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# THE ROLE OF INTERTARGET DISTANCE IN VISUAL SEARCH FOR MULTIPLE TARGETS

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# THE ROLE OF INTERTARGET DISTANCE IN VISUAL SEARCH FOR MULTIPLE TARGETS

Subsequent search misses (SSM) refer to the decrease in accuracy in detecting a second target after the first target has been found in visual search task. The experiment investigated the role of intertarget distance in a dual-target visual search. The subject's task was to find a target or targets (T letters) among distracters (L letters). In each trial there was either one high-salient target, one low-salient target, two targets (one high-salient and one low-salient) or no targets. In the dual-target condition, the targets were presented at various distances. Accuracy and reaction time for dual-target conditions and for one low-salient target condition were compared. The results revealed the role of intertarget distance in SSM. The SSM errors were observed only at particular intertarget distances. The results of the present study are discussed in relation to attentional blink studies and experiments on the dead zone of attention.

JEL Classification: Z.

Keywords: visual search, visual attention, subsequent search misses

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## Introduction

The typical laboratory-based visual search task requires participants to search for a single target, although a lot of real life activities, including life-saving jobs like radiology and baggage screening, often require searching for more than one item. Multiple-target searches are especially error prone: after the first target is found, the subject is likely to miss other targets (e.g. Tuddenham, 1962). This phenomena was originally described in radiology studies and was called satisfaction of search, assuming the prematurely ending of the search is related to the subject's satisfaction after finding the first target.

Other studies in radiology (e.g., Berbaum et al., 1991) and in cognitive psychology (e.g. Fleck, Samei, & Mitroff, 2010) cast doubt on this explanation. In particular, the subjects scan displays for the same amount of time regardless of whether one or multiple targets are present (Berbaum et al., 1991) and the second target miss errors arise even in motivated participants with external pressure (Fleck et al., 2010). Given that the second target miss errors are related at least not only to satisfaction mechanisms, the term satisfaction of search is no longer used in cognitive psychology studies. This phenomenon was renamed to subsequent search misses (SSM) (Adamo, Cain, & Mitroff, 2013).

According to perceptual set theory, SSM errors occur due to the targets' perceptual similarity. After the first target is found, the subject becomes biased to find perceptually similar targets and to miss perceptually dissimilar targets (Berbaum et al., 1991). This idea is consistent with the experimental data: SSM errors are reduced in the case of perceptual (Gorbunova, 2016) and conceptual (Biggs et al., 2015) target similarity. Nevertheless, Fleck et al. (2010) revealed SSM errors even for identical targets thus perceptual set formation cannot be the only mechanism inducing SSM.

An alternative explanation is resource depletion theory, implying that the location and identity of the first target stored in working memory is consuming cognitive resources (attention and/or working memory) which reduces the subsequent search accuracy (Cain & Mitroff, 2013).

This theory is consistent with the results of experiments, in which dividing one multiple-target search into several single-target searches, separated by unrelated trials (Cain et al., 2014) and removing found targets from the display or making them salient and easily segregated colour singletons (Cain & Mitroff, 2013) improved subsequent search accuracy. In addition, the recent study by Adamo, Cain, & Mitroff (2015) revealed the decrease of second target detection accuracy when the visual clutter was increased.

Nevertheless, perceptual set theory and resource depletion theory do not have mutually exclusive. The first target's representation stored in the working memory at the time of the subsequent search can cause both perceptual bias and working memory overload. Moreover, perceptual set formation can be a way of filtering reconfiguration to adapt to a high working memory load.

SSM errors in spatial visual search have a striking similarity to the temporal visual search phenomena known as attentional blink (Raymond, Shapiro, & Arnell, 1992). The attentional blink paradigm assumes that presenting stimuli in a rapid serial visual presentation (RSVP) stream where stimuli are briefly displayed one at a time and the observer's task is to report the target stimuli. Attentional blink is a decrease in accuracy for detecting a second target (T2) after the first target (T1) has been detected. The usual time of one stimuli presentation in RSVP task is 100 ms. T2 is missed when it is presented in the second place after T1 (lag2) or on the third place after T1 (lag3). Longer lags produce better accuracy know as recovery from the blink. When T2 is presented immediately after T1, T2 performance is often reported being as good as that at long lags—lag1 sparing effect (Potter et al., 1998). Attentional blink and SSM are probably related to the same working memory resource depletion mechanisms. Moreover, eye-tracking SSM errors analysis revealed the decrease in accuracy after T1 fixations similar to attentional blink (Adamo et al., 2013).

Another phenomena, similar to SSM errors, is the dead zone of attention (Utochkin, 2011). The dead zone was discovered in visual searches for changes in natural scenes. The search for marginal changes in the presence of central one was more accurate for far changes than near changes. These results support the notion of a dead zone of attention surrounding the attentional focus. The location of the dead zone is around $5^o$ distance from focus, according to this study.

Considering these data, the existence of a general—both spatial and temporal—dead zone of attention can be assumed. Moreover, SSM errors can be related to a dead zone formed after the first high salient target has been detected. In this way, SSM errors can be associated with the distance between the first and the second target. In the current study, we address this issue.

# Method

## Participants

24 volunteers, 2 male and 22 female, all students of Higher School of Economics participated in the study. All were native Russian speakers with normal or corrected to normal vision. The age varied between 17 and 20 y.o. (*M* = 18.23, *SD* = 0.96). All participants were naive to the experimental hypothesis.

## Stimuli and apparatus

The stimuli were T and L letters, angular size $1.38^o \times 1.38^o$. L letters were various shades of grey, rgb: [70, 70, 70]; [90, 90, 90]; [105, 105, 105]. T letters were various shades grey, rgb: [70, 70, 70] (high-salient) and [105, 105, 105] (low-salient). The T letters were used as targets, the L letters were used as distracters. Both targets and distracters could have various orientations: $0^0$, $90^0$, $180^0$, $270^0$. The stimuli were presented on a grey background, rgb: [128, 128, 128]. There were always 20 items per display. For each trial there were one, two or no targets present. For a single target, it could be high-salient or low-salient; two targets, one target was always high-salient and the other low-salient. The stimuli located in random order (except targets in dual-target condition) in a regular 20 × 14 invisible grid. The distance between the centres of two targets had five levels: $2.07^o$ (lag1), $4.14^o$ (lag2), $6.20^o$ (lag3), $8.27^o$ (lag4), $10.32^o$ (lag5). The levels were chosen based on the dead zone in natural scene data (Utochkin, 2011) and on attentional blink studies (e.g. Raymond, Shapiro, & Arnell, 1992). The relative positions of two targets were equally distributed as the second target was located directly on the right, left, above or below the first target. No distracters were placed directly between the targets. At the bottom of the screen were “NO” and “OK” buttons, each size $6.85^o \times 4.32^o$. These buttons were used for participant answers.

Participants sat in a dark room 45 cm from a 19 inch LACIE electron 19 blue III monitor (screen resolution 1024 × 768, refresh rate 85 Hz) with their heads supported in a chin rest. Stimuli were displayed with Psychopy v. 1.82.01, OS Ubuntu. Participant’s responses were registered with a standard mouse. The example of the trial design is shown in *Figure 1*.

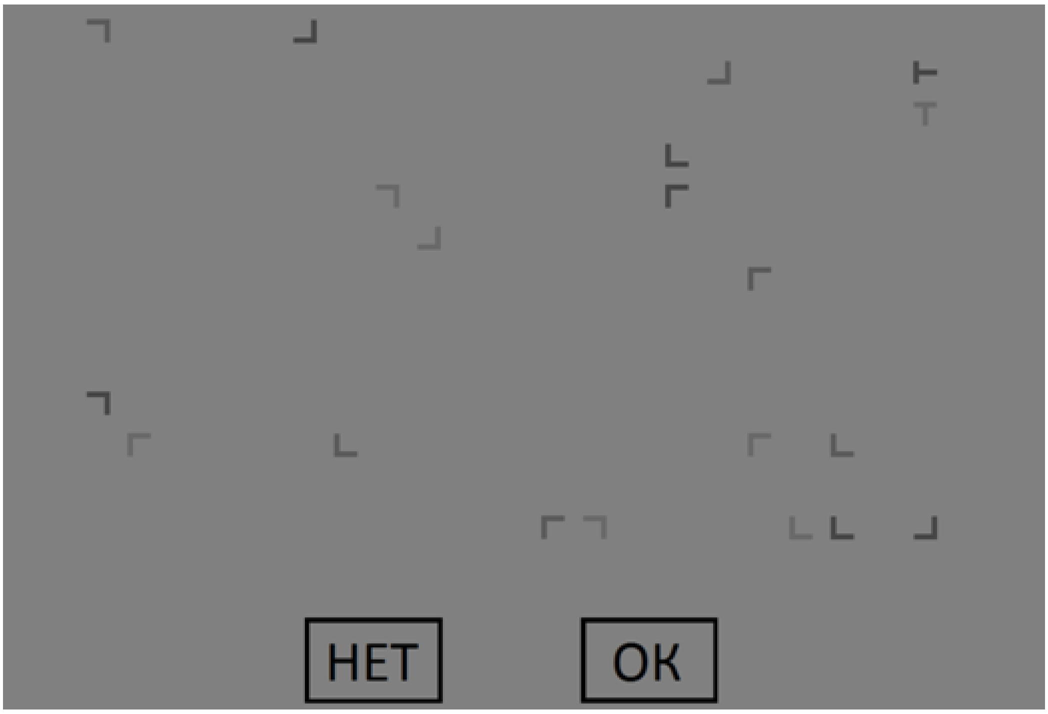


**Fig. 1. An example of experimental trial (dual-target lag1 condition).**

**Procedure**

Experiment was run individually. The experiment consisted of 550 trials. In 50 trials the target was not present (catch-trials), 150 trials included one high salient target, 150 trials included one low salient target, the other 200 trials included two targets (40 trials per each level of between target distance). The order of presentation was randomized.

The participant's task was to find all targets or to report their absence. The participant reported target stimuli by clicking on them directly with the mouse. The participant reported the absence of target stimuli by clicking the "NO" button. In each trial, two mouse clicks were made. In case of two targets, the instruction was to click once on each target. For a single target, the first click was on the target and the second on "OK" button. In case of no targets, the participant was instructed to clicks the "NO" button twice. Each trial had a limit of 20s, after which the screen cleared. The participant pressed the "space" key on the keyboard to begin the next trial. The participant was able to take small breaks during the experiment. The participants were instructed to perform both ~~fast~~ quickly and accurately. A training session of 5 trials preceded the experiment.

## Results

Accuracy and reaction times for all dual-target conditions (lag1, lag2, lag3, lag4, lag5) and the single low salient target condition were compared. The accuracy analysis in the dual-target conditions were calculated as the percentage of correct answers for second (low salient) target if the first (high salient) target was found. Accuracy analysis in the single target condition was calculated as the percentage of correct answers, considering the number of single low salient target trials as 100%.

The RT analysis included the comparison of the time of the first and the second mouse clicks separately and only for correct trials. Trials with RTs over and under 2 SDs were excluded from the RT analysis.

Data analysis was performed using SPSS 20.0. Repeated measures analysis of variance was used. Greenhouse-Geisser corrections were applied due to significant Mauchly's Spherity tests. A priori simple contrasts were applied to compare each of dual-target conditions (lag1, lag2, lag3, lag4, lag5) with the single low salient target condition.

**Accuracy**

Repeated measures ANOVA revealed the main effect of the location factor, $F$ (3, 76) = 3.46, $p$ = .017, $\eta p^2$ = 0.131. The simple a priori contrast test revealed significant differences between the lag5 condition ($M$ = 75.85, $SD$ = 16.26) and the single low salient target condition ($M$ = 81.53, $SD$ = 14.27), $F$ (1, 23) = 7.82, $p$ = .010, $\eta p^2$ = 254. Other contrasts are not significant. All contrasts are in *Table 1*. The accuracy data are presented in *Figure 2*.

**Tab. 1. A priori simple contrasts for accuracy data**

| Conditions compared | F | Sig. | Partial Eta Squared |
|---|---|---|---|
| Lag1 VS one low salient target | 2.36 | .138 | .093 |
| Lag2 VS one low salient target | 1.35 | .256 | .056 |
| Lag3 VS one low salient target | 2.20 | .151 | .087 |
| Lag4 VS one low salient target | 1.01 | .325 | .042 |
| Lag5 VS one low salient target | 7.82 | .010 | .254 |

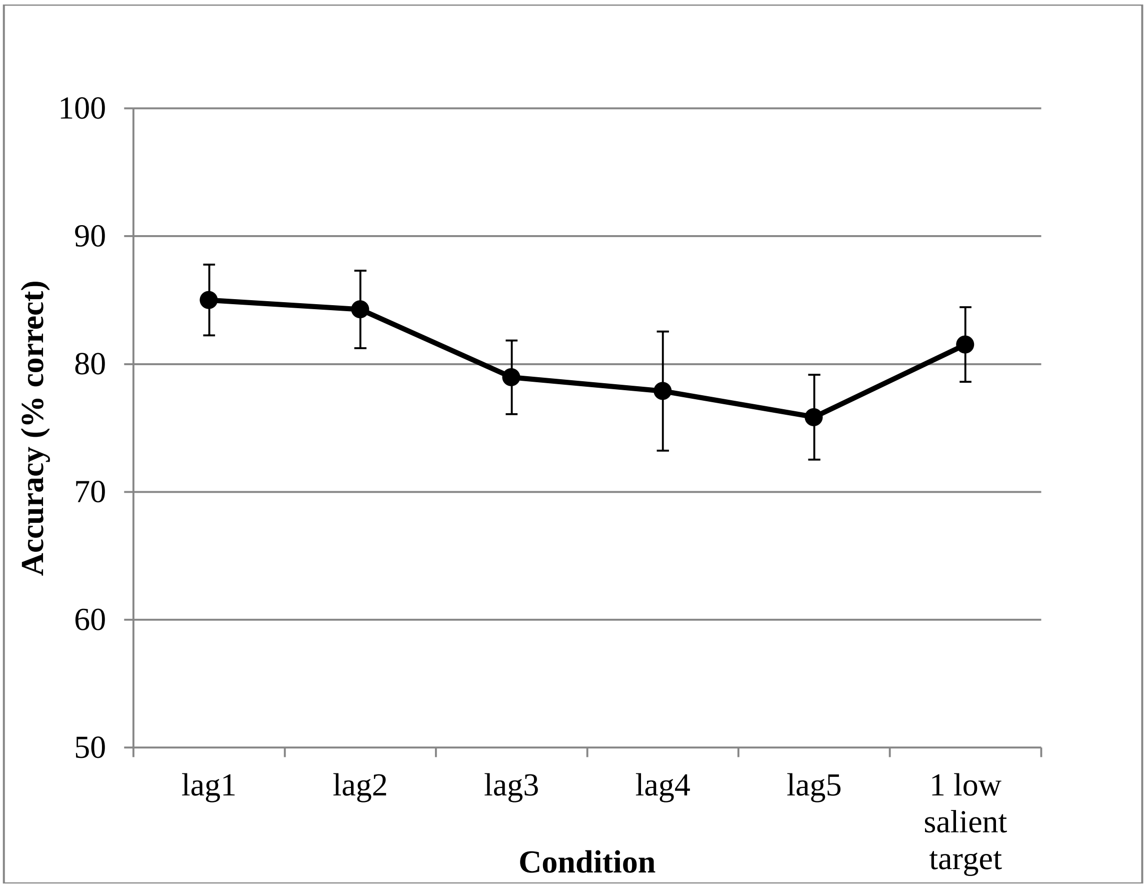

**Fig. 2. Accuracy (% correct) data. Error bars represent standard error means.**

**Reaction time**

Repeated measures ANOVA revealed the main effect of the location factor for the first mouse click, $F$ (2, 52) = 27.89, $p$ = .000, $\eta p^2 = 0.548$. The simple a priori contrast test revealed significant differences for all dual-target conditions compared to single target condition. All contrasts are in *Table 2*.

**Tab. 2. A priori simple contrasts for RTs of the first mouse click.**

| Conditions compared | F | Sig. | Partial Eta Squared |
|---|---|---|---|
| Lag1 VS one low salient target | 35.36 | .000 | .606 |
| Lag2 VS one low salient target | 47.23 | .000 | .673 |
| Lag3 VS one low salient target | 35.74 | .000 | .608 |
| Lag4 VS one low salient target | 53.41 | .000 | .699 |
| Lag5 VS one low salient target | 15.68 | .001 | .405 |

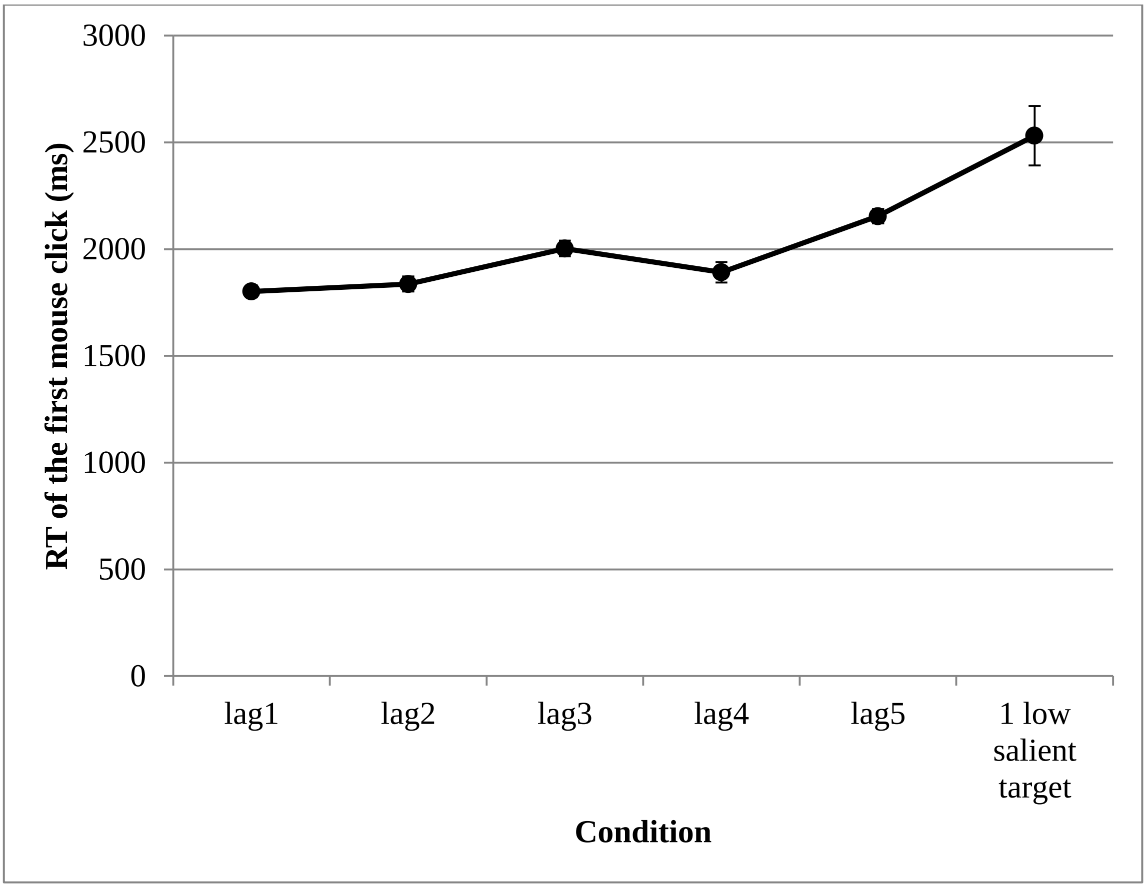


**Fig. 3. The RTs for the first mouse click. Error bars represent standard error means**

Repeated measures ANOVA revealed the main effect of the location factor for the first mouse click, $F$ (1, 32) = 45.34, $p$ = .000, $\eta p^2$ = 0.663. The simple a priori contrast test revealed significant differences for all dual-target conditions compared to the single target condition. All contrasts are in *Table 3*.

The RT data are presented in *Figure 3* and *Figure 4*.

**Tab. 3. A priori simple contrasts for RTs of the second mouse click.**

| Conditions compared | F | Sig. | Partial Eta Squared |
|---|---|---|---|
| Lag1 VS one low salient target | 70.55 | .000 | .754 |
| Lag2 VS one low salient target | 50.35 | .000 | .686 |
| Lag3 VS one low salient target | 39.00 | .000 | .629 |
| Lag4 VS one low salient target | 70.55 | .000 | .754 |
| Lag5 VS one low salient target | 50.35 | .000 | .686 |

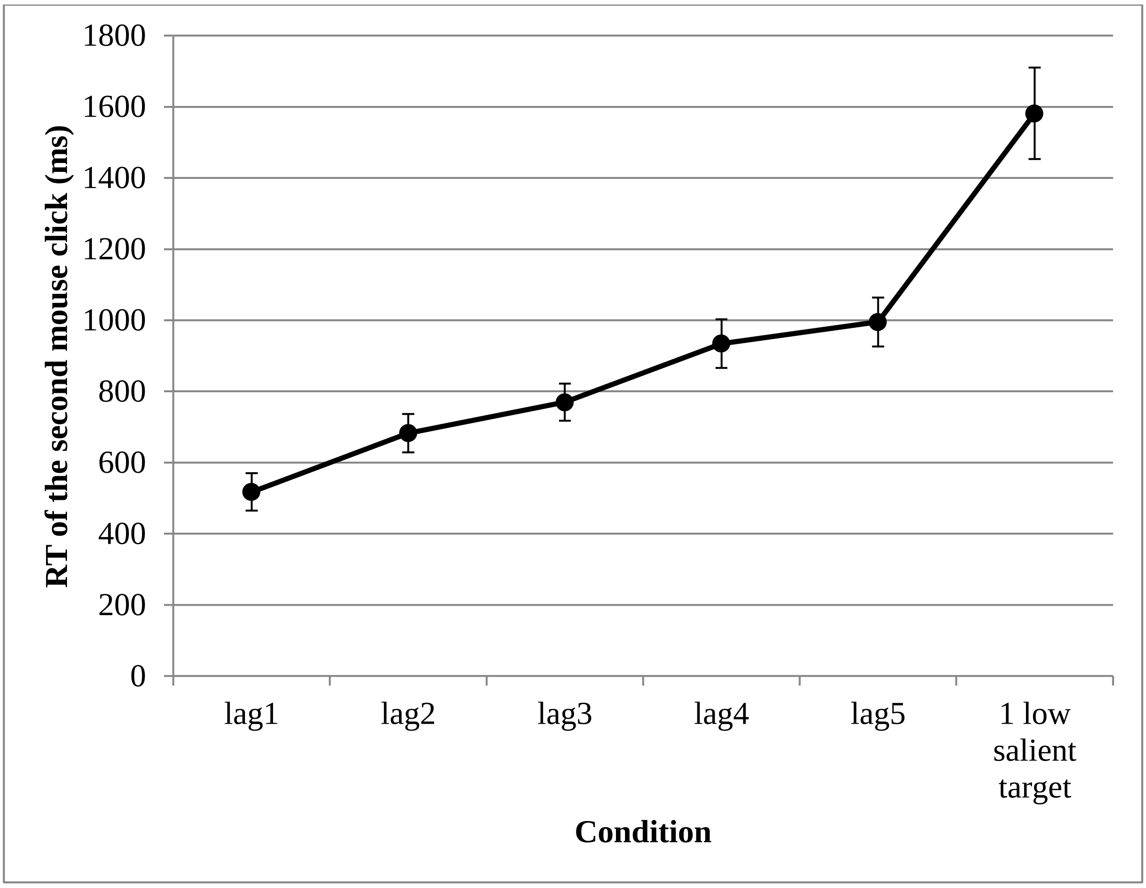


**Fig. 4. The RTs for the second mouse click. Error bars represent standard error means.**

## Discussion

The results revealed the role of intertarget distance in SSM. The accuracy decreases with increasing distance between the targets. A significant SSM effect was present only when the distance between the targets was $10.32^{o}$ (lag 5 condition). These results suggest the existence of a dead zone around the first target. When the second target is present in this area it is less likely to be detected.

Nevertheless, the dead zone discovered in our experiment has other parameters compared to the dead zone in change detection studies. The dual-target visual search dead zone is located at a greater distance than the dead zone discovered in change detection experiments. This might be related to the fact that a change detection task requires more attentional resources that a simple visual search task. According to the spotlight of attention theory (Posner, Snyder, & Davidson, 1980), the intensity of the attentional spotlight (attentional resources) is related to the spotlight allocation (the distance of distribution). As a simple visual search task required less resources than a change detection task, it can be assumed that the additional resources of the attentional spotlight could be distributed in the area around the focus, assuming the bias of the dead zone is farther from the focus. These results are also comparative with the lag1 sparing effect discovered in attentional blink studies. When the second low salient target is present near the first high salient target, it is detected just as well as a single low salient target.

The reaction time of the first mouse click was less than the single target condition for all dual-target conditions . The time required to find at least one of two targets is less than the time required to find a single target as the probability of finding the target while scanning is higher when there are two targets present. The reaction time of the second mouse click is also greater for the single target than for dual-target conditions. This result matches the data from previous experiments with a standard single target visual search task. In our experiment, the second mouse click for single target trials assumed the participant pressed the OK button, which is similar to the response in target-absent trials in the single target search task. According to single target visual search studies, the RT is increased in trials when the target is absent compared to trials when the target is present (e.g. Kwak, Dagenbach, & Egeth, 1991; Moraglia, 1989). Moreover, the RT of the second mouse click increases with the distance between targets. This result can be related to the movement of the spotlight of attention (Posner et al., 1980) and the time required for moving it from one target to another.

Overall, our results revealed the role of intertarget distance in dual-target visual searches, assuming there is a particular distance at which the accuracy of detecting the second target is decreased. This research opens up the prospects for further investigation both on the dead zone of attention and on SSM errors.

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