

Dwelling on distractors varying in target-distractor similarity

Gernot Horstmann^{a,*}, Daniel Ernst^a, Stefanie Becker^b

^a Bielefeld University, Germany

^b University of Queensland, Australia

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ABSTRACT

Present day models of visual search focus on explaining search efficiency by visual guidance: The target guides attention to the target's position better in more efficient than in less efficient search. The time spent processing the distractor, however, is set to a constant in these models. In contrast to this assumption, recent studies found that dwelling on distractors is longer in more inefficient search. Previous experiments in support of this contention all presented the same distractors across all conditions, while varying the targets. While this procedure has its virtues, it confounds the manipulation of search efficiency with target type. Here we use the same targets over the entire experiment, while varying search efficiency by presenting different types of distractors. Eye fixation behavior was used to infer the amount of distractor dwelling, skipping, and revisiting. The results replicate previous results, with similarity affecting dwelling, and dwelling in turn affecting search performance. A regression analysis confirmed that variations in dwelling account for a large amount of variance in search speed, and that the similarity effect in dwelling accounts for the similarity effect in overall search performance.

1. Introduction

Our days are filled with visual search. Beginning with the search for the mug to pour the coffee in for breakfast, localizing the keys somewhat later, scanning the traffic while driving, we continue to search for objects the entire day. In visual search, attention is shifted in space in order to selectively include visual information currently needed for the task at hand, and to exclude information that is not needed and possibly interfering. Often attention shifts are accompanied by eye movements that align the high-resolution fovea with the focus of attention, allowing the analysis of fine details. Covert shifts of attention precede the eye movements (Deubel & Schneider, 1996), and may additionally be functional in determining the next landing end-point of gaze. The aim of a visual search is usually to find a target (or several targets, as in foraging, Wolfe, 2013) among a number of non-targets, often called distractors. There are considerable differences in the difficulty of searches, and accordingly in the efficiency of finding a target (Wolfe, 1998). Some searches are efficient and the target can be located on a single glance (Treisman, 1985). Others are inefficient, and considerable time is spent on checking non-targets before the target is finally found, or until it is decided that there is no target.

Important models of visual search models such as Guided Search (GS, Wolfe, Cave, & Franzel, 1989; see also Wolfe, 1994, 2007) and the Target Acquisition Model (TAM, e.g., Zelinsky, 2008) explain

differences in search efficiency by differences in *target guidance*. For example, in GS, the assumed characteristics of the target are represented in a mental representation of the (search-relevant features of the) target, often called the *target template*. Features that are represented in this target template interact with preattentive information, that is, signals extracted in parallel from the search display. For each location, evidence for a target is accumulated in an activation map, where the amount of activation at one location corresponds to the evidence that the location contains the target. A gradient descent algorithm is used to schedule sequential shifts of attention. A high peak in the activation map at the target's location thus leads to an early focusing of attention on that location, and search is efficient. When some of the non-targets share features with the target, multiple peaks arise in the activation map, and because of inherent noise in the system, the target location may not always have the highest activation in the activation map. Thus, according to guidance centered models of visual search, search efficiency is a function of activation at the target location relative to the non-target locations. Search is easy when the target provides a strong guidance signal and only weak spurious guidance by distractors, and it is difficult when the guidance signal by the target is not much stronger than that of the non-targets. This essentially holds because with a strong guidance signal, less distractors have to be checked (or: more distractors can be skipped) before the target is found than with a weak guidance signal. According to guidance centered

* Corresponding author at: Department of Psychology, Bielefeld University, PO-Box 100 131, 33 501 Bielefeld, Germany.

E-mail address: gernot.horstmann@uni-bielefeld.de (G. Horstmann).

models of visual search, efficient search is achieved by distractor skipping.

For such a guidance-centered approach to visual search, guidance is the one and only variable needed to explain search efficiency. As guidance helps the visual searcher to find the target without inspecting all stimuli in a display, efficient search is effectively the result of skipping a large number of objects in the visual field. Possibly due to the popularity of these models, distractor rejection as another determinant of search time has received far less attention (but see, for instance, Godwin, Walenchok, Hout, Hout, & Goldinger, 2015; Walenchok, Hout, & Goldinger, 2016; Wolfe & Horowitz, 2017). Among the factors that have been neglected are the dwelling on and the revisiting of distractors. Dwelling is the time needed to process each distractor (or group of distractors). Revisiting refers to the (re-)processing of stimuli that have been processed before. Both can be inferred best from eye movements recorded during visual search activity.

Variations in gaze dwell time during visual search have been reported (e.g., Becker, 2011; Gould, 1967, 1973; Hooge & Erkelens, 1998; Horstmann, Herwig, & Becker, 2016; Horstmann, Becker, & Ernst, 2017, but see Zelinsky & Sheinberg, 1997). Becker (2011) found dwelling to be affected by target-distractor similarity and target difficulty, using simple stimuli. With complex naturalistic stimuli, Hout, Robbins, Godwin, Fitzsimmons, and Scarince (2017) found dwelling, revisiting, and the proportion of fixated distractors being affected by the searcher's certainty about the target features. Horstmann et al. (2016, 2017) found that target-distractor similarity causes differences in dwelling. Furthermore, as regression analyses revealed, dwelling strongly influences search speed, and this influence was at least as strong a predictor for search efficiency as indicators of target guidance. In other words, search efficiency is determined by the time spent on processing each of the visited items (i.e., distractor dwell time), in addition to the number of items visited during search (distractor skipping), but also Revisiting – multiple visits to a stimulus during search – has received sporadic attention in the visual search literature (e.g., Humphreys & Müller, 1993; Wolfe, 2007), but is not often considered explicitly as a determinant of search efficiency, with the notable exception of Hulleman and Olivers (2017). One might think that neglecting rescanning as a possible influence is justified by its small impact on search performance. In contrast to this assumption, however, Horstmann et al. (2017) found revisiting to have a substantial influence on search efficiency. Interestingly, revisiting was only a strong determinant of search efficiency in a large and less structured search display containing 10 items, but not in a small and structured display containing only 4 search items (Horstmann et al., 2016). This is consistent with the assumption that memory for already visited display locations is limited (Hulleman & Olivers, 2017), and thus vulnerable to loss when set sizes (i.e., number of items in the search display), exceeds this limit.

1.1. Aims of the present study

In our previous studies (Horstmann et al., 2016, 2017), we presented different target categories among the same, unchanging set of distractors (see also Horstmann & Becker, 2019). The distractors were emotionally neutral faces. In target absent trials, only these neutral faces were presented. In target present trials, one of the faces had a happy expression. To induce different degrees of search difficulty, two target categories were presented in different blocks, which plausibly differed in target-distractor similarity (Duncan & Humphreys, 1989). In similar blocks, participants searched for a happy face with a closed mouth smile. Because the distractors also all had closed lips, these targets were regarded as similar to the distractors. In contrast, in dissimilar blocks, the target was a happy face with an open mouth, which should be dissimilar to the closed lipped distractors. The value of this approach is that the effect of different target templates on the processing of exactly the same distractors could be assessed.

The strategy to hold the distractors constant in Horstmann et al. (2016, 2017) was instrumental in demonstrating how differences in the target template impact on dwelling on and skipping of distractors. The drawback is that similarity effects cannot be separated from effects of the target itself. For example, it might be easier to form and maintain a search template for more prototypical members of a category (Robbins & Hout, 2015). Relatedly, Hout et al. (2017) found search to be more efficient with more specific knowledge about the features of a categorical target (a societally important vehicle such as a police car) than when the target's features were more variable (in case of civilian vehicles). It seems that the open mouth target is a better member of the natural category (Rosch, 1973) of happy faces than the closed mouth target (Horstmann, 2002). Thus, one might argue that forming and maintaining a search template for an open mouth happy face could be easier than for a closed mouth happy face.

Our main aim in the present study was to examine the impact of target-distractor similarity on the visual search parameters of skipping, dwelling, and revisiting, while excluding possible effects that depend solely on the target. Therefore, we presented the same (neutral face) target in the context of similar distractors consisting of crowds of closed mouth happy expressions in some blocks, and in the context of dissimilar distractors consisting of crowds of open mouth happy expression in other blocks.

With this change, the possible problem of target category effects independent of target-distractor similarity could be avoided, as the target is the same in all blocks. If the target category was a decisive factor for the previously observed strong effects on dwelling and revisiting, we should find generally weak effects. Target-distractor similarity, in contrast, is basically the same when the roles of targets and distractors are switched (but see Horstmann, Scharlau, & Ansorge, 2006). If target-distractor similarity is the most important factor, we should obtain roughly the same results as before.

With this alternative manipulation of target-distractor similarity, it is additionally possible to rule out a concern with regard to target template switching in Horstmann et al. (2017). Switching the target category between blocks back and forth could have compromised the creation, maintenance, or application of the target template during visual search (similar to the effects of an incongruent mapping of targets and distractors, cf. Schneider & Schiffman, 1977), rendering guidance unnecessarily weak and dwelling unrealistically strong. The possible problem of target template formation should be attenuated with a constant target. As a consequence, guidance might contribute more to search efficiency as compared to the previous studies, in which the targets always switched (e.g., Horstmann et al., 2017).

Finally, we sought additional information on dwelling. First, we analyze the composition of dwell times, as longer dwell times may be due to additional fixations or to variations in fixation duration. Second, we follow up on a result in Horstmann et al. (2017), where dwell times were found to be longer on a target than on distractors. On consideration, this might be an averaging artifact, because target fixations very frequently included the time required for response related processes, which is not the case for distractor fixations. Therefore we aim to identify the last fixations in target present and target absent trials, and compare the corresponding dwell times. The result is possibly relevant to diffusion process modelling of distractor rejection (Ratcliff, 1978).

2. Methods

2.1. Participants

Twelve students participated in the study, eight women and four men, with a mean age of 23.25 ($SD = 2.73$) years. They received €4 for their 30 min participation. One participant had to be excluded because of excessive errors in target present trials. Thus, the data of 11 participants were analyzed. Sample size was based on previous studies with



Fig. 1. Examples of the neutral target face (left), the similar distractor (center), and the dissimilar distractor (right).

a similar design (Horstmann et al., 2016, 2017).

2.2. Stimuli

The stimuli were the same as in Horstmann et al. (2017). They were drawn from the NimStim stimulus set (Tottenham et al., 2009). Five female models and five male models provided a neutral face and two variants of friendly faces each, one with an open mouth and visible teeth (dissimilar distractor), and one with a closed mouth (similar distractor, see Fig. 1). The neutral target faces all had a closed mouth. Thus, a total of 30 pictures of faces were used. Each color picture subtended 77×99 pixels and $2.1^\circ \times 2.8^\circ$ (see Fig. 1 for an example of the three expressions that were used from each model).

Search displays consisted of ten pictures presented in 10 cells, randomly selected from a 3×5 matrix excluding the center position. The spacing of the cells was 100 pixels (2.8°) horizontally and 130 pixels (3.6°) vertically. In the center position we presented only the fixation stimulus, never a search stimulus. Picture positions were based on the centers of the cells, with an additional random jitter of 5 ± 5 pixels horizontally and vertically.

2.3. Apparatus

Stimuli were presented on a 19-in. display CRT-monitor (100-Hz refresh rate, resolution 1024×768 pixels) at a distance of 71 cm. A video-based tower-mounted eye tracker (EyeLink 1000, SR Research, Ontario, Canada) with a sampling rate of 1000 Hz was used for the recording of eye movements. The participants' head was stabilized by a chin and forehead rest, and in all participants, the right eye was monitored. Before the experiment commenced, the eye tracker was calibrated using a 9-point calibration. The experiment was programmed using Experiment Builder 1.10.165 (SR Research, Ontario, Canada), and eye tracking data were preprocessed using Data Viewer 2.2.1 (SR Research, Ontario, Canada).

2.4. Design

The experiment comprised 7 blocks, which differed only in the distractor category (open versus closed mouth targets, or distractor-dissimilar versus distractor-similar target, respectively). The target category remained the same, being an emotionally neutral face. Each block contained 20 trials, 10 of which were target present trials, and 10 were target absent trials. Blocks with similar distractors alternated with blocks with dissimilar distractors. Half of the participants started with a similar distractor block. The first block was considered as practice and omitted from further analysis.

For each trial, one of the ten models (facial identities) was selected. If the trial was designated as a target present trial, this model displayed the neutral face; if the trial was designated as a target absent trial, this

model showed the same happy face as the other distractors. Each model was presented once in a block as a target. The remaining nine stimulus positions were filled randomly with the remaining nine models which all displayed a happy expression (open or closed mouth, depending on the block-wise similarity condition). Target absent trials within a block consisted of the same assembly of happy faces (open or closed mouth, depending on similarity condition). The designated target face, which was in an absent trial of the same type as the remaining distractor faces, served as comparison stimulus (the “foil target”) in some analyses.

2.5. Procedure

Each trial started with a fixation control, which was terminated with a key press (with the left hand) that also initiated the presentation of the search display. The task was to press one of two keys (with the index or middle finger of the right hand) depending on whether one of the ten possible instances of the target category was presented in a trial. The search display was shown until the key press response was registered. Prior to each block, the ten possible targets were displayed side by side on the monitor for ad lib inspection, with the aim of providing an overview of their appearances to the participant.

2.6. Eye tracking data preprocessing

Raw eye position data were parsed by eye tracker software's standard experimental setting which uses a speed threshold ($30^\circ/s$) and an acceleration threshold ($8000^\circ/s^2$) to detect saccades. Areas of interest (AOIs) were defined that enclosed the face pictures almost exactly (i.e., they were 1–2 pixels larger than the picture). The fixation during which the display started was regarded as fixation index zero and omitted from further analysis; that is, first following fixation was fixation index = 1. The final fixation duration, during which the manual response was registered, was truncated by the response.

From these preprocessed data, four variables were derived for analysis. Each stimulus was classified as being fixated within a given trial or not. If a stimulus was fixated, dwell time was assessed, which is the sum of the fixation durations over the first continuous series of fixations on that stimulus. Note that this measure excludes the additional dwell time that accrues with revisits to keep the variables dwelling and revisiting independent and un-confounded. Also, the latency of the fixation relative to the onset of the search display was recorded. This measure is conceptually similar to a reaction time, with the difference that for n fixations in a given trial, n latencies were registered. Furthermore, we recorded whether a stimulus was visited only once, or whether it was revisited, that is, selected twice during a trial.

The basic variables of our analysis, however, were trial statistics. *Skipping* is defined as the proportion of stimuli that had not been fixated in a trial. *Skipping* is the variable which drives trial RT, as assumed by guidance based theories of visual search. *Dwelling* is the average dwell

time for the stimuli visited in a trial. We predict dwelling to have a substantial influence on RT, whereas guidance based theories treat dwelling as a constant. In addition to dwelling and skipping, we also assessed the proportion of stimuli that had been revisited, because *Revisiting* is a third possible source of variance in RT. Finally, we also measured RT, that is, the time between display onset and the pressing of the correct answer key.

3. Results

Our analysis consists of two parts. The first part presents the standard Analysis of Variance for factorial designs. We will examine, in particular, whether similarity influences search time (i.e., RT), dwelling, skipping, and revisiting, and whether the effect of similarity on dwelling is due to more fixations on a stimulus or the duration of these fixations.

The second part uses a linear regression model that regresses search time (RT) on a given trial on the average time gaze fixated an item (dwelling) in that trial, the number of items not looked at in that trial (skipping), and the number of items that have been looked at repeatedly (revisiting). In such an analysis, the regression coefficients inform not only about whether or not a predictor has an effect on the dependent variable or not, but also allows comparisons between variables with respect to their relative contributions.

3.1. Error rates

Mean proportion correct for the target absent trials were 0.99 vs. 0.98 for the similar and dissimilar distractor conditions, respectively, and 0.88 vs. 0.93 for the target present trials. An ANOVA with the variables similarity (similar vs. dissimilar distractors) and target presence (present vs. absent) revealed a significant main effect for target presence, $F(1,10) = 18.13$, $p = .002$, $\eta_G^2 = 0.40$, a marginally significant main effect for similarity, $F(1,10) = 3.55$, $p = .089$, $\eta_G^2 = 0.05$, and a significant interaction, $F(1,10) = 6.18$, $p = .032$, $\eta_G^2 = 0.08$. The interaction revealed that errors were disproportionate frequent in trials with a similar target. The interaction revealed that the similarity effect in errors was only significant in target present trials, $t(10) = 2.35$, $p = .041$, $d_z = 0.46$, but not in target absent trials, $t(10) = 0.69$, $p = .506$, $d_z = 0.19$. In the following analyses, only trials with correct answers were included.

3.2. Reaction times

Trials with errors in the search task, in which RTs were implausibly short (< 300 ms, 0 instances) or exceeded the .99th percentile of the RT distribution (6313 ms, 13 instances) were discarded from this and all following analyses (Fig. 2). An ANOVA computed over the mean RTs with the variables similarity (similar vs. dissimilar) and target presence (present vs. absent) revealed significant main effects for both variables (presence: $F(1,10) = 168.08$, $\eta_G^2 = 0.51$; similarity: $F(1,10) = 55.09$, $\eta_G^2 = 0.36$; both $ps < 0.001$). Target present RTs were shorter than target absent RTs (2135 ms vs. 3202 ms), and dissimilar targets rendered shorter RTs than similar targets (2277 ms vs. 3059 ms). The similarity effect was stronger in target absent trials (see Fig. 2), as revealed by the significant Target presence \times Similarity interaction, $F(1,10) = 75.68$, $p < .001$, $\eta_G^2 = 0.03$. Thus, the RT analysis established a strong similarity effect in both target present and target absent trials, which was however more pronounced in target present trials.

3.3. Dwell times

Fixation dwell times that were either very short (40 ms, 120 instances) or exceeded the 99th percentile of the dwell time distribution (804 ms, 100 instances) were excluded from the analyses of dwell times. Fig. 3a provides an overview of the first run dwell times on

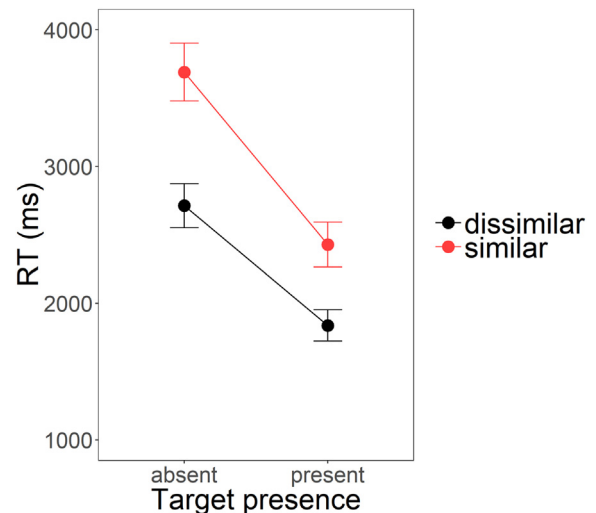


Fig. 2. Mean RTs for trials with high and low target-distractor similarity, in target absent and present trials, respectively. Error bars are standard errors (i.e., SD / \sqrt{N}) of the means.

distractors and targets in target present trials, and on distractors and foil targets (i.e., the target placeholder) in target absent trials. First run dwell times are the sum of fixation durations during the first continuous visit on a stimulus.

An ANOVA of the dwell times with the variables target presence (present vs. absent), similarity (similar vs. dissimilar), and stimulus type (distractor vs. target/foil target) rendered significant main effects for all variables. The dwell time on a stimulus was longer in target present (322 ms) than absent trials (231 ms), $F(1,10) = 33.08$, $p < .001$, $\eta_G^2 = 0.32$, longer with similar (298 ms) than dissimilar distractors (256 ms), $F(1,10) = 28.03$, $p < .001$, $\eta_G^2 = 0.09$, and longer for the target/foil stimuli (331 ms) than on the distractors (222 ms), $F(1,10) = 39.56$, $p < .001$, $\eta_G^2 = 0.41$. Among the interaction effects, only the Target presence \times Stimulus type interaction was significant, $F(1,10) = 33.38$, $p < .001$, $\eta_G^2 = 0.38$, (other $F_s < 4.27$, $ps > 0.06$, η_G^2 s < 0.01). This was due to the much longer dwell times on targets (429 ms) than on distractors (216 ms) in target present trials, $t(10) = 6.07$, $p < .001$, $d_z = 0.78$, whereas there was no difference between distractors (230 ms) and foil targets (236 ms) in target absent trials, $t(10) = 1.36$, $p = .20$, $d_z = 0.10$.

3.4. Decomposition of dwell times

Before we proceed to our other main variables, we further analyzed the first run dwell time differences. As dwell times, by definition, may include a variable number of fixations, we can ask again: Is it the number of fixations within a dwelling period, or the duration of individual fixations that leads to prolonged dwelling with similar distractors? The number of fixations for each first run dwell time was not significantly affected by similarity. The only significant effect in the ANOVA pertained to the target, for which the mean number of fixations was 1.55, while the mean number of fixations on the distractors in the target trial was 1.20, resulting in a significant main effect for stimulus type, $F_s < 36.29$, $ps > 0.001$, η_G^2 s < 0.23, and a significant interaction with target presence (remaining effects $F_s < 4.11$, $ps > 0.07$, η_G^2 s < 0.02 (the nonsignificant trend reflects, however, a small increase in the order of 5% for similar distractors).

As the number of fixations is not affected by similarity, the cause of increased dwell times must be the duration of fixations. To check this conclusion, we analyzed the first fixation for the first visit on a stimulus. The ANOVA of the fixation duration revealed a main effect for target presence, $F(1,10) = 30.78$, $p < .001$, $\eta_G^2 = 0.19$, for similarity, $F(1,10) = 101.92$, $p < .001$, $\eta_G^2 = 0.28$, and stimulus type, F

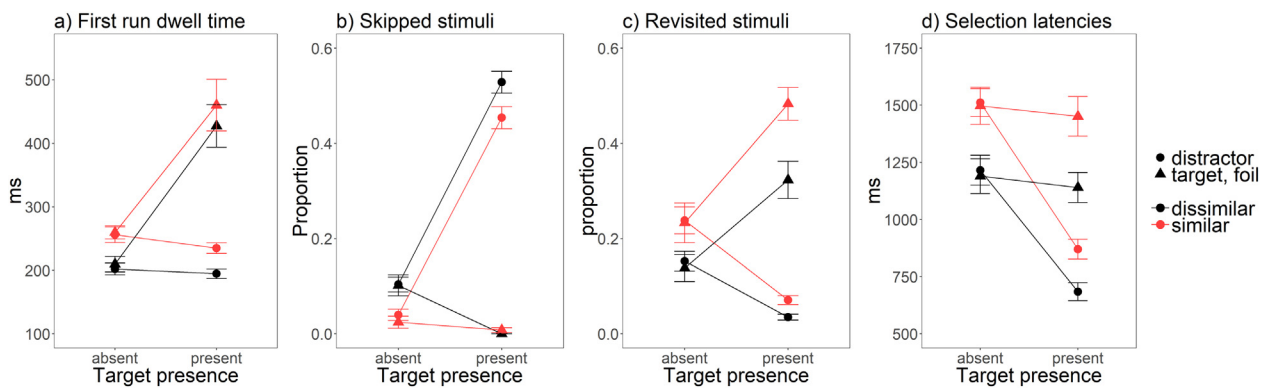


Fig. 3. Mean dwell times, proportions of skipped stimuli, proportions of revisited stimuli and fixation latencies for blocks with high and low target-distractor similarity in target and present trials. Error bars are standard errors (i.e., SD / \sqrt{N}) of the means.

(1,10) = 49.12, $p < .001$, $\eta_G^2 = 0.40$. The main effect for similarity was due to longer first fixations on similar than dissimilar stimuli (228 vs. 193 ms). The main effects of presence and stimulus type were qualified by a significant interaction, $F(1,10) = 58.41$, $p < .001$, $\eta_G^2 = 0.36$. The first fixation on the target was much longer than on a distractor in a target trial (267 vs. 180 ms), while there was no difference between the foil and the distractor in target absent trials (199 vs. 196 ms). No further interaction approached significance, $F_s < 1.71$. We repeated the analysis for the (much rarer) second fixations with virtually the same results. To summarize, the longer dwelling on distractors with similar distractors is due to longer fixation duration, but not to more fixations.

3.5. Dwelling on targets and distractors

Average dwell time was much longer on targets than on distractors. It might be observed that this could possibly be an artifact of the analysis, because the dwell times of most of the distractors do not include response related processes, whereas the opposite is true for the target. We thus identified in present and absent trials the last fixation during which the response was made. An ANOVA with the variables target presence (absent vs. present), and similarity (similar vs. dissimilar) revealed two main effects only (interaction: $F < 1$). The main effect for presence, $F(1,10) = 60.94$, $p < .001$, $\eta_G^2 = 0.33$, shows that the longer dwell times on the target vs. distractors (446 ms vs. 319 ms) are robust also when only the last fixation in a trial is examined. The main effect for similarity, $F(1,10) = 5.68$, $p < .038$, $\eta_G^2 = 0.07$, reflects longer dwell times on similar than dissimilar targets and distractors (408 ms vs. 357 ms).

3.6. Proportion of fixated and skipped stimuli

Fig. 3b provides an overview of the proportion of fixated versus skipped distractors and targets in target present trials, and on distractors and foil targets in target absent trials. An ANOVA of the skipping proportions with the variables target presence (present vs. absent), similarity (similar vs. dissimilar), and stimulus type (distractor vs. target/foil target) rendered significant main effects for all variables ($F_s > 43.09$, $ps < 0.001$, $\eta_G^2s > 0.20$), all two-way interactions ($F_s > 4.77$, $ps < 0.054$, $\eta_G^2s > 0.03$), and the three way interaction, ($F = 18.55$, $p < .002$, $\eta_G^2s = 0.05$). Skipping was more frequent in target present than in absent trials (0.25 vs. 0.07), more frequent in dissimilar than in similar distractor trials (0.18 vs 0.13), and more frequent for distractors than for targets (0.28 vs. 0.03). The interaction effects reflected essentially that skipping was nearly zero for targets, while for distractors there were two main effects for target presence and similarity without interaction (see also Fig. 2).

3.7. Revisiting

Fig. 3c provides an overview of the proportions of revisits on distractors and targets in target present trials, and on distractors and foil targets in target absent trials. An ANOVA of the revisiting proportions with the variables target presence (present vs. absent), similarity (similar vs. dissimilar), and stimulus type (distractor vs. target/foil target) rendered significant main effects of similarity, $F(1,10) = 19.20$, $p = .002$, $\eta_G^2 = 0.21$, and stimulus type, $F(1,10) = 104.12$, $p < .001$, $\eta_G^2 = 0.47$. The main effect of target presence was not significant, $F(1,10) = 1.6$, $p = .023$, $\eta_G^2 = 0.04$. Two significant two-way interactions modified the main effects: Target presence \times Stimulus type, $F(1,10) = 84.90$, $p < .001$, $\eta_G^2 = 0.49$, and Similarity \times Stimulus type, $F(1,10) = 5.52$, $p = .05$, $\eta_G^2 = 0.03$. Furthermore, the Target presence \times Stimulus type \times Similarity three-way interaction was significant, $F(1,10) = 15.92$, $p = .003$, $\eta_G^2 = 0.02$, (other $F_s < 1.99$, $ps > 0.19$, $\eta_G^2s < 0.02$).

To clarify the complex interaction pattern entailed in the three-way interaction, two separate ANOVAs were conducted for target absent and present trials. For target absent trials, only the main effect for similarity was significant, $F(1,10) = 14.52$, $p = .004$, $\eta_G^2 = 0.18$, reflecting a higher proportion of revisits on similar than dissimilar distractors (0.24 vs. 0.15) (other $F_s < 1$).

For target present trials, the main effect for similarity, $F(1,10) = 15.05$, $p = .003$, $\eta_G^2 = 0.25$, and stimulus type, $F(1,10) = 118.50$, $p < .001$, $\eta_G^2 = 0.81$, and the interaction, $F(1,10) = 11.01$, $p = .008$, $\eta_G^2 = 0.12$, were significant. Stimuli were revisited more often in similar than in dissimilar blocks (0.28 vs. 0.05), and the target was revisited more often than a distractor (0.40 vs. 0.05). The interaction was due to the fact that the similarity effect was much more pronounced for the targets than for distractors.

3.8. Guidance by the target

The RT analysis already indicated that the target is found faster in the dissimilar than in the similar condition. Guidance would register in short fixation latencies on the target, with selection latency being defined as the time from the display onset to the first fixation on a stimulus. However, short fixation latencies may have causes different from guidance. In particular, short latencies may be due to short dwell times on distractors before the target is fixated, and also to infrequent rescanning of distractors during search. Scanning and dwelling, however, would also be active in target absent trials, whereas guidance by the target can only be active target present trials. Thus, to balance similarity effects on distractor processing, we compared selection latency for the target with selection latency for the foil target within each similarity condition. Latencies lower than 100 ms (46 instances) or exceeding the 99th percentile of 3747 ms (95 instances) were excluded

from this and following analyses of selection latencies.

Fig. 3d gives an overview of the mean selection latencies. As shown in Fig. 3d, the distractor fixation latencies are dominated by the fact that in absent trials, nearly all stimuli are gazed at, which renders selection latency relatively long. In contrast, in present trials a smaller number of distractors is visited, because without target guidance, half of the distractors should be visited on average, and with target guidance, the average number of distractors visited before target should be even less. Thus, the average selection latency for distractors should be considerably lower in present than in absent trials, and this is also reflected in the data.

A 2×2 ANOVA with the variables target type (target vs. foil) and similarity (similar vs. dissimilar) revealed only a significant main effect of similarity, $F(1,10) = 57.68$, $p < .001$, $\eta_G^2 = 0.28$, (other $F_s < 1$, $p_s > 0.34$, $\eta_G^2 < 0.01$). Guidance would be revealed if the target is fixated earlier than the foil target. Surprisingly, this was not the case, as there was only a small advantage for the target over the foil target (1296 vs. 1344 ms). The significant main effect for similarity was due to earlier fixations in the dissimilar than in the similar condition (1165 vs. 1474 ms), on both targets and foil targets.

3.9. Contributions of dwelling, skipping, and rescanning to search times

Search times are basically the product of the number of fixations and their mean durations. The analysis so far revealed that similarity influences dwelling, skipping, and revisiting. In the next step we determine the specific contribution of skipping, rescanning, and dwelling to overall search time using a regression approach. Table 1 presents the bivariate correlations between RT, revisiting rate (revisiting), skipping rate (skipping), and dwell time (dwelling) on the level of trials separately for target absent and present trials. Fig. 4 presents the scatterplots corresponding to the correlation coefficients. Whether a given trial was from a similar or a dissimilar block is color-shape coded (red circles and blue diamonds, respectively; absent trials on the left side, present trials on the right side).

We can make a number of observations: (a) the first column of Table 1 shows the effects of similarity on the measured variables, with similarity explaining considerable amounts of variance in these variables (moderate to large effects according to Cohen, 1992); (b) the second column shows the uncorrected (very strong) effects of dwelling, skipping, and revisiting on search time; (c) the third and the fourth column shows that dwelling, skipping, and revisiting are correlated, implying that, for instance, the correlation of dwelling and search time may partly include effects of skipping and revisiting as well; (d) concerning the scatterplots, there are clear linear relations between the predictor variables dwelling, skipping, and revisiting, respectively, and the dependent variable RT, which are roughly the same for blocks with dissimilar and similar targets, as red and blue dots align without apparent discontinuity on a single linear function.

To take into account the correlations among the predictors and to

Table 1

Correlation matrix for the variables similarity, RT, skipping, dwelling, and revisiting in target absent and target present trials.

		Similarity	RT	Skipping	Revisiting
Absent	RT	<u>0.51</u>			
	Skipping	<u>-0.35</u>	<u>-0.55</u>		
	Revisiting	<u>0.25</u>	<u>0.66</u>	<u>-0.25</u>	
	Dwelling	<u>0.49</u>	<u>0.76</u>	<u>-0.30</u>	<u>0.17</u>
Present	RT	<u>0.31</u>			
	Skipping	<u>-0.13</u>	<u>-0.81</u>		
	Revisiting	<u>0.20</u>	<u>0.59</u>	<u>-0.43</u>	
	Dwelling	<u>0.34</u>	<u>0.46</u>	<u>-0.19</u>	<u>0.14</u>

Note. Correlations were calculated on trial measure. Underlined coefficients are statistically significant ($p < .001$).

obtain the unique effects of the predictors on RT, we analyzed the data by regressing RT on dwelling, skipping, revisiting, and similarity. We used a linear multilevel regression with random intercepts and fixed slopes for the twelve subjects to separate within-subject variations in dwelling, skipping, revisiting, and search time from between-subject variations. We z -transformed metrical variables prior to our analyses to make regression coefficients comparable. For the experimental factor of target-distractor similarity, low similarity was coded as zero and high similarity was coded as one. As the t -distribution converges with the standard normal distribution when the degrees of freedom are high, $z = 1.96$ corresponding to $p = .05$ was used to evaluate statistical significance of regression coefficients. Thus t -values > 1.96 indicate that the regression coefficient is larger than zero.

3.10. Target absent trials

Table 2a shows the results for predicting trial RTs on the basis of 640 target absent trials. The variance inflation factor (VIF) was used to guard against collinearity among the predictor variables, which was however acceptable, with all $1/VIF > 0.69$. All predictors had significant effects, and the effects of revisiting and dwelling were particularly strong. Marginal R^2 was 0.90 (Nakagawa & Schielzeth, 2013). To test the differences between the b_s against chance, we used a simple t -test, assuming that the standard error of the difference between the slopes b_1 and b_2 is given by $\sqrt{SE_{b_1}^2 + SE_{b_2}^2}$. According to this procedure, all slopes were significantly different from each other (i.e., exceeding $t = 1.96$).

3.11. Target present trials

Only distractor fixations were analyzed for target present trials to be consistent with the previous analysis. We applied the same trial-based multilevel regression model as for the target absent trials to target present trials. The total number of observations was 578. Indications of collinearity were low, $1/VIF > 0.79$. All slopes were significant (see Table 2b). That the effect of skipping is dominating in this analysis is no surprise as in target present trials, the target is found after variable numbers of inspected distractors and search is terminated. Thus, skipping is expected to be the most important determinant of RT in target present trials, which should not be interpreted as guidance because it is a rather trivial consequence of randomly finding the target early or late in the trial. Marginal R^2 was 0.80. With the exception of the difference between dwelling and revisiting, all slopes were significantly different from each other (i.e., exceeding $t = 1.96$, see above).

3.12. Contributions of dwelling, skipping, and revisiting to the similarity effect

We next analyzed the contributions of skipping, rescanning, and dwelling to the similarity effect, defined as the difference in RT between similar and dissimilar blocks. To account for the similarity effects, the differences in RT (similar-dissimilar) were regressed on the differences (similar-dissimilar) in skipping, rescanning, and dwelling, respectively, using simple least squares regression. Table 3 presents the correlations for target absent and target present trials.

3.13. Target absent trials

For target absent trials, all $1/VIF > 0.69$. The multiple regression yielded significant effects for dwell time, $t(7) = 3.36$, $p = .004$, and revisiting, $t(7) = 2.73$, $p = .029$ (skipping: $t(7) = -1.18$, $p = .276$). The standardized weights are $b = 0.57$ for dwell time, $b = -0.17$ for skipping, and $b = 0.44$ for revisiting (all SEs between 0.13 and 0.17). For the whole model, explained variance was $R^2 = 0.85$. To summarize, dwelling and revisiting contributed significantly to the similarity effect in target absent trials, while skipping did not.

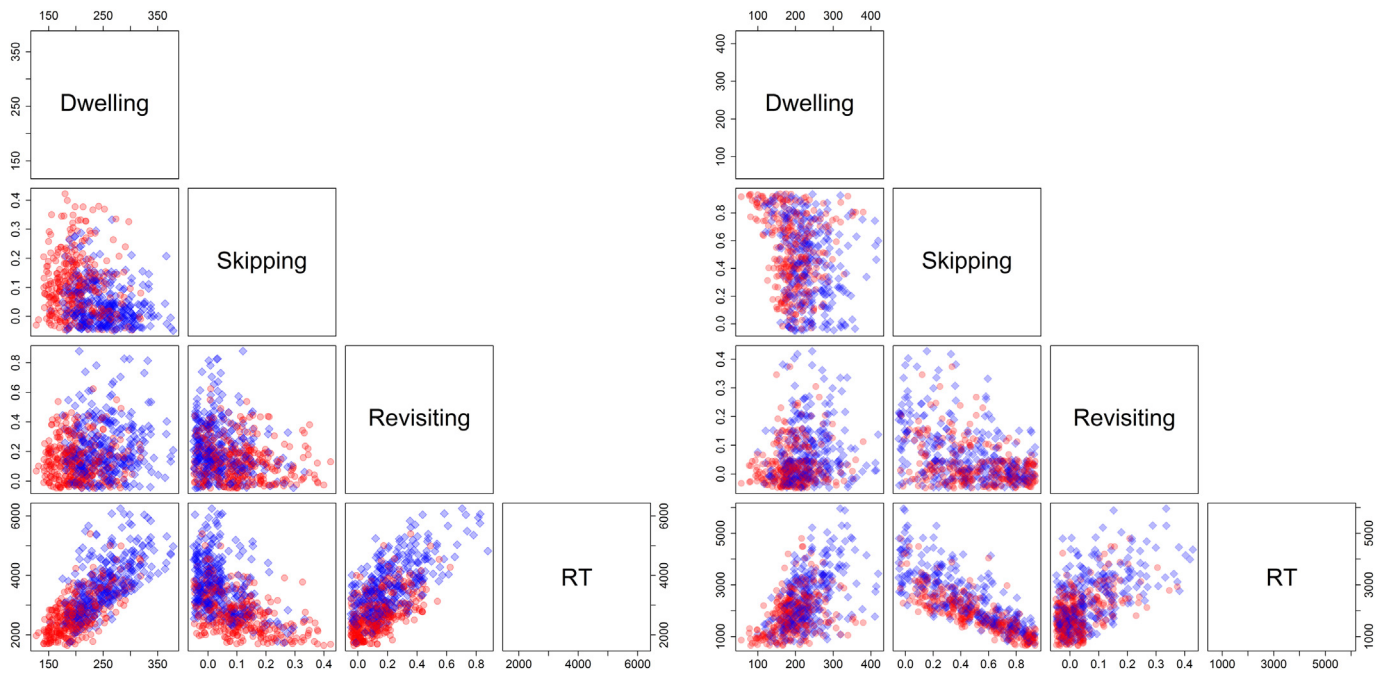


Fig. 4. Bivariate relationship between trial search times (RT), revisiting rates (Revisiting), skipping rates (Skipping), and dwell times (Dwelling), for distractors in target absent trials (left panel) and target present trials (right panel) per participant. Target-dissimilar and target-similar distractors are presented as red, or blue, dots, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 2

Linear multilevel regression of target absent and present trial reaction times on dwelling, skipping, revisiting, and similarity as fixed effects and random intercepts for participants.

	<i>b</i>	<i>SE(b)</i>	<i>t</i>
a) Target absent trials			
Intercept	-0.05 (0.12)	0.04	-1.14
Dwelling	<u>0.54</u>	0.02	31.37
Skipping	<u>-0.23</u>	0.01	-17.53
Revisiting	<u>0.47</u>	0.01	37.69
Similarity	<u>0.10</u>	0.03	3.32
b) Target present trials			
Intercept	-0.10 (0.27)	0.08	-1.21
Dwelling	<u>0.21</u>	0.02	12.82
Skipping	<u>-0.65</u>	0.02	-37.93
Revisiting	<u>0.24</u>	0.02	15.11
Similarity	<u>0.18</u>	0.03	5.76

Notes. *b* = regression coefficient; *SE* = standard error of regression coefficient; models allowed for random intercepts between subjects; estimation method was full maximum likelihood; with the exception of similarity, all metrical variables were *z*-transformed prior to analyses; for similarity “dissimilar target” was coded as zero and “similar target” as one; standard deviations of random intercepts are reported in brackets; underlined coefficients are statistically significant by *t*-values exceeding ± 1.96.

Table 3

Correlation matrix for the differences (similar-dissimilar) in RT, skipping, dwelling, revisiting in target absent and target present trials based on subject's averages.

		RT	Skipping	Revisiting
Absent	Skipping	-0.53		
	Revisiting	<u>0.79</u>	-0.55	
	Dwelling	<u>0.80</u>	-0.20	0.45
Present	Skipping	<u>-0.79</u>		
	Revisiting	0.57	-0.21	
	Dwelling	<u>0.86</u>	<u>-0.69</u>	0.36

Note. Underlined coefficients are statistically significant, *p* < .05.

3.14. Target present trials

For target present trials, *1/VIFs* were > 0.47. The regression analysis for target present trials rendered significant effects for dwelling, *t* (7) = 2.77, *p* = .028, and revisiting, *t*(7) = 2.40, *p* = .047. The effect for skipping just failed to reach significance, *t*(7) = -2.31, *p* = .054. The standardized weights for the effects were *b* = 0.49 for dwelling, *b* = -0.39 for skipping, *b* = 0.31 for revisiting (all *SEs* were between 0.12 and 0.18, *R*² = 0.86).

3.15. Comparisons with Horstmann et al. (2017)

In the introduction, we expressed concerns that strong effects of distractor rejection (dwelling and revisiting) relative to effects of target guidance (skipping) may be due to the target itself, or to the switching of target templates between blocks, rather than to target distractor similarity. To directly test whether the effects of dwelling, skipping, and revisiting differ between varying and constant targets, the datasets of Horstmann et al. (2017) and the present study were merged and re-analyzed. Table 4 shows the model for regressing RTs on the gaze parameters, the similarity effect, and study (where the present study and Horstmann et al., 2017, were coded as zero, and one, respectively). In addition, the interactions between study and the remaining predictors were included to test whether their effects changed between both experiments. We will only present the results of the theoretically most important target absent trials.

The effects of dwelling, skipping, and revisiting are basically the same as in our main analysis. The effect of study relates to faster search in Horstmann et al. (2017) where the distractors were constant and the target switched between trials. Of the interactions with study, two (with skipping and revisiting) were very weak and will not be interpreted. The interaction with similarity indicates that the unique effect of similarity was stronger with constant distractors (i.e., the former study). The interaction with dwelling indicates that the effect of dwelling was stronger with variable distractors (i.e., the present study).

Note that the similarity effect in this interaction reflects the impact of similarity on RT that is not explained by skipping, dwelling, and

Table 4

Linear multilevel regression of target absent trial reaction times on dwelling, skipping, revisiting, similarity, experimental session as fixed effects and random intercepts for participants.

Target absent trials	<i>b</i>	<i>SE(b)</i>	<i>t</i>
Intercept	0.07 (0.08)	0.03	2.29
Dwelling	0.61	0.02	37.71
Skipping	-0.31	0.02	-18.95
Revisiting	0.48	0.01	39.70
Similarity	0.05	0.03	1.96
Study (2017)	-0.34	0.03	-11.82
Dwelling*Study	-0.24	0.02	-11.85
Skipping*Study	0.05	0.02	2.44
Revisiting*Study	-0.04	0.02	-2.19
Similarity*Study	0.24	0.04	5.50

Notes. *b* = regression coefficient; *SE* = standard error of regression coefficient; models allowed for random intercepts between subjects; estimation method was full maximum likelihood; with the exception of similarity, all metrical variables were *z*-transformed prior to analyses; for similarity “dissimilar target” was coded as zero and “similar target” as one; for Study, the present study was coded with zero and Horstmann et al. (2017) was coded with one; standard deviation of random intercepts is reported in brackets; underlined coefficients are statistically significant by *t*-values exceeding ± 1.96 .

revisiting. We interpret this as an indication that the simple additive model used here does not fully explain the data, possibly because of interactions between skipping, dwelling, and revisiting. These unique effects of similarity were weaker in the present experiment than in the previous study.

4. Discussion

The present study was conducted because in previous related research, target-distractor similarity was confounded with target category. Therefore, target-distractor similarity was manipulated by changing the distractor category between blocks while keeping the target category constant.

Target-distractor similarity influenced RT, as well as dwell time, the proportion of skipped items, and the proportion of revisited items. Adding to previous analyses, we found that the effect on dwell time can be traced back to the duration of the individual fixations, rather than the number of fixation on an item. The regression analysis revealed that dwelling, skipping, and revisiting predicted RT in both absent and present trials. In absent trials, dwelling was the strongest predictor, followed by revisiting, and then skipping. In present trials, skipping was the strongest influence, but dwelling and revisiting remained significant contributors. Finally, the similarity effect was predicted best by dwelling and revisiting in target absent and present trials.

The present results closely replicate Horstmann et al. (2017), using the same set of stimuli but with an important difference: While the previous study varied target-distractor similarity by varying the target, the present study varied the distractor context for a target that was constant over blocks. With this change, the present results rule out that the strong effects of dwelling and revisiting on search time are target-related effects and confirm that these effects are actually driven by target-distractor similarity. A statistical comparison revealed only minor differences between the experiments for skipping and revisiting, while the effect of dwelling on RTs was somewhat stronger in the present experiment with a constant target than in the previous experiment with a varying target. We do not want to overstate this result as long as it is not replicated; however, this was opposite to the concern formulated in the introduction that varying the target might compromise the effect of skipping and artificially boost the effect of dwelling. If anything, the evidence is neutral for skipping and revisiting, and in the opposite direction for dwelling.

We also aimed at clarifying a second possible concern being that

switching target categories between blocks impeded the ability to form a consistent target template. The present experiment did not show any indication that this might have been a decisive factor. The patterning of the effects, with beta values of 0.51, -0.25, 0.45, for dwelling, skipping and revisiting in absent trials, was very similar to Horstmann et al. (2017), with corresponding values of 0.43, -0.31, 0.44. It should be noted though, that this concern presumes that the target template is an abstraction of the target category. If this is true, then in fact, the target template must change with changing target categories but not with a constant target category.

On consideration, however, a rather different stance seems much more plausible. We would argue that the target template is also influenced by the distractor context, and actually captures essentially the difference between the target and the distractor (see also Becker, 2011; Zelinsky, 2008). With such a relational view, the difference between the present experiment and Horstmann et al. (2017) regarding target-template changes may be more apparent than real. Specifically, the target template needs to be adjusted when the same target is searched for in different distractor contexts, to the same extent as when the target changes and the distractor context remains the same. Note that while it is tempting to assume that the search template for A among B is the negative of the search template for B among A, there is actually no guarantee that this is the case. As the discussion on search asymmetries (Treisman & Souther, 1985; Wolfe, 2001) has shown, when A and B differ in feature *f* that is present in A and absent in B, *f* can be used to find A, but the absence of *f* cannot be used as well to find B (see also Horstmann et al., 2006).

We analyzed the last stimulus visit in present and absent trials to test whether targets are indeed dwelled on longer than distractors. The results strongly support this suspicion. Testing stimuli for being a distractor versus a target may be viewed as a decision that can be modeled by a diffusion process (Ratcliff, 1978; Wolfe, 2007) where a noisy process accumulates information over time. This accumulation proceeds until one of two boundaries (thresholds) has been reached, which corresponds to the choice between the two alternatives. Dwelling may be seen (partially) as a reflection of this accumulation process. Similarity affects dwelling because a different amount of time is needed to reach either boundary. When target and distractors are dissimilar, information in favor of the target is gained quickly. However, when target and distractors are similar, information samples often contain noise; correspondingly, the rate of progress towards either of the thresholds is slowed. Free parameters in a diffusion process are the average rate, the border separation, and the starting point. We focus here on the borders and the starting point (see Wolfe, 2007, for an example of how rate parameters can be used to model distractor rejection). The setting of starting point and border separation biases the behavior of the diffuser. For example, moving the starting point nearer to the distractor border (as in Wolfe, 2007) biases the process towards a decision that a stimulus is a distractor because fewer evidence is needed to reach the distractor than the target border. The current results are in accord with such a bias, as the distractor decision is obviously made earlier than the target decision. However, a similar effect can be achieved by setting the drift rate (or more specifically, the zero point of drift; cf. Ratcliff & McKoon, 2008). For example, assuming that the lower border represents the decision that a stimulus is a distractor, a negative drift rate continuously drives the diffusion process towards the distractor border. The higher the drift rate (i.e., the more negative in the example) is, the stronger is the time difference between distractor and target. We might mention the symmetry of the similarity effect on distractors and targets. This symmetry, which has also been observed before (Horstmann et al., 2017) is interesting, because rate and border distance interact in their effect on decision time. The symmetry might be useful to limit possible parameter combinations in the diffusion process.

We should clarify that the decision whether a stimulus is the target or a distractor is not the only determinant of dwell time. Saccade planning must, by necessity, also be done during dwelling on a

stimulus. While there is evidence that saccade planning is done in parallel to stimulus analysis (Ludwig, Rhys Davies, & Eckstein, 2014), some studies report that saccade amplitude registers in fixation duration, indicating that either the processes are not completely parallel, or that saccade planning is sometimes longer than stimulus analysis (Unema, Pannasch, Joos, & Velichkovsky, 2005). However, the exact relationship between fixation duration and saccade amplitude is unclear. Some studies found fixation duration to increase when saccade amplitude decreases (Antes, 1974), other found the opposite (Viviani and Swensson (1982). Unema et al. (2005) found the relation to be non-linear: There was a strong increase in saccade amplitude for short fixation durations peaking around 100 ms. After the peak, the relation reversed and fell back to an asymptotic zero correlation. Thus, given the present state of research, this issue cannot be handled with certainty. With respect our data, we note two observations. First, an additional analysis revealed that saccade amplitudes were somewhat larger with dissimilar than similar distractors (4.43° vs. 4.17°), and correspondingly, saccade durations, were somewhat longer (39.48 ms vs. 38.32 ms). Second, we ran an additional model which included saccade duration, but the increment in explained variance was tiny. To conclude, saccade duration does not seem to play an important role in the present search task.

4.1. A theory-free look at the details of search time

How exactly did the more or less similar distractor context influence search? Similar distractors were looked at longer, skipped more frequently, and were more often revisited. Corresponding effects were obtained for the target. The differences between similar and dissimilar distractor contexts were sizable. For instance, in each absent trial, one stimulus more was skipped, and one stimulus less was revisited, when distractors were dissimilar from the target. Moreover, distractor dwell time was 50 ms shorter when it was dissimilar from the target. Skipping a dissimilar distractor subtracts about 200 ms of dwell time from overall search time. Likewise, rescanning a similar distractor adds about 250 ms of dwell time to overall search time.

Search time must be (roughly, see below) the product of the number of visited objects and the average dwell time. Assuming – based on our results – that roughly 10 stimuli (with one of the 10 stimuli skipped and one rescanned) are visited in an absent trial with dissimilar distractors, and that roughly 12 stimuli (zero skipped but 2 rescanned) are visited in a corresponding trial with a similar distractor, one can deduce the following estimated search times (eST):

$$\text{eST (similar distractors)} = 10 \times 200 = 2000 \text{ ms} \quad (1)$$

$$\text{eST (dissimilar distractors)} = 12 \times 250 = 3000 \text{ ms} \quad (2)$$

Note that a large amount of the difference is accounted for by the difference in dwell time. Assuming constant dwell times as done in many models of visual search (Hulleman & Olivers, 2017; Wolfe, 1994, Zeliinsky, 2008), the difference would be smaller (e.g. 450 ms, assuming a constant dwell time of 225 ms). Furthermore, note that this model is of course a simplification, as it does neither take into account the time that the eyes remain at fixation after display onset, nor differences in dwell times due to saccade planning or later post-decisional or response processes. Yet, the present results show that the simple model can also explain search efficiency when target-distractor similarity is varied by the distractors rather than by the target (as in Horstmann et al., 2017).

We already noted that the model omitted a number of variables that probably also add to search time. First, our model excludes saccadic movement time. Saccadic movement time could also be influenced by search difficulty. For instance, saccadic movement times are shorter with smaller (compared to larger) saccades, which is often discussed under the term main sequence in eye movement research. Easier searches often require fewer eye movements as a larger number of stimuli can be processed with a single fixation (Hulleman & Olivers, 2017).

Second, the dwell time could be different on the first and a second visit. This is in particular true for lag-1 revisits (Godwin, Reichle, & Menneer, 2017). Third, the time from the start of the display to the first stimulus fixations is not included, neither is the additional constant in dwell time for the last item that is fixated when the response is made. There are two main reasons for not including these variables. The first reason is that our unit of analysis is the stimulus. Search is analyzed by asking: how many stimuli are in the display, how many of them are skipped, how many revisited, and how long does the searcher dwell on a stimulus, on average. Second, and relatedly, it seems somewhat fruitless to add all fixation latencies and fixation durations to predict search time. In fact, doing so would be completely circular because search time, by definition is exactly that. The aim of an analysis or a model is often to use a simplified version of reality to gain a basic understanding of what is going on. This is what we are aiming for here.

5. Conclusion

Our present study shows a similarity effect in visual search that is best explained by distractor rejection duration, rather than target guidance. Moreover, this effect does not hinge on changing the target category, but can also be observed when the target category is constant during the entire experiment.

It is possible that such a results pattern is obtained mainly when stimuli are complex, where search is generally very inefficient, and guidance is weak. Future research has to test whether these contentions hold; Becker's (2011) study using Landolt-c, however, casts some doubts that stimulus complexity really is an important issue, as this study found systematic differences in dwell time, as does the study by Hout et al. (2017), who presented more complex stimuli in a search where guidance was strong.

The possible limitation that not all searches might show this strong effect of dwelling does not invalidate the imperative that theories of visual search need to include attentional or gaze dwell time as an additional variable instead of treating it as a constant. Of course, an inclusion of dwelling to guidance centered models changes the interpretation of search slopes. In a model that features guidance as the main explanatory variable for search efficiency, differences in search slopes are easily interpreted as differences in guidance. If dwelling is included, differences in search slope might be due to different amounts of guidance or different durations of dwelling (not considering different amounts of revisiting here). For researchers looking for “attention guiding feature” (i.e., features that can be pre-attentively extracted from a display) this means that they should not base their conclusions solely on search slopes, but also on other criteria such as the effortless segregation of figure and ground (Wolfe & Horowitz, 2004). The problem is probably absent if only efficient searches are considered, where the slope of the RT-set size function is zero. However, often search slopes are not completely flat, and search asymmetries (Treisman & Souther, 1985) are more a matter of degree (for an example see Levin, 2000, on race as visual feature, or the research on facial affect as a guiding feature, cf. Becker, Horstmann, & Remington, 2011; Horstmann, 2007, 2009; Horstmann & Bauland, 2006; Horstmann, Becker, Bergmann, & Burghaus, 2010; Horstmann et al., 2006; Savage, Lipp, Craig, Becker, & Horstmann, 2013;). In many cases it seems also advisable to use eye tracking to measure fixations and their durations, which allows distinguishing between dwelling and more guidance related factors.

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