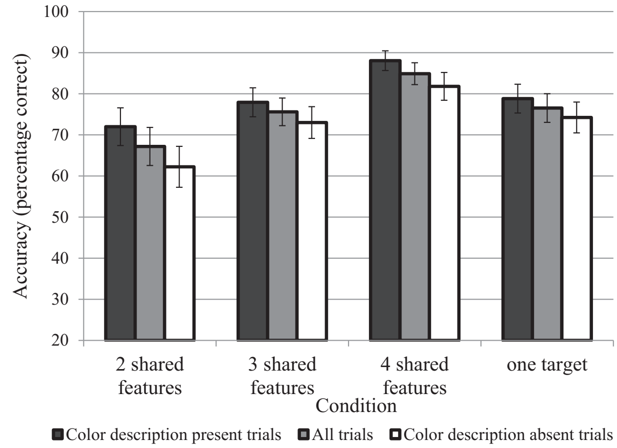

Fig. 2. The results of SSM errors analysis (T2|T1) for conditions with two target stimuli with different number of shared features and for condition with one target. The accuracy for two targets condition assumes the percentage of correct answers for the second target if the first target is found (trials with no targets found are excluded). The accuracy for one target condition assumes the percentage of correct answers. Error bars represent standard error of the mean.

(Duncan & Humphreys, 1989). Nevertheless, the results of the first study of SSM phenomenon on a standard visual search task (Fleck et al., 2010) are inconsistent with this theory. SSM are still present even if the targets (in case of this study – T's among L's) are identical to one another. In fact, the explanations of SSM errors by working memory overload and perceptual bias are not necessary contradictory. The first target can load the representation into the working memory which can cause perceptual bias and working memory overload at the same time.

The recent study by Biggs, Adamo, Dowd, and Mitroff (2015) also revealed the role of conceptual set in visual search for multiple targets. "Big data" from the mobile application "Airport scanner" was analyzed. The targets could be identical or distinct. The distinct targets could have contextual or perceptual similarity or be dissimilar. The perceptual set bias was predicted for two targets drawn in the same color (e.g. two blue targets). The conceptual set bias was predicted for two targets having the same function or categorical relationship (e.g. a gun and bullets). The results revealed the main effect of conceptual bias. The conceptual set bias had a significant influence on SSM errors when controlling for possible perceptual influences, but the perceptual set bias produced a smaller influence when controlling for possible conceptual influences.

Nevertheless, the results of Biggs et al. (2015) could be due to limiting the perceptual analyses to a single feature rather than multiple features. Therefore, the perceptual set can have a bigger impact on SSM errors when analyzing more than one feature. On this article, we address this issue.

For this experiment we investigated visual search for targets defined by combination of two features. In each trial there could be one, two or no target stimuli. In case of two targets they could have two, three or four shared features. We hypothesized that SSM errors will change with the number of features shared in first and second target stimuli.

2. Method

2.1. Participants

21 volunteers, students of National Research University Higher School of Economics participated in the study. Results of 1 participant were excluded due to the extremely low accuracy (caused by misunderstanding the instruction). The final data set included results from 20 participants, 4 male and 16 female. All of them were native Russian speakers with normal or corrected to normal vision. The age varied between 17 and 21 y.o. ($M = 18.63$, $SD = 0.93$). All participants were naive to the experimental hypothesis.

2.2. Stimuli and apparatus

The stimuli were ellipses and crosses, black (CIE $xy = 0.267, 0.262$; luminance $= 1.073$ cd/m^2) and white (CIE $xy = 0.277, 0.310$; luminance $= 161.540$ cd/m^2), small and big, oriented horizontally and vertically. The stimuli size was $1.29° \times 1.07°$ for big stimuli and $0.74° \times 0.56°$ for small stimuli. The stimuli were presented on gray background, CIE $xy = 0.273, 0.304$; luminance $= 40.897$ cd/m^2). There were always 20 items per display. On each trial there were one, two or no targets present. In case of two targets, they could have two, three or four shared features (in the last case the targets were identical). Features

Table 1
Descriptive statistics and pairwise comparisons for SSM errors analysis. Cells contain p-values for pairwise comparisons.

		Condition, mean, standard deviation (real accuracy)			
Condition, mean, standard deviation (SSM errors)		Two shared features, $M = 67.18$, $SD = 20.72$	Three shared features, $M = 75.6$, $SD = 15.02$	Four shared features, $M = 84.88$, $SD = 11.88$	One target, $M = 76.53$, $SD = 15.58$
	Two shared features, $M = 67.18$, $SD = 20.72$	–	0.005[a]	0.000[a]	0.002[a]
	Three shared features, $M = 75.6$, $SD = 15.02$	0.005[a]	–	0.002[a]	0.558
	Four shared features, $M = 84.88$, $SD = 11.88$	0.000[a]	0.002[a]	–	0.004[a]
	One target, $M = 76.53$, $SD = 15.58$	0.002[a]	0.558	0.004[a]	–

[a] The mean difference is significant after the Bonferroni – Holm p-value adjustment procedure, considering the initial alpha 0.05.