The preview benefit and feature guidance: Constraints in feature and conjunction search

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Abstract

In three studies I investigated restrictions and prerequisites of feature guidance (see e.g. Wolfe et al., 1989) and the preview benefit (see e.g. Watson and Humphreys, 1997) in feature and conjunction search. In all studies observers performed a visual search task, where they searched for either a constant, known target or a randomly varying target.

Study 1 showed that the observation of Meinhardt and Persike (2015) of no preview benefit in conjunction search with random item positioning and random target is not caused by the heterogeneous colors, which are typically present in color × form search, but not in form search. In a letter search task with heterogeneous colors I found a preview benefit in feature search irrespective of heterogeneous or homogeneous colors, but no preview benefit in conjunction search.

Study 2 investigated the influence of the efficiency of the used features on both the preview benefit and feature guidance. The efficiently searched feature color was combined with an inefficiently searched form feature. A preview benefit was observed in both feature and conjunction search. Furthermore, evidence for feature guidance in conjunction search was presented.

Since it was hinted that the efficiency of the used features affects the appearance of feature guidance and the preview benefit in conjunction search, one efficiently searched feature (color) was combined with a form feature with different search efficiencies in study 3. Evidence for feature guidance in feature search was found in efficient, but not in inefficient form search, whereas evidence for feature guidance in conjunction search was only gathered in highly inefficient form search. A preview benefit was found in feature search irrespective of task difficulty, whereas it was only observed in inefficient conjunction search.

My results from three visual search studies indicate that feature guidance depends on the efficiency of the used features, since it is only observed with one

efficiently searched feature, but not two. The same is supposed for the preview benefit in conjunction search, whereas a preview benefit is found in feature search irrespective of search efficiency. The disruption of both feature guidance and the preview benefit in efficient conjunction search is assumed to derive from attentional capture by salient stimuli (see e.g. Theeuwes, 2004) and also from the target form which is shared by part of the distractors in conjunction search. With highly inefficient search such attentional capture can be prevented. Moreover, my findings hint that in situations, where no clear priority for one feature to guide search can be built, priming (see e.g. Kristjánsson et al., 2002) can facilitate visual search.

Contents

List of Figures

List of Tables

Chapter 1

Theoretical background

1.1 Everyday Search

In our everyday world, we have to search for particular stimuli while ignoring others. Many mechanisms help us to focus our attention on relevant objects, whilst irrelevant ones can be disregarded. Imagine being at your local store, where you want to buy your favorite brand of chocolate. You immediately head to the location, where you last found your favorite sweet and where you remember the sweets aisle. Then, you scan the aisle for the different brands of chocolate. You know that the packaging of the chocolate you seek is green. Thus, you focus your attention on all green objects in the sweets shelf and there is no need to look at chocolate packages of other colors. Next, you remember the size and form of the chocolate- about as big as your hand and rectangular. Moreover, you remember that the last time you sought the chocolate, it was positioned in the upper part of the shelf, not the lower part. There it is. When you grab the chocolate, your search for it has been guided by several aspects: Remembered location information as well as information about features, such as color, size and form.

Searching for specific information or objects among others is important in many parts of everyday life, such as searching for abnormalities in the results of imaging methods, finding a friend in a crowd of people, or, as illustrated before, buying your favorite products at a store. A psychophysical paradigm to investigate the human capacity to allocate their attention is visual search.

1.2 Theories

In visual search tasks, observers state whether a target stimulus is present or absent among distracting elements (Estes and Taylor, 1966). A highly influential theory on visual search is the feature integration theory (FIT, Treisman and Gelade, 1980). FIT describes two fundamental modes of visual search: In feature search, the target differs from distracting elements in one feature dimension, such as in search for a blue T among brown T's. In conjunction search however, a particular combination of features, which are shared by the distractors characterizes the target, such as in the search for a pink O among green O and pink N distractors (Treisman and Gelade, 1980).

Search may be executed serially (Atkinson et al., 1969), which is reflected by a linear function of Reaction Time × Set Size ("search function"). This means that the observer looks at every element of the search display one by one, so that the slope of the search function reveals the additional time that is needed for search when one item is added to the display ("search rate"). Search is usually ended if either an observer finds the target or if all elements of the search display have been investigated, which is described as "self-terminating" (Van Zandt and Townsend, 1993). A 1:2 ratio of the search rates for target and no - target trials indicates that observers need on average search only through half of all elements if a target is present compared to target absence (Sternberg, 1969). On the other hand, "efficient" search is set in motion if the target is detected in one global access, because it seems to "pop out" of the distractor elements (Treisman and Souther, 1985). Efficient search is characterized by flat RT × Set Size functions, because scanning all elements one by one is not necessary, so that search times are unaffected by the number of display elements.

According to FIT, elementary features are coded in specific modules, which create feature maps for the diverse feature values (Treisman, 1988). For example, a color module can contain feature maps for "blue" or "red", while an orientation module can contain feature maps for different orientations of stimuli. In feature search, the information which is present in one feature map can lead to segregation of the target element from all distractors. In conjunction search, focal attention at each stimulus location is necessary to bind together the outputs of several maps into an extensive stimulus representation (Treisman and Gormican, 1988). Attention works within a master map of locations to serially retrieve feature information from the feature maps that are matched to active locations in the master map of locations (Treisman and Souther, 1985).

Treisman and Gelade (1980) verified their predictions by letting their subjects search for a green T among brown Ts and green Xs. Moreover, they searched for a blue letter embedded in a set of all brown or all green distractors or for a S among all Xs or Ts. While the search for the blue letter or the S resulted in flat search functions, search for the green T among brown Ts and green Xs yielded search rates of 67 ms/item in target absent and 28.7 ms/item in target present trials, so that a 1:2 slope ratio for target present to target absent trials was observed. More evidence supporting feature integration theory was presented by Treisman (1988) and Treisman and Gormican (1988).

However, several studies observed flat slopes of the Reaction time × Set Size function with different examples of conjunction searches, such as for the conjunction of shape and direction of motion (McLeod et al., 1988), orientation and spatial frequency (Sagi, 1988), contrast polarity and shape (Theeuwes and Kooi, 1994), different shape elements (Quinlan and Humphreys, 1987) or color and form (Wolfe et al., 1989). These studies challenged the assumption of conjunction search being necessarily inefficient, since shallow search function slopes for conjunction search cannot be explained by FIT (Wolfe et al., 1989).

This laid the foundations for the Guided Search Theory (Wolfe et al., 1989). Wolfe et al. (1989) criticized that in FIT, no information is transferred to later serial stages, when parallel search on a specific feature map does not lead to target detection. However, using information from the parallel stage of processing could be advantageous. Imagine search for a red X as target among green Xs and red Os as distractors. In this case, a serial search among the green elements is not necessary, since the target is red, so that green elements cannot contain the target. A parallel process, which sorts elements into likely and unlikely target elements would thus be beneficial for search efficiency. The Guided Search Theory describes such a flow of information from parallel to serial stage, which decides where the attention of the observer will be allocated (Wolfe et al., 1989).

Perfect guidance would mean that the target should be detected immediately, indicated by a flat slope of the Reaction Time × Set Size function (Wolfe et al., 2010). However, many studies investigating guidance observed slopes, which are shallow, but not flat and thus lie between the typically observed slopes for pop-out and serial search (see also Wolfe (2000)). For example, Wolfe et al. (1989) observed slopes of 12.6 ms/item in target absent trials and 7.5 ms/item in target present trials for a conjunction of color and form. A possible explanation for imperfect guidance is noise from distractors, which hampers efficient guidance if the difference in saliency is not high enough between target and distractor elements. Then, some distractors are unnecessarily examined (Wolfe et al., 1989).

According to the Guided Search Model, attention is guided by degrees of activation in a topographically organized activation map (Wolfe, 1994). Activation of locations in the activation map is weighted and averaged of both bottom-up activation due to saliency of a stimulus compared to other stimuli and top-down activation due to knowledge about target features in the feature maps for different features such as color or orientation. The activation map gives no information about which feature caused the activation, attention is simply guided to the location which shows the highest degree of activation in the map. If the target is not present at that location, attention will be deployed to locations in order of decreasing degrees of activation.

Not all features are fit to provide guidance. To provide guidance, several prerequisites have to be met: First of all, features which lead to immediate target detection have a good chance to be able to guide search (Wolfe and Horowitz, 2004). Pop-out is often observed with basic features (Wolfe, 2000), so that these are often used in studies investigating guidance. One prominent example is color (Wolfe, 2000). It is easy to group stimuli based on similar colors (Bundesen and Pedersen, 1983; Wolfe, 2000) and, as shown by Anderson et al. (2010), observers can use color as a cue to guide their search to a higher degree than orientation. However, orientation and motion are also features which are fit to provide guidance (Wolfe and Horowitz, 2017). In contrast to this, configural features, such as faces, which do not lead to pop-out (Nothdurft, 1993), fail to provide guidance. Wolfe and DiMase (2003) investigated whether spatial configurations can be used to guide search. They observed a search rate of 96 ms/item for search for a + element with two intersecting lines among ∟ elements without intersection. From this, they came to the conclusion that spatial configurations cannot provide guidance.

For guidance to occur, there must be a salient difference in feature level between the target and distractors (Wolfe et al., 1989; Wolfe, 1994). Salience is higher, if target and distractors become less similar, while distractors among each other become more similar (Duncan and Humphreys, 1989), which leads to more efficient search. With highly similar target and background elements, search efficiency decreases (Farmer and Taylor, 1980). For example, the shape difference between a "2" as target and "5s" as distractors was apparently not salient enough to provide guidance, since the search functions showed steep slopes (Wolfe and DiMase, 2003). For color, a large enough difference in hue between target and distractors is necessary for search to be efficient (Nagy and Sanchez, 1990; D'Zmura, 1991; Wolfe and Horowitz, 2004).

How can we decide if participants are able to guide their attention to only those stimuli that are relevant, e.g. that have the target color, but not to others? Wolfe and Horowitz (2017) suggest to take a look at the slope of the Reaction Time × Set Size function: If one half of the elements possess the target feature, then the slope should be halved compared to the slope of the search function with all elements, since only half of all elements have to be searched. This procedure is typically used in another field of research, namely research on the so-called preview benefit (Watson and Humphreys, 1997). The preview benefit demonstrates, that not only features can be used to guide search, but also the former history of search, which in this case gives spatial information (Wolfe and Horowitz, 2017).

Watson and Humphreys (1997) let their subjects search for a blue H among blue As, which were half of all items (half-element baseline) or blue As and green Hs (conjunction condition). In the so-called gap condition, one half of the distracting stimuli (green Hs) was shown 1 second before the rest of the search display was filled with stimuli (blue As and, if present, the blue H). For the half-element baseline, a slope of 14 ms/item was observed, while the search rate for conjunction search was 26 ms/item. Interestingly, the slope of the search function for the gap condition was equal to the slope of the feature search baseline with only half of all elements. From this, the authors concluded that participants were able to look only at the "new" elements due to the preview, so that they termed this halving of the slope the preview benefit. Watson and Humphreys (1997) account for the preview benefit by visual marking, meaning that observers first encode the locations of the old elements and then inhibit these locations at search, so that the old elements do not compete for attentional resources with the new ones and thus the new elements are prioritized.

In the following a growing body of research provided evidence for visual marking (Humphreys et al., 2002; Kunar et al., 2003a,b; Watson and Humphreys, 2000, 2002; Watson et al., 2003; Watson and Humphreys, 2005). Moreover, several attributes of the preview benefit have been established: The preview benefit needs a time interval between old and new elements of at least 400 ms to occur (Watson and Humphreys, 1997), whereas attentional capture only needs about 100 ms to occur (Yantis and Gibson, 1994). Moreover, it has a surprisingly large capacity, since a preview benefit is observed with up to 15 new elements (Theeuwes et al., 1998) and 30 old elements (Jiang et al., 2002a). Yet, the preview benefit needs cognitive resources, since it is reduced if a secondary task has to be performed during the preview period (Watson and Humphreys, 1997; Humphreys et al., 2002; Olivers and Humphreys, 2002). As Humphreys et al. (2002) showed, this is different for different modalities dependent on the time course: If the secondary task was carried out at the appearance of the preview display, not only a visual, but also an auditory secondary task led to a disturbance of the preview benefit. After the preview period, the preview benefit was only disrupted if a visual secondary task was carried out, not an auditory task. That the preview benefit is disrupted by the operation of secondary tasks during or after the preview period suggests an active encoding mechanism, which can be hampered if attentional resources are withdrawn from it (Olivers and Humphreys, 2002).

However, another theory explains the preview benefit solely by bottom-up onset capture by the new elements (Donk and Theeuwes, 2001, 2003; Donk and Verburg, 2004). The authors claim, that attention is captured by the new elements' onset, if these change their luminance. In the study of Donk and Theeuwes (2001), the new elements' onset either appeared with a change in luminance or old and new elements had the same luminance. A preview benefit was only observed, if the old and new elements differed in luminance, but not if the new elements did not appear with a change in luminance (Donk and Theeuwes, 2001). In another study, the authors investigated whether their participants necessarily prioritize the new stimuli or whether they prioritize the old items if this represents an advantage for them. The target appeared either equally probable among old and new items or it was more probable that it would appear among the old items. Their participants favored the new elements for search, even if the target had a higher probability to appear among the old than among the new elements. Donk and Theeuwes (2003) took this as evidence that observers automatically orient their attention to new items due to capture by changes in luminance.

Yet, several aspects argue against an explanation of the preview benefit solely based on bottom-up luminance changes. First of all, the necessary time interval of 400 ms for the preview benefit to arise is longer than the 100 ms time necessary for onset capture (Watson and Humphreys, 1997). Furthermore, in the study of Braithwaite et al. (2005) a preview benefit was observed if new items were presented isoluminant or if old items appeared with an onset and changed luminance. Moreover, other studies support the notion that a luminance change at old positions does not lead to disrupting the preview benefit

(Watson et al., 2008; Watson and Humphreys, 2002). The negative influence of the execution of secondary tasks during the presentation of the preview (Watson and Humphreys, 1997; Humphreys et al., 2002; Olivers and Humphreys, 2002) argues also against a mechanism based on onset capture, since onset capture should not be influenced by cognitive capacity constraints.

Evidence supporting an inhibition mechanism comes from behavioral studies as well as neuroimaging studies. Watson and Humphreys (2000) showed with a dot-probe detection task, that probes which appeared at old positions were more difficult to find than probes that appeared at new positions. Moreover, observers showed a decreased ability to discover contrast increments of gabor stimuli which appeared at previewed locations (Allen and Humphreys, 2007). Neuroimaging studies support a mechanism with two stages. First, the previewed elements are encoded. This is accompanied by elevated activity in primary visual cortex and the precuneus (Payne and Allen, 2011) as well as parieto-occipital areas, which are important for spatial filtering (Humphreys et al., 2004). Afterwards, distractors are inhibited and visual cortex activity is diminished (Payne and Allen, 2011).

With preview, elements can be separated into "old" and "new" elements. This temporal separation is incorporated into another account, which accounts for the preview benefit by grouping based upon time, more specifically the temporally asynchronous onsets of old and new elements (Jiang et al., 2002b). In their study, the authors showed with several experiments that the preview benefit was disturbed if old and new elements changed at the same time. Yet, if old and new items changed asynchronously, a preview benefit was found. Moreover, the preview benefit was robust against alterations in the background of the display. From this, Jiang et al. (2002b) gathered that the preview benefit is induced by the temporally asynchronous occurrence of both item halves, which facilitates grouping into two different events, so that new items may be attended. The role of grouping based on time in the preview benefit was also acknowledged by Watson et al. (2003).

In feature search, temporal asynchrony is a critical grouping cue to segregate old and new elements, since both the preview and the remaining elements share the same feature, e.g. the same color, so that both item halves cannot be separated if all elements have entered the search display. This means, that observers need to rely on memory to remember all old locations and then only search through the new items (Jiang and Wang, 2004). Otherwise, more elements than necessary are searched. Jiang and Wang (2004) propose both a high-capacity memory for asynchrony as well as a visual short-term memory for new locations, which has only limited capacity. In conjunction search old and new elements are not only separated by temporal asynchrony, but also by their different colors (Theeuwes et al., 1998). Evidence suggests that not only location information is used, but that features also assume a role in the preview benefit (Braithwaite et al., 2003; Gibson and Jiang, 2001; Olivers and Humphreys, 2002). For e-xample, the preview benefit is diminished if old and new elements have similar colors (Braithwaite et al., 2003; Gibson and Jiang, 2001) and there are negative carry-over effects if previously ignored elements show feature similarity to to-be-attended elements (Olivers and Humphreys, 2002). These findings challenge the view of visual marking as a purely location-based mechanism or as a mechanism build solely on temporal asynchrony.

1.3 Controversies

Looking at the results of early studies supporting either Feature Integration Theory or Guided Search Theory mentioned in the section on theories for visual search reveals an interesting controversy worth mentioning. Both Treisman and Gelade (1980) and Wolfe et al. (1989) used the features form and color in their studies, more precisely, letters of different colors. Yet, their observed results are highly different. The observed slope of 28.7 ms/item observed by Treisman and Gelade (1980) was about four times the slope of 7.5 ms/item found by Wolfe and colleagues.

This raises the question why both studies using the same features to configure their stimuli found such different results. A way which may enlighten this topic is to have a look at how guidance is actually tested. Typically, studies investigating guidance use two features, which are both considered to be able to guide search. However, one does not know which feature is really used by the observers to guide search. In color $\times$ form search, one can either use form, color, or one may even use both or switch between strategies using the different features. This could prove a barrier for efficient search and lead thus to imperfect guidance as well as unclear results. A possible way to decompose how guidance is provided by one feature or another could be to combine features with different capabilities to provide guidance. If, for example, a feature which is assumed to be a sure guiding feature, is combined with a feature which cannot provide guidance, results indicating guidance can only be attributed to the supposed guiding feature. This aspect constitutes a large part of my thesis. I investigated guidance with differently constructed stimuli, using multiple features with varying degrees of capability to provide guidance.

Another controversy concerns the prediction of visual marking for feature and conjunction search. If participants are able to guide their search to only the new elements by ignoring the preview, both feature and conjunction search should have equivalent search rates, which are half the search rate for feature search without preview. In color $\times$ letter search, the second item half contains only elements of one color, which are distinguished by their shape. If, for example, the target is a blue H, like in the study of Watson and Humphreys (1997), the second item half in conjunction search contains blue As and, if present, the target, which were preceded by a preview of green Hs. In feature search all elements are blue. Ignoring the preview would mean that participants can perform a feature search for an H among As in both conditions, because all elements which need to be searched are of the same color. If higher slopes than half the search rate of feature search without a preview are observed, this is a hint that not all previewed elements can be ignored, so that participants search through more elements than strictly necessary.

Although feature and conjunction search should become equivalent with preview, conjunction search actually provides more information for observers to use. In feature search, participants must use memory to remember the previewed locations, since old and new item sets are only divided because of their temporally asynchronous onsets (Jiang and Wang, 2004). Thus, if observers cannot remember all old locations, they revisit some old item positions so that the preview benefit is diminished. In conjunction search, reliance on memory is not necessary, since old and new elements are also segregated by their color, not only by temporal asynchrony (Theeuwes et al., 1998). Thus, a separation of both item halves along the color dimension should still be possible in the search display of conjunction search.

Interestingly, a study by Meinhardt and Persike (2015) observed different results for feature and conjunction preview search. They used a letter task in which subjects searched for either a known target letter or a target letter that varied from trial to trial in random fashion. Furthermore, elements were presented both in feature and conjunction search arrangements either positioned at random positions or as spatially coherent blocks. For feature search, the authors observed a preview benefit for both target types, which did not depend on the spatial positioning of the elements. For conjunction search, the authors only observed a preview benefit if the target remained the same throughout the experiment or if elements appeared as spatially coherent blocks. These results seem even more surprising considering that the prerequisites for conjunction search are better than for feature search, since old and new elements could also be grouped based on their different colors (see also Theeuwes et al. (1998)).

These apparent differences between the prediction of visual marking and the results of Meinhardt and Persike (2015) for feature and conjunction search build the ground for another large aspect of my thesis. I investigated the preview benefit in both feature and conjunction search with differently constructed stimuli. With this procedure, I hope to shed light on the question why the preview benefit is sometimes disrupted in conjunction search, although the prerequisites are overall favorable in conjunction search compared to feature search. In all shown experiments, subjects searched for either a known target or for a target that varied in random manner from one trial to the next. Hence, I try to provide new findings concerning the guidance of attention by features as well as location information.

1.4 Thesis Outline

My thesis is subdivided into five parts: Theoretical background (chapter 1), three studies (chapter 2-4) and a General Discussion (chapter 5).

In my first study (chapter 2), the preview benefit and the influence of target knowledge on visual search are investigated in a classical letter search task and constraints on feature and conjunction search due to the heterogeneity of the search display are studied.

The second study (chapter 3) further elaborates the roles of feature guidance based on target knowledge and spatial guidance (preview benefit) in a search task with spatial configuration stimuli. With these stimuli the mechanism of feature guidance shall be investigated in a deeper matter so that guidance should only be possible by one feature (color), but not by the spatial configuration cue.

The named aspects are further investigated in my last study (chapter 4). By constructing stimuli with four varying degrees of target-distractor similarity, the role of stimulus similarity is examined in establishing feature and spatial guidance.

The General Discussion (chapter 5) brings the findings from studies 1-3 together to draw conclusions about constraints of guidance by features and locations in feature and conjunction search and highlights probable causes. Moreover, implications for future research will be discussed.

Chapter 2

The preview benefit in a letter search task

2.1 Synopsis

Previewing distractors in visual search may initiate active encoding and later inhibition at search (visual marking, Watson and Humphreys, 1997). While visual marking predicts equal search efficiency for feature and conjunction search, evidence by Meinhardt and Persike (2015) suggests that the preview benefit in conjunction search is reduced compared to feature search with randomly varying target features and random item positioning. In an experiment with randomly rotated letters I found a preview benefit in feature search irrespective of target knowledge and the usage of heterogeneous colors in the search display. For conjunction search, no preview benefit was found. My results indicate that worse search efficiency for conjunction than feature search is not due to ensemble based coding of different colors in conjunction search (Rosenholtz et al., 2012). Instead, I propose that participants inhibit not only the locations of elements during preview, but also feature information, which leads them to inhibit the target defining feature in conjunction, but not feature search and thus reduces search efficiency.

2.2 Introduction

In our complex visual environment, facilitating search tasks by restricting search to only relevant elements is highly advantageous. Top-down strategies can be used if observers have positional or feature foreknowledge about the likely target (Braithwaite and Humphreys, 2003).

One strategy is a spatial memory-based mechanism called visual marking (Watson and Humphreys, 1997). As noted in the theoretical background, Watson and Humphreys (1997) observed that when half of the distracting items (all of one color) in a conjunction search were shown 1000 ms before the remaining elements, the slope of the Reaction Time $\times$ Set Size function for this preview condition was equal to the slope of feature search with half of all elements. The authors explained this "preview benefit" by visual marking, which means that the elements are encoded at preview and then inhibited, so that just the new elements on the search display are searched. Since then, numerous evidence for visual marking has been presented (Humphreys et al., 2002; Kunar et al., 2003a,b; Watson and Humphreys, 2000; Watson et al., 2008).

Visual marking predicts equal search performance for feature and conjunction search, since in both cases only half of all elements, all of the same color in a color $\times$ form search, have to be searched. These elements can be distinguished by their form, so that participants only have to conduct a feature search among the new elements and a search rate which is half that of feature search with all elements should result.

However, the prerequisites for conjunction search are better than for feature search, since old and new elements can not only be distinguished by temporal asynchrony, but also by their color (Theeuwes et al., 1998). This means that remembering all old items, which is necessary in feature search to avoid accidentally searching old elements is not necessary in conjunction search. Yet, results by Meinhardt and Persike (2015) indicate that conjunction search cannot always be searched as efficiently or even more efficient than feature search. The authors found only a preview benefit in conjunction search, if old and new items were arranged into spatially coherent color blocks or if the target remained fixed throughout the whole experiment, while a preview benefit was consistently observed in feature search, irrespective of target type (varying from trial to trial vs. fixed) and spatial positioning (spatial blocking vs. random positioning). This leads to the question why participants are apparently not as able in conjunction as in feature search tasks to use the information provided by the preview to facilitate their search.

Feature and Conjunction search differ in the information that has to be processed during search: In a classical feature search task the target differs from all other elements in only one feature, such as its shape (e.g. search for an orange H among orange As). The finding of the target can be based on saliency, since the target differs highly from all distractors, so that it captures attention automatically (Itti and Koch, 2001). Such a bottom-up process is not possible in conjunction search, since there, the target differs in one feature from both groups of distractors, but all distractor elements differ in two features. Consider a search for an orange H among orange As and green Hs. While the target differs in the shape attribute from the orange elements, it differs in the color attribute from the green elements. Yet, orange As and green Hs differ in both color and shape, meaning that the target is not the most salient element in the display, so that the observer does not look at the target, but at salient neighbours (Sobel et al., 2009). This indicates that while a salience-based approach can work effectively in a feature search task, the nature of conjunction search interferes with a bottom-up search mechanism based on saliency.

Indeed, an account by Rosenholtz et al. (2012) suggests that bottom-up pooling of neighboring elements can have a negative impact on search performance in conjunction, but not in feature search. According to this account, search is not considered to be purely item-based, but it is assumed that observers consider larger regions of overlapping spatial patches across the display. This means that items of different colors could be pooled with random item positioning (Rosenholtz et al., 2012). This would make search more demanding than a simple shape comparison based on salience in feature search, since both colors have to be processed if different colors appear randomly intermixed, so that search cannot be simplified to a form comparison, such as in feature search. Pooling should leave the preview benefit in feature search intact, since all elements in a patch have the same color in feature search.

However, the assumption of bottom-up pooling of different colored items suggests that different colors should not depend on search type and thus should not only impair conjunction search, but also feature search, if elements appeared in two colors.

Another difference between feature and conjunction search concerns the nature of a possible visual marking mechanism. While visual marking is described as the inhibition of locations of old elements (Watson and Humphreys, 1997), evidence hints that feature information can also be inhibited, since the preview benefit is diminished if both item halves have the same color (Braithwaite et al., 2003; Gibson and Jiang, 2001). Note that in conjunction search the target is defined with the same feature as the old elements, e.g. it has the same form in a color × form search. Yet, if inhibition of the old elements is not only location-, but also feature based, this could mean that the form which was part of the preview was also inhibited. In feature search this would be advantageous for participants, since the old elements differ in their form from the target. In conjunction search the feature form is ambiguous, since it characterizes the old elements as well as the target. Thus, inhibiting the feature form in conjunction search means that the target form is inhibited, which could lead to conjunction search being more inefficient than feature search, since form inhibition interferes with search for the target form in conjunction, but not in feature search.

In the following, I present results of a letter search task in which items in all conditions appeared with heterogeneous colors. Letter search can be overlearned (Wolfe and Horowitz, 2017). Because of this, I added orientation noise to increase task difficulty, since there is only a possibility for a preview to become effective and lead to more efficient search, if slopes of the RT × Set Size functions are not already flat and thus indicating parallel search.

I tested whether different results for feature and conjunction search can be explained by the different information which has to be processed in both types of search, in this case color. For this, feature search conditions in which the elements appeared in two colors were introduced. If the processing of different colors is the reason for worse performance in conjunction than feature search, no differences between feature and conjunction search should be observed and the preview benefit should be disrupted in both types of search, if two colors are part of the feature search conditions.

2.3 Methods

2.3.1 Ethics Statement

Participants were informed about the course and expected duration of the experiment prior to their participation. They received a general description of the purpose of the experiment but not about specific outcome expectations. All subjects signed a written consent form according to the World Medical Association Helsinki Declaration and were informed that withdrawing from the experiment would be possible at any time without penalty. At the time of data collection, no local ethics committee was instated. Noninvasive experimental studies without deception do not require a formal ethics review provided the experiment complies with the relevant institutional and national regulations and legislation which was carefully ascertained by the author. A summary of their individual data was shown to the observers after completing the experiment and the results were illustrated within the scope of the purpose of the study.

2.3.2 Sample

In this experiment, 52 students of psychology from the university of Mainz participated, which were split into two groups (random and fixed target group), each containing 26 subjects. For their participation they were paid or given course credit. In the random target group, 22 of the subjects were female (mean age = 23.5, age range = 18-35). In the fixed target group, 20 were female observers (mean age =24.5, age range = 18-39). All had normal or corrected-to-normal visual acuity. The participants were randomly chosen for participation in either the random or fixed target group.

2.3.3 Experimental Outline and Design

In my study I used the same letter stimuli as in the study of Meinhardt and Persike (2015). The letters A and H were utilized, which could be presented in either light-green or orange. Stimuli were positioned on a circular array around a fixation cross, where either 8, 12 or 16 stimuli appeared. To increase task difficulty all stimuli were randomly tilted across positions between $-45°$,$0°$ and $45°$ visual angle.

There were two basic target conditions: search for an unknown target, where the target varied randomly from trial to trial and search for a known target, which was chosen for each participant beforehand and which remained the same throughout the whole experiment. To avoid potential carryover effects, both conditions were executed by two different groups of participants (random target group vs. fixed target group). In the random target group target and distractors varied and the definition of color and letter as distractors or target changed from trial to trial. Both colors were equally likely to appear. In the fixed target group the target was randomly chosen for each participant and remained fixed throughout the experiment. The target could be either an orange A, light-green A, orange H or light-green H. The following conditions were used in the experiment:

Feature homogeneous baseline: All elements appeared in either green or orange. Distractors were all the same letter, e.g. green Hs and the target was the other letter in the same color, e.g. a green A. Thus, subjects searched for the deviant letter (see figure 2.1).

Feature heterogeneous baseline: In the feature heterogeneous baseline subjects also searched for the deviant letter (e.g. a green A), but the distractors, which were all the same letters, appeared in both green and orange (e.g. green Hs and orange Hs). Examples are displayed in figure 2.1.

Feature homogeneous condition with homogeneous preview: A preview containing distractors of the same color (e.g. orange Hs) appeared randomly positioned 2 seconds before the remaining stimuli entered the display. The target was the other letter in the same color (e.g. orange A) and could only appear among the second item half. Thus, participants knew that they only had to search through the second item half and could also identify the target letter (see figure 2.2).

Feature heterogeneous condition with heterogeneous preview: The arrangement was the same as in the feature heterogeneous baseline, but one half of the distractors appeared at random positions 2 seconds before the remaining elements. The preview consisted of both green and orange elements, which were the same letter (e.g. green and orange Hs, for examples see figure 2.3). In this case, the target could be either an orange A or a green A. Participants of the random target group could find out the target letter, but not its color.

Conjunction heterogeneous condition with heterogeneous preview: Two homogeneous letter sets of different colors were presented (e.g. green Hs and orange As). One half of these items was presented 2 seconds before the other half. This preview was heterogeneous, because it contained items of both letter sets in equal frequency and at random positions. Participants of the random target group knew that the target had to be the other letter in one of the color sets (in this case, green A or orange H). Moreover, it was made clear that the target could only appear among the second item half (see figure 2.3).

Feature heterogeneous condition with homogeneous preview: Overall, the display contained the same letters in both colors (e.g. green and orange Hs). Yet, all stimuli of one color (e.g. green Hs) appeared at random positions 2 seconds before the stimuli in the other color (orange Hs). Examples are displayed in figure 2.2. The second item half could contain the target, which had to be the other letter in this color homogeneous group (in this case, orange A). Participants of the random target group could thus infer that the target had to be the other letter in the opposite color of the preview.

Both groups were tested with the same Condition × Trial Type (present/absent) × Set size (8/12/16) design.

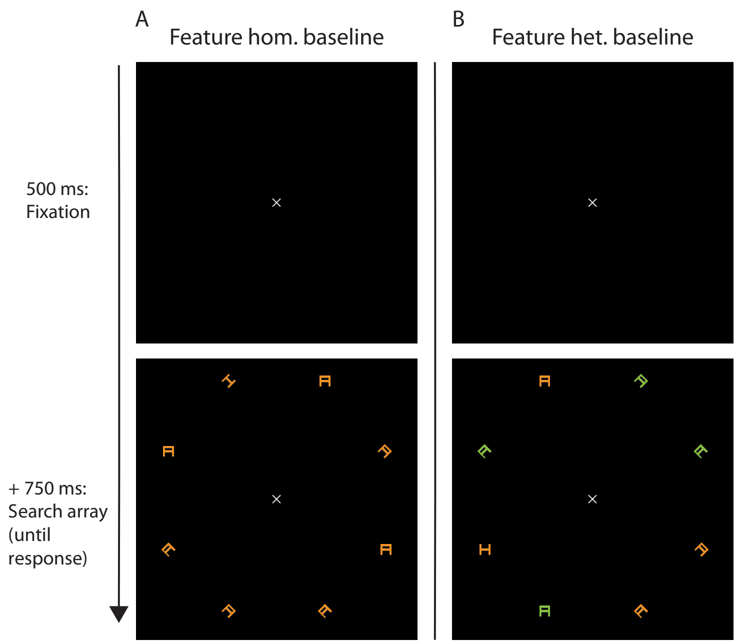


Figure 2.1: Trial examples for the feature homogeneous baseline and the feature heterogeneous baseline with a set size of 8 items. In all conditions an orange H is the target. The item orientation alternates randomly across positions between $-45°$, $0°$, and $45°$.

2.3.4 Experimental predictions

A preview benefit is usually indicated if the slope of the Reaction Time × Set Size function is halved compared to the feature baseline, because it is assumed that participants are able to search through only half of all elements and there perform a feature search, since the new elements all share the same color.

In my experiment two baseline conditions were presented (feature homogeneous baseline, feature heterogeneous baseline). These conditions differed only in the heterogeneity of the display, since in the feature heterogeneous baseline both orange and green elements were presented, while all elements had the same color in the feature homogeneous baseline. Since I wanted to investigate whether the disruption of the preview benefit in conjunction search is due to the pooling of different colored items, I had to take into consideration that it could be possible that the heterogeneous colors could not only hinder search with preview, but also in the baseline. This would mean that the preconditions for the establishment of a preview benefit could be worse if elements appeared with heterogeneous colors than with homogeneous colors. Thus, I tested in a pre-test whether search slopes differed significantly between the feature homogeneous and the feature heterogeneous baselines. As you can see in the section ”Pre-Test of the feature baselines”, slopes for both conditions were parallel. From this I concluded that the heterogeneity of the search display did not hinder search without preview.

Table 2.1: Experimental predictions of study I. The table shows the predictions of the slopes, a, of the RT $\times$ Set Size function, to its corresponding baseline.

Target	Search	Prev	Prediction
Random	Feat. hom.	Hom.	a = 0.5 a of Feat. hom. Baseline
Random	Feat. het.	Het.	a = 0.5 a of Feat. het. Baseline
Random	Conj. het.	Het.	a = 0.5 a of Feat. het. Baseline
Random	Feat. het.	Hom.	a = 0.5 a of Feat. hom. Baseline
Fixed	Feat. hom.	Hom.	a = 0.5 a of Feat. hom. Baseline
Fixed	Feat. het.	Het.	a = 0.5 a of Feat. het. Baseline
Fixed	Conj. het.	Het.	a = 0.5 a of Feat. het. Baseline
Fixed	Feat. het.	Hom.	a = 0.5 a of Feat. hom. Baseline

If the preview can be ignored completely by the participants at search, a slope of the RT $\times$ Set Size function which is half the slope of the function for the corresponding baselines should be observed. For those conditions with heterogeneous preview the feature heterogeneous baseline is used as reference (feature heterogeneous condition with heterogeneous preview, conjunction heterogeneous condition with heterogeneous preview). For those conditions that have a homogeneous preview (feature homogeneous condition with homogeneous preview, feature heterogeneous condition with homogeneous preview) the feature homogeneous baseline is chosen as reference. The precise predictions are presented in table 2.1.

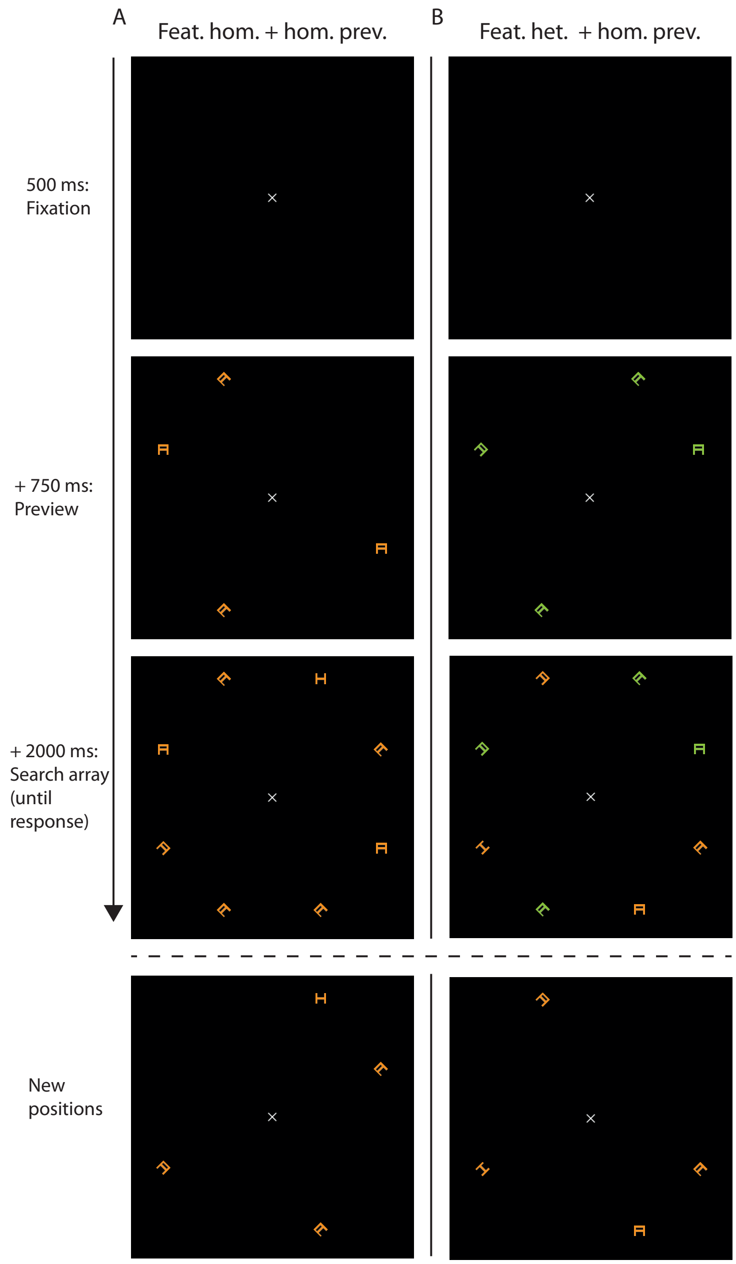


Figure 2.2: Trial examples for the feature homogeneous condition with homogeneous preview and the feature heterogeneous condition with homogeneous preview with a set size of 8 items. In all conditions an orange H is the target. The item orientation alternates randomly across positions between −45°, 0°, and 45°. In the lower row the items on the new positions are shown.

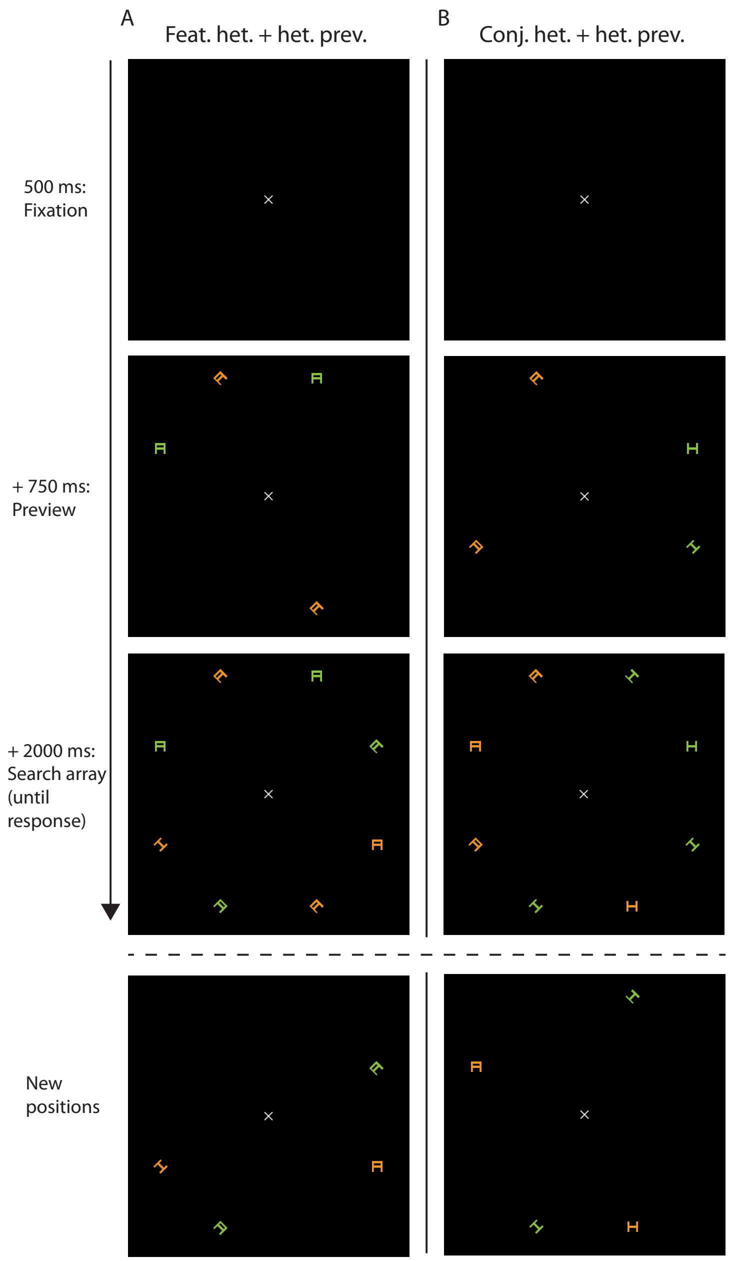


Figure 2.3: Trial examples for the feature heterogeneous condition with heterogeneous preview and the conjunction heterogeneous condition with heterogeneous preview with a set size of 8 items. In all conditions an orange H is the target. The item orientation alternates randomly across positions between $-45°$, $0°$, and $45°$. In the lower row the items on the new positions are shown.

2.3.5 Apparatus and Stimuli

The experiment was run using Inquisit 5 by Millisecond LLC. Participants viewed the display binocularly at a distance of 70 cm and patterns were presented on NEC Spectra View 2090 screens at 1600 × 1200 resolution with a refresh rate of 60 Hz. The stimulus colors orange and light-green were calibrated to an isoluminance at 59 cd/ m ^{2} using a ColorCal Colorimeter by Cambridge Research Systems (Rochester, UK). No gamma correction was utilized. The black background of the screen had a luminance of 0.11 cd/m^2. The letters A and H were used. They had physical dimensions of 21 × 29 pixels (w × h), which corresponded to 0.44° × 0.6° visual angle. All lines in each letter had a line thickness of 5 pixels, corresponding to 0.1° visual angle. The stimuli were placed on the vertices of a regular n-gon (n=8, 12, 16). Each vertex had a center-distance of 288 pixels, corresponding to 5.98° visual angle. The polygon center was marked with a fixation cross. All stimuli were randomly tilted to orientations between −45°, 0°, and 45°. Participants gave responses on an external Cedrus RB-830 response pad with built-in clock for precise reaction time measurements. The participants received acoustical feedback via headphones, with a brief "tack"-tone indicating a correct response and a "tack tack"-tone indicating an error.

2.3.6 Procedure

The experiment was run as a Yes/No forced choice search task. Each subject went through six different conditions. Each condition was run in a separate experimental block comprising three different set sizes (8,12 or 16 elements). Each block contained 18 target absent and 18 target present trials, which, as well as the different set sizes, were presented randomly interleaved. In the fixed target group participants were informed about the chosen target. Furthermore, subjects of both groups were instructed that target absent and target present trials were equally frequent, that the set size would vary across the trials and that the target would never appear at previewed locations if a preview was presented. Subjects were alerted to respond both accurately and fast. Each of the six conditions was practiced. In the baseline conditions the search array appeared 750 ms after the fixation interval of 500 ms. The temporal order in the preview conditions was as follows: fixation mark (at 500 ms) - preview (+750 ms) - search array (+ 2000 ms, until response). Each participant had to go through 864 trials (648 test trials and 216 practice trials), which took one and a half hours. I randomized the order of the experimental blocks for each participant. Participants could make brief pauses between the experimental blocks.

2.3.7 Data analysis

Reaction time data of correct responses as well as accuracy was analyzed with mixed factor ANOVA. Target Type (random/fixed) served as a grouping factor. Condition (feature homogeneous baseline/ feature heterogeneous baseline/feature homogeneous condition with homogeneous preview/feature heterogeneous condition with heterogeneous preview/conjunction heterogeneous condition with heterogeneous preview/feature heterogeneous condition with homogeneous preview), Set Size (8/12/16) and Trial Type (absent/present) were entered into ANOVA as repeated measurements factors. Furthermore, I analyzed the Condition $\times$ Set Size function to evaluate whether the slopes of the functions were parallel. I further explored those comparisons by calculating slope ratios to evaluate if the half-slope prediction of visual marking was fulfilled. All analysis was performed by using STATISTICA 13 software.

2.4 Results

2.4.1 Pre-Test of the feature baselines

To test whether the heterogeneity of the display hindered search in the feature heterogeneous baseline I tested beforehand whether the slopes of the Reaction Time $\times$ Set Size functions of the feature heterogeneous and feature homogeneous baselines were parallel. Results are presented in table 2.2. As can be seen there, the slopes did not differ significantly for the baseline conditions in all trial types and for both target types. From this I concluded that search was not hampered by the heterogeneous colors in the feature heterogeneous baseline, so that both search displays provided equal prerequisites for the establishing of a preview benefit.

Table 2.2: Ratios of search rates for the feature homogeneous baseline against the feature heterogeneous baseline. The table shows the slope ratios, q_x, as percent values, as well as F- ratio and p- value for testing the corresponding Condition × Set Size interaction. The F- tests have 2 denominator and 40 nominator degrees of freedom.

		Target present			Target absent		
Target	Preview	q_x	F	p	q_x	F	p
Random	No	139.6	2.45	0.099	107.6	0.42	0.658
Fixed	No	102.7	0.17	0.842	107.5	0.38	0.688

2.4.2 Accuracy

Accuracy results are depicted in table 2.3 and table 2.4. Overall, accuracy was high, yet it was different for the different conditions (F(5,200) = 10.8, $p < 0.001$) and modulated by target type, meaning that participants who searched for a random target made more errors than participants who searched for a fixed target (F(1,40) = 4.76, $p < 0.05$). The highest error rate was observed for the conjunction heterogeneous condition with heterogeneous preview (Condition × Target Type, F(5,200) = 3.36, $p < 0.05$). Furthermore, participants were less accurate at a higher set size (F(2,80) = 92.61, $p < 0.001$).

Table 2.3: Mean percentage accuracy rates for random target search of study 1.

			Target present			Target absent		
Target	Search	Preview	8	12	16	8	12	16
Random	Feat. hom.	No	92.1	89.7	87.3	97.4	98.1	98.7
Random	Feat. het.	No	92.9	91.8	84.9	99.7	98.7	97.1
Random	Feat. hom.	Hom.	94.3	90.0	82.3	96.5	97.1	96.8
Random	Feat. het.	Het.	95.5	88.1	81.0	98.1	97.4	97.4
Random	Conj. het.	Het.	88.1	82.3	75.1	94.7	94.7	91.3
Random	Feat. het.	Hom.	95.0	91.8	86.2	96.3	94.2	93.9

Table 2.4: Mean percentage accuracy rates for fixed target search of study 1.

			Target present			Target absent		
Target	Search	Preview	8	12	16	8	12	16
Fixed	Feat. hom.	No	92.6	89.7	88.1	97.9	97.4	96.8
Fixed	Feat. het.	No	95.5	93.9	92.3	99.2	99.2	97.6
Fixed	Feat. hom.	Hom.	96.6	88.9	82.0	97.1	98.1	98.4
Fixed	Feat. het.	Het.	97.3	92.6	86.7	96.1	97.4	97.2
Fixed	Conj. het.	Het.	94.4	90.7	80.4	96.9	97.7	97.4
Fixed	Feat. het.	Hom.	96.6	93.4	88.4	97.4	96.6	97.6

Accuracy was also lower in target present than in target absent trials (F(1,40) = 155.5, $p < 0.001$) and here especially at larger set sizes (Set Size × Trial Type, F(2,80) = 71.13, $p < 0.001$). This was especially found for the conjunction heterogeneous condition with heterogeneous preview and the feature homogeneous condition with homogeneous preview at larger set sizes (Condition × Set Size × Trial type, F(10,400) = 2.79, $p < 0.05$), which explains also the significant two-way interactions Condition × Set Size (F(10,400) = 2.4, p< 0.05) and Condition × Trial Type (F(5,200)= 5,4 p < 0.001).

2.4.3 Reaction Times

Mean reaction times as a function of set size are depicted in figures 2.4 and 2.5. Overall slopes agreed fairly well with a 1:2 ratio of target present compared to target absent trials, indicating serial self-terminating search (see last columns of tables 2.5 and 2.7). Most striking is that for both fixed and random target search a preview benefit was observed for all feature preview conditions, but not for conjunction search.

Reaction times were influenced by Target Type (F(1,40) = 24.3, $p < 0.001$), showing that generally, participants who searched for a randomly varying target gave slower responses than participants who searched for a fixed target. Furthermore, I observed effects of Condition (F(5,200) = 92.2, $p < 0.001$), Set Size (F(2,80) = 302.3, $p < 0.001$) and Trial Type (F(1,40) = 167.5, $p < 0.001$). Reaction times increased with larger set sizes and were longer in target absent than target present trials.

Moreover, all two-way and three-way interactions except the interaction of Trial Type × Target Type (F(1,40) = 2.7, p = 0.11) were significant, yet these results can be explained by the significant interaction of Condition × Set Size ×

Trial Type × Target Type (F(10,400) = 3.9, $p < 0.001$). As can be seen in figure 2.5 (panel B), this means that reaction times increase the most with increasing set size for the conjunction heterogeneous condition with heterogeneous preview in target absent trials if participants search for a random target.

I also calculated the slope ratios for all conditions in reference to either the feature homogeneous baseline (feature homogeneous condition with homogeneous preview, feature heterogeneous condition with homogeneous preview) or the feature heterogeneous baseline (feature heterogeneous condition with heterogeneous preview, conjunction heterogeneous condition with heterogeneous preview) and analyzed with the Condition × Set Size interactions if the slopes deviated from parallelism.

For random target search the slope of the feature homogeneous condition with homogeneous preview was nearly halved compared to the feature homogeneous baseline condition (see table 2.5), yet the Condition × Set Size interaction showed only a significant deviation from parallelism in target absent trials, while it was failed in target present trials (target present: $F(2, 40) = 0.93, p = 0.403$, target absent: $F(2, 40) = 9.48, p < 0.001$). A clear fulfillment of the half-slope prediction was observed in the feature heterogeneous condition with homogeneous preview, where the slope was less than half the slope of the feature homogeneous baseline, which is substantiated by significant deviations from parallelism (target present: $F(2, 40) = 5.89, p < 0.01$, target absent: $F(2, 40) = 13.19, p < 0.001$). In comparison to the feature heterogeneous baseline the slopes of the feature heterogeneous condition with heterogeneous preview were significantly different and fulfilled the half-slope prediction (target present: $F(2, 40) = 4.41, p < 0.05$, target absent: $F(2, 40) = 5.95, p < 0.01$). The slopes of the conjunction heterogeneous condition with heterogeneous preview and the feature heterogeneous baseline differed significantly in target absent trials, since the slope of the conjunction heterogeneous condition with heterogeneous preview was nearly 2 times the slope of the feature heterogeneous baseline in target absent trials ($F(2, 40) = 11.98, p < 0.001$). In target present trials the slopes of the conjunction heterogeneous condition with heterogeneous preview and the feature heterogeneous baseline were not significantly different ($F(2, 40) = 1.98, p = 0.151$). The slopes of both the feature homogeneous and feature heterogeneous baseline were equal (see tables 2.2 and 2.5).

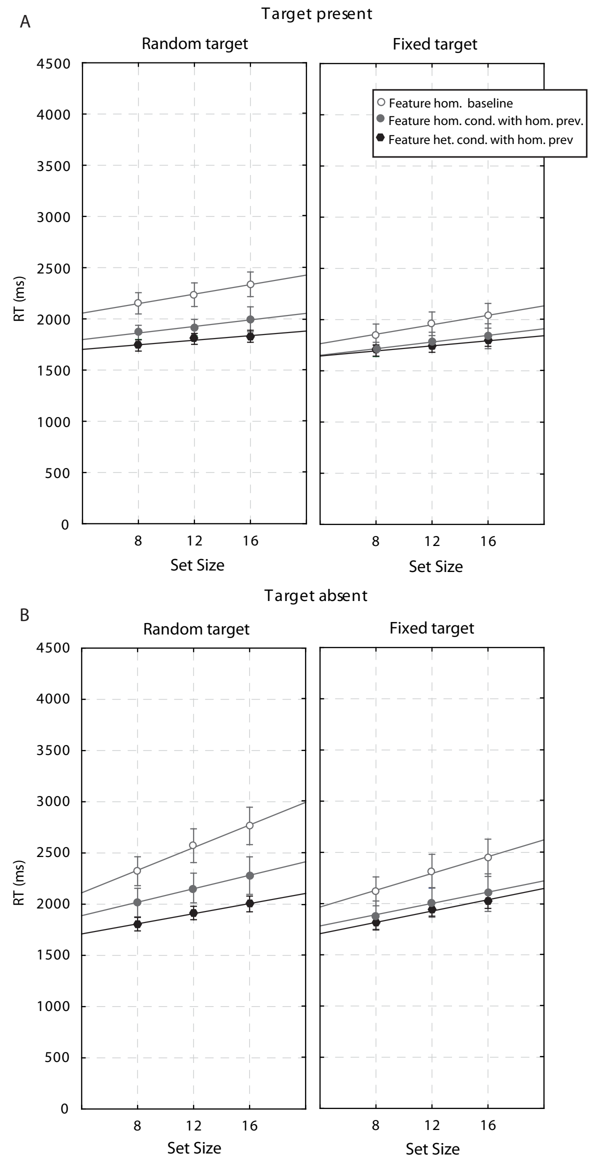


Figure 2.4: Mean correct reaction times are shown as a function of set size for conditions with homogeneous preview displays and the feature homogeneous baseline as reference. Mean reaction times with preview are indicated by filled symbols, without preview by open symbols. Error bars indicate 95% confidence limits of the means. The straight lines indicate linear regression functions. The upper panels show data for target present trials, the lower ones for target absent trials.

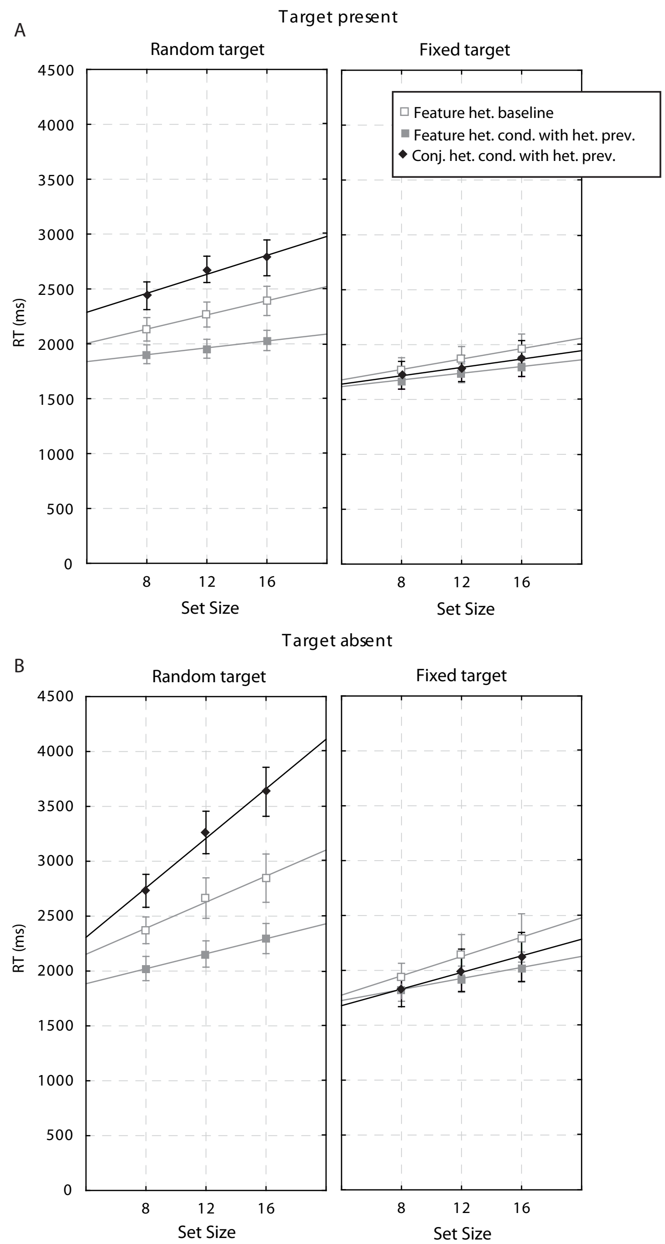


Figure 2.5: Mean correct reaction times are shown as a function of set size in heterogeneous preview displays and the feature heterogeneous baseline as reference. Mean reaction times with preview are indicated by filled symbols, without preview by open symbols. Error bars indicate 95% confidence limits of the means. The straight lines indicate linear regression functions. The upper panels show data for target present trials, the lower ones for target absent trials.

Table 2.5: Slope estimates for the search functions obtained for random target search in study 1. The table lists the slope estimates (search rates), a, and the slope ratios of each preview condition with the corresponding baseline, q_p. The last column shows the slope ratios of target present and absent trials, q_t. All ratios are listed as percent (%) values.

			Target present		Target absent		
Target	Search	Preview	a	q_p	a	q_p	q_t
Random	Feat. hom.	No	23.2		55.2		42.0
Random	Feat. het.	No	32.3	139.6	59.4	107.6	54.4
Random	Feat. hom.	Hom.	16.0	69.1	32.9	59.6	48.7
Random	Feat. het.	Het.	15.7	48.6	34.1	57.5	46.0
Random	Conj. het.	Het.	43.2	133.6	112.8	190.0	38.3
Random	Feat. het.	Hom.	11.2	48.3	24.7	44.8	45.3

Table 2.6: Ratios of search rates for the feature heterogeneous condition with homogeneous preview against the conjunction heterogeneous condition with heterogeneous preview. The table shows the slope ratios, q_x, as percent values, as well as F- ratio and p- value for testing the corresponding Condition $\times$ Set Size interaction. The F- tests have 2 denominator and 40 nominator degrees of freedom.

		Target present			Target absent		
Target	Preview	q_x	F	p	q_x	F	p
Random	Prev	25.9	10.46	< 0.001	21.9	45.73	< 0.001
Fixed	Prev	65.0	2.64	0.084	72.9	4.19	< 0.05

While color was a task irrelevant feature in the feature heterogeneous baseline and feature heterogeneous condition with heterogeneous preview it was task relevant in both the feature heterogeneous condition with homogeneous preview and the conjunction heterogeneous condition with heterogeneous preview. Thus, I compared the search functions of the feature heterogeneous condition with homogeneous preview and the conjunction heterogeneous condition with heterogeneous preview. As can be seen in table 2.6, the slope of the feature heterogeneous condition with homogeneous preview was quartered compared to the conjunction heterogeneous condition with heterogeneous preview and these results are substantiated by significant results of the F-test.

Table 2.7: Slope estimates for the search functions obtained for fixed target search in study 1. The table lists the slope estimates (search rates), a and the slope ratios of each condition with the corresponding baselines, q_p. The last column shows the slope ratios of target present and absent trials, q_t. All ratios are listed as percent (%) values.

			Target present		Target absent		
Target	Search	Preview	a	q_p	a	q_p	q_t
Fixed	Feat. hom.	No	23.1		41.0		56.4
Fixed	Feat. het.	No	23.8	102.7	44.0	107.5	53.9
Fixed	Feat. hom.	Hom.	16.2	69.9	27.5	67.1	58.8
Fixed	Feat. het.	Het.	15.2	64.2	25.1	57.0	60.7
Fixed	Conj. het.	Het.	19.1	80.2	37.8	85.9	50.4
Fixed	Feat. het.	Hom.	12.4	53.5	27.6	67.4	44.9

For fixed target search slopes and slope ratios with either the feature homogeneous baseline or feature heterogeneous baseline are presented in table 2.7. For fixed target search the slopes of the feature homogeneous condition with homogeneous preview were reduced compared to the feature homogeneous baseline, but the F-test only showed a significant result in target absent trials (target present: $F(2, 40) = 2.02, p = 0.146$, target absent: $F(2, 40) = 6.92, p < 0.01$). The slopes of the feature heterogeneous condition with homogeneous preview were not parallel to the slopes of the feature homogeneous baseline and fulfilled the half-slope prediction (target present: $F(2, 40) = 4.99, p < 0.05$, target absent: $F(2, 40) = 3.99, p < 0.05$). The slope of the feature heterogeneous condition with heterogeneous preview was halved compared to the feature heterogeneous baseline and this was substantiated by significant deviations from parallelism in target absent trials ($F(2, 40) = 16.66, p < 0.001$). In target present trials the slope was reduced, but the F-test failed significance ($F(2, 40) = 2.4, p = 0.104$). Last but not least, the slopes of the conjunction heterogeneous condition with heterogeneous preview were a bit shallower than the slopes of the feature heterogeneous baseline, but this comparison failed significance (target present: $F(2, 40) = 0.84, p = 0.438$, target absent: $F(2, 40) = 1.4, p = 0.257$).

As for random target search I compared the search rates of the feature heterogeneous condition with homogeneous preview to those of the conjunction heterogeneous condition with heterogeneous preview (see table 2.6). The slope ratio was about 0.6 in target present and 0.7 in target absent trials, indicating that the search rate of the feature heterogeneous condition with homogeneous preview was reduced compared to the conjunction heterogeneous condition with heterogeneous preview. This was substantiated by a significant result of the F-test in target absent trials, while significance was slightly failed in target present trials.

I also compared reaction times and slopes of the RT × Set Size function for all conditions for fixed and random target search. Slope ratios q $^{a_{\text{fixed}}}/_{a_{\text{random}}}$ as well as results of the significance tests are presented in table 2.8. For both baseline conditions the slopes do not differ significantly between random and fixed target group. The same was found for the feature homogeneous condition with homogeneous preview, the feature heterogeneous condition with heterogeneous preview and the feature heterogeneous condition with homogeneous preview. However, for the conjunction heterogeneous condition with heterogeneous preview, the ratio lies beneath 0.5 in both trial types and this is substantiated by a significant result of the F- test (see table 2.8). Thus, there is an advantage due to fixed target search in this condition.

Table 2.8: Ratios of search rates for search with a fixed target compared to search with a random target in study 1. The table shows the slope ratios, q_s, as percent values, as well as F- ratio and p- value for testing the corresponding Condition × Set Size interaction. The F- tests have 2 denominator and 80 nominator degrees of freedom.

		Target present			Target absent		
Search	Preview	q_s	F	p	q_s	F	p
Feat. hom.	No	99.9	0.32	0.727	74.2	2.76	0.07
Feat. het.	No	73.5	1.41	0.25	74.1	2.12	0.127
Feat. hom.	Hom.	101.0	0.39	0.678	83.6	0.59	0.559
Feat. het.	Het.	97.1	0.1	0.902	73.6	2.03	0.138
Conj. het.	Het.	44.1	7.06	< 0.01	33.5	31.44	< 0.001
Feat. het.	Hom.	110.6	1.39	0.255	111.7	0.41	0.666

2.5 Discussion

The results of study 1 indicate that the presence of different colored elements does not lead to disrupting the preview benefit in feature search. I found a preview benefit for all feature preview conditions and for both target types, yet, for the conjunction heterogeneous condition with heterogeneous preview, no preview benefit was observed for both the fixed and the random target group. Slopes for the conjunction heterogeneous condition with heterogeneous preview were about doubled compared to the feature heterogeneous baseline in target absent trials and 1.3 times the slope of the feature heterogeneous baseline in target present trials for random target search. In fixed target search they were about 80 to 85 percent of those of the feature heterogeneous baseline. Furthermore, target knowledge had no significant effect on search rates for the feature search conditions, but on the conjunction heterogeneous condition with heterogeneous preview, where the slope was halved in fixed target compared to random target search.

2.5.1 The preview benefit

Watson and Humphreys (1997) showed that participants can use information about elements' locations to search only partly through the search display if stimuli are presented temporally segregated into two groups. This visual marking means that participants are able to inhibit the spots of the old elements, so that those elements compete less for attention. Perfect visual marking indicates that participants only have to search through half of all elements (Watson and Humphreys, 1997). Extensive evidence for visual marking has been provided (Olivers and Humphreys, 2002; Watson and Humphreys, 2000, 2002; Watson et al., 2008).

In my study I found a preview benefit consistently for feature search. The preview benefit in feature search depends on memory, since old an new elements are only separated by their temporally asynchronous appearance (Jiang and Wang, 2004). If participants cannot remember all old locations, it is possible that they recheck some old items, leading to a slope more than half the slope of the feature search baseline. That I found a preview benefit in feature search indicates that participants were able to encode and then inhibit old locations at search. For conjunction search I did not observe a preview benefit. This is somewhat surprising, since participants need not necessarily use memory in conjunction search, since old and new elements are not only separated by temporal asynchrony, but also by different colors (Theeuwes et al., 1998). Thus, the prerequisites for conjunction search are advantageous to feature search. Furthermore, several studies indicate that not only locations, but also features assume a role in a possible visual marking mechanism, since similar colors of old and new elements can diminish the preview benefit (Braithwaite et al., 2003; Gibson and Jiang, 2001; Olivers and Humphreys, 2002).

My findings thus raise the question whether the different colors in conjunction search are not supporting visual marking, but are hindering the mechanism to become effective with random item positioning.

2.5.2 Less efficiency in conjunction than feature search is not due to ensemble based coding

One typical difference which is found between feature and conjunction search are, e.g. in color × form search, the heterogeneous colors of conjunction, but not feature search, since in feature search, all elements are presented in the same color. As outlined in the introduction, worse search performance for conjunction than feature search can be explained if it is not assumed that every item is solely encoded at search, but that observers consider larger, overlapping regions of elements (Rosenholtz et al., 2012). With random item positioning a patch could contain different colored elements in e.g. color × form search. This means that search cannot be simplified to a form comparison within the new elements, because a patch can also contain some old elements. In feature search, pooling should have no negative effect on search performance because all elements have the same color. This pooling should however be independent of the search type, if feature search contained also two heterogeneous colors and not only conjunction search.

Pooling should lead to a disruption of the preview effect in the feature heterogeneous condition with heterogeneous preview, the conjunction heterogeneous condition with heterogeneous preview and the feature heterogeneous condition with homogeneous preview since in all three conditions, both orange and green elements are present in the search display. Yet, a disruption was only observed for the conjunction heterogeneous condition with heterogeneous preview. Moreover, the slopes for the feature heterogeneous condition with heterogeneous preview and the feature heterogeneous condition with homogeneous preview compared to the slopes of the feature homogeneous condition with homogeneous preview. This means that even if color was task irrelevant, as in the feature heterogeneous condition with heterogeneous preview, it did not lead to worse search performance than if elements appeared all in the same color. Further evidence for this is provided by the comparison of the feature search baselines, which showed no difference between the baseline with homogeneous color and heterogeneous colors.

Interesting is also the comparison of the search rates for the feature heterogeneous condition with homogeneous preview and the conjunction heterogeneous condition with heterogeneous preview (see table 2.9). In both conditions color is task relevant and elements of the search display contain both colors. However, as can be seen in table 2.9, search is always more efficient in the feature heterogeneous condition with homogeneous preview than in the conjunction heterogeneous condition with heterogeneous preview. In the random target group ratios are around 0.25, which means that only about one fourth of the time per item is needed in feature compared to conjunction search. In the fixed target group the ratio is higher, but still search in the feature heterogeneous condition with homogeneous preview is more efficient than in the conjunction heterogeneous condition with heterogeneous preview. That the ratio is higher in fixed than random target search is most likely due to more efficient conjunction search in the fixed than random target group.

Table 2.9: Ratios of search rates for the feature heterogeneous condition with homogeneous preview against the conjunction heterogeneous condition with heterogeneous preview. The table shows the slopes, a, as well as the slope ratios, q_x, as percent values.

			Target present		Target absent	
Target	Search	Preview	a	q_x	a	q_x
Random	Conj. het.	Het.	43.2		112.8	
Random	Feat. het.	Hom.	11.2	25.9	24.7	21.9
Fixed	Conj. het.	Het.	19.1		37.8	
Fixed	Feat. het.	Hom.	12.4	65.0	27.6	72.9

Overall, my results indicate that worse search performance in conjunction than feature search is not due to pooling of different colored items, since this should also take effect in color heterogeneous feature search. Note that the feature heterogeneous condition with homogeneous preview and the conjunction heterogeneous condition with heterogeneous preview do not differ in the frequency of the used colors, but of the other used feature, form. While both forms (A and H) are equally frequent among the distractors of the conjunction heterogeneous condition with heterogeneous preview, all distractors of the feature heterogeneous condition with homogeneous preview have the same form.

Moreover, part of the old elements share the target form in the conjunction heterogeneous condition with heterogeneous preview, but no element shares the target form in the feature heterogeneous condition with homogeneous preview.

2.5.3 The inhibition of target features

While visual marking is described as the inhibition of the locations of the old items, so that these objects compete less for an observer's attention (Watson and Humphreys, 1997), evidence suggests that also features can be inhibited during visual marking (Braithwaite et al., 2003; Gibson and Jiang, 2001).

A phenomenon where reaction times to a previously ignored stimulus are slowed is negative priming (Tipper, 2001). Studies investigating negative priming typically use a prime trial, in which the observer has to ignore a stimulus while attending to another and a probe trial, in which the preliminarily ignored distractor item appears as the target (Fox, 1995a). Numerous evidence for negative priming has been presented (Driver and Baylis, 1993; Fox, 1995b; Tipper and Cranston, 1985). Furthermore, Kristjánsson and Driver (2008) showed the negative impact of a role reversal effect, meaning that reaction times were slowed if a previous distractor became a target in the next trial and vice versa. In conjunction search inhibition of the form of the old distractors could have a negative impact on search times. Since target and old elements share their form, the target form would be inhibited too, if participants not only suppress the positions of the old items at search, but also their features. In feature search inhibiting the form of the old items is advantageous, since it differs from the target form.

For all feature preview conditions in my experiment slopes were clearly reduced in comparison to the corresponding baselines and fulfilled the half-slope prediction of visual marking. For conjunction preview search the half-slope prediction was not fulfilled, since the slopes of the Reaction Time × Set Size function were steeper than those of the feature heterogeneous baseline condition. That search performance for conjunction search was worse than for feature search argues strongly in favor of an assumption of a feature inhibition mechanism during the preview period.

Overall, my findings indicate that the critical difference between feature and conjunction search is the matching of the target feature to that of the old elements in conjunction, but not in feature search. Feature-based inhibition can thus hinder efficient usage of the preview in conjunction search.

2.5.4 The influence of target knowledge

Participants were overall faster, if they had target knowledge compared to if the target varied in random manner from one trial to the next. Yet, this effect was not so clearly observed on search rates as it was on the intercepts and thus overall reaction times. Taking a look at table 2.8, it can be seen that fixed target search had a clear and significant advantage to random target search in the conjunction heterogeneous condition with heterogeneous preview. Moreover, some small reductions in the ratio $a_{\text{fixed}}/a_{\text{random}}$ were observed for the feature homogeneous baseline, the feature homogeneous preview condition with homogeneous preview and the feature heterogeneous condition with heterogeneous preview in target absent trials as well as the feature heterogeneous baseline in both trial types. Yet, it seems surprising that the search advantage of fixed to random target search was not greater.

The Guided Search Theory (Wolfe et al., 1989) predicts that observers can use knowledge about target features to search through less elements by guiding attention to only those elements containing target features.

This could be beneficial in this experiment, since observers then had to search through only the elements of the target color. In the feature heterogeneous baseline condition, this means that observers only need to look at half the elements compared to the feature homogeneous baseline. In the feature heterogeneous preview condition with heterogeneous preview as well as the conjunction heterogeneous condition with heterogeneous preview half of the old and half of the new items had the target color (see figure 2.3), which could, combined with the temporal separation due to the preview, make search a lot more efficient.

However, this improvement is only small in feature search and the F-Test shows no significant results. Moreover, the feature heterogeneous condition with heterogeneous preview compares in size to the feature homogeneous condition with homogeneous preview, indicating that the information about the target color cannot be used to a great extent to facilitate search further compared to the preview. How can this be accounted for?

As elaborated in the section "Controversies" of the introduction, search with two efficiently searched features, like color and form, did not lead to clear results concerning guidance. It may be possible that color and the letter forms were too equal in their search efficiencies so that observers could not limit their search to only elements of the target color. Yet, if only one efficiently searched feature and one inefficiently searched feature are used to construct stimuli, this should provide better prerequisites for observers to use target knowledge to guide and thus facilitate their search. I investigated this in study 2.

Chapter 3

The impact of feature and spatial guidance on highly inefficient search

3.1 Synopsis

The Guided Search Model predicts that if observers know target features, they can guide their search to only those elements containing those features (Wolfe et al., 1989). Yet, the combination of two efficiently searched features led to conflicting and differing results, such as in the studies of Treisman and Gelade (1980) and Wolfe et al. (1989) using a color $\times$ form conjunction. I combined a configural form attribute, which was searched highly inefficiently, with color, which was found efficiently. Conjunction search without target knowledge was highly difficult, yet, for conjunction search with target knowledge, the slope was halved compared to feature search, meaning that only the elements of the target color were searched. I also observed spatial guidance provided by a preview, which improved feature and conjunction search and was not different for fixed and random target search. Most effective in increasing search efficiency was the combination of feature and spatial guidance. Overall, my results indicate that feature guidance can take effect if two features with different search efficiencies are combined, so that guidance can only be provided by one feature.

3.2 Introduction

The Feature Integration Theory describes two principal modes of visual search: feature and conjunction search (Treisman and Gelade, 1980). While feature search is characterized as efficient, since the reaction time is independent of the number of stimuli present in a search display, conjunction search is described as inefficient. The slope of the Reaction Time $\times$ Set Size function increases linearly with the number of display items, which is assumed to reflect the additional time which is needed to look at an additional element. Yet, as noted in the section "Theoretical background", several studies observed flat slopes for conjunction search (McLeod et al., 1988; Quinlan and Humphreys, 1987; Sagi, 1988; Theeuwes and Kooi, 1994; Wolfe et al., 1989), which shows that the distinction of efficient feature search and inefficient conjunction search is not always applicable.

This led Wolfe et al. (1989) to the formulation of the Guided Search Theory, which assumes that foreknowledge about target features can be used to guide the search to likely target elements, so that less elements have to be searched. Features differ in their capability to provide guidance and both color and shape are assumed to be undoubted or probable candidates for guiding features (Wolfe and Horowitz, 2004, 2017). In contrast, it has been shown that configurations, like faces, do not show the pop out phenomenon (Nothdurft, 1993) and search tasks leading to flat slopes are supposed to contain a feature that is able to guide search (Wolfe and Horowitz, 2004). Thus, it is surprising that, while Wolfe and colleagues observed search function slopes of 7.5 ms/item in target present and 12.6 ms/item in target absent trials for a conjunction of color and form (Wolfe et al., 1989), Treisman and Gelade (1980) observed slopes of 28.7 ms/item in target present and 67 ms/item in target absent trials using the same features (see section "Controversies" for a broader overview).

How can these discrepancies be explained? One possible reason is, that with the combination of two features fit to guide search, it is not clear, which feature is really used for guidance and which not, or whether participants even use the same feature for guidance through the whole experiment or change strategies. This could lead to unclear results. Clarity regarding these questions could be gained by combining two features which differ in their capability to provide guidance: one which is supposed to be able to guide search and one which cannot provide guidance. Then, if guidance is observed, it can only stem from the supposed guiding feature.

How can we numerically determine whether search is guided or not? If participants can, for example, use color to guide their attention to only the elements of the target color and one half of all elements contains this color, then a slope which is halved compared to the slope of the RT $\times$ Set Size function for all elements should be observed. This would then indicate, that only the elements of the target color were searched (Wolfe and Horowitz, 2017). This is a common procedure in research on the preview benefit, which was first introduced by Watson and Humphreys (1997) and which is assumed to indicate spatial guidance due to the preview (for further overview see "Theoretical background").

This provides the basis for my study. I constructed stimuli, which combined one feature which is supposed to be an undoubted guiding feature (color) with a feature which should not be able to guide attention (spatial configuration cue). I used green and orange triangle stimuli, which had a thick bar on either the right or left. Furthermore, participants have to know the target color beforehand to be able to use it to guide their attention. For this, I compared search performance for a group, who searched for a known target, which remained the same in the experiment (fixed target group), with search performance for another group, who had no knowledge about target features, because the target changed randomly after every trial (random target group). Moreover, by introducing conditions with a preview, I provided a reference for a possible guidance mechanism.

In the following, I provide evidence that conjunction search can be executed more efficiently than feature search, if two features with different search efficiencies are paired and if participants know the target color, so that they can guide their attention to only stimuli containing the target color.

3.3 Methods

3.3.1 Ethics Statement

Before taking part in the experiment, participants received information about the expected duration and course. The general purpose was explained, without giving details about specific expectations. Every participant had to sign a consent form according to the World Medical Association Helsinki Declaration. Participants were told that withdrawal from the experiment was always possible without penalty. No local ethics committee was appointed during data collection, since noninvasive experiments without deception of the participants do not need a formal review of ethics if they comply with the corresponding national and institutional legislation and regulations. This was ascertained. A summary of the individual results was shown and explained to each participant after participation in the experiment.

3.3.2 Sample

Observers were 36 undergraduate students of psychology from the university of Mainz.[1] The mean age was 26.5 years (age range= 18-47) and 32 were female. All participants showed normal or corrected-to-normal visual acuity. They received course credit for participating in the experiment. 18 participants were randomly selected for the random target group, who searched for a randomly varying target from trial to trial, while 18 participants searched for a known target, which remained the same (fixed target group). Moreover, 9 participants were randomly selected from each group to take part in the measurement of the color search baseline.

3.3.3 Experimental Outline and Design

Stimuli were orange and light-green triangle elements which had a thicker left or right leg. With these stimuli I wanted to ensure that one feature (color) could be used to provide guidance and the other (form as a spatial configuration cue) could not do so. Form could not be evaluated by its absence or presence, but only by its spatial configuration, so that it should not be able to provide guidance. With pilot measurements (color search baseline) I verified that color targets could be found effortlessly, thus providing the best prerequisites for guidance. Finding a triangle with a thicker bar among other triangles was shown to be inefficient (feature baseline), so that I concluded that no guidance should be possible by form.

One half of the participants searched for a fixed, known target (fixed target group), whilst the other searched for a randomly varying target (random target group). For each subject of the fixed target group a target was randomly chosen, which remained the same in all experimental conditions. Choice of target (orange + thicker left bar; orange + thicker right bar; green + thicker left bar; green + thicker right bar) was counterbalanced across the subjects. For participants of the random target group the target varied in random manner from one

[1] The data were collected in the context of my master thesis at the Johannes Gutenberg University Mainz.

trial to the next, so that it could not be guessed on basis of the foregoing trials.

Color search baseline: All distractor triangles were shown in one of the two colors orange and light-green, while the target, if it was present, appeared in the other of the two colors. Both the color and form assignments of target and distractors varied randomly in every trial.

Feature baseline: As can be seen in figure 3.1, all elements appeared in one color. The target could be distinguished by the thicker bar on the alternative side as the distractors.

Conjunction baseline: One half of the elements was presented in orange, while the other was presented in green and colors were intermixed at random positions. The elements of one color had the thicker bar on one side, while the elements of the other color had the thicker bar on the alternative side (see figure 3.1). The form assignment of the target was reversed within one color, e.g. in figure 3.1 the target is an orange triangle with a thicker left bar among green triangles with a thicker left bar and orange triangles with a thicker right bar.

Feature preview condition: As can be seen in figure 3.2, the same display as in the feature baseline was shown, but half of the stimuli were shown as a preview 2000 ms before the remaining elements entered the display. The target could only appear among the "new" elements and had the thicker bar on the alternative side than the preview.

Conjunction preview condition: The display was the same as in the conjunction baseline, yet all elements of one color appeared 2000 ms before the elements of the other color. The target could only be shown within the second color and had the bar on the same side as the preview, but in the second color (see figure 3.2).

3.3.4 Experimental Predictions

In my experiment I investigated the effect of feature guidance and spatial guidance by preview. Feature guidance should, as mentioned in the section on the experimental outline and design, only be possible by color, but not by form in my experiment.

Guidance should only be possible if participants know the target beforehand (fixed target group), but not if it varies in random fashion from one trial to the next (random target group). Furthermore, spatial guidance could also be possible due to the presentation of the preview.

If participants of the fixed target group can use color to guide their search to only the elements of the target color, the search function of the conjunction baseline condition should be halved compared to the feature baseline condition, since subjects only have to search through half of all elements (those of the target color) and can there conduct a feature search, since all distractors have the alternative form as the target. Participants of the random target group do not know the target color, so that they cannot exclude elements from their search. This means that they have to search through both colors and, since both forms are present in the display, they cannot simplify their search to a feature search, so that search should be more complex than in the feature baseline.

Table 3.1: Experimental predictions. The table shows the predictions of the slopes, a, of the RT $\times$ Set Size function, to its corresponding baseline.

Target	Search	Prev	Prediction
Random	Feat.	No	
Random	Feat.	Prev	a = 0.5 a of Feat. Baseline
Random	Conj.	No	a > a of Feat. Baseline
Random	Conj.	Prev	a = 0.5 a of Feat. Baseline
Fixed	Feat.	No	
Fixed	Feat.	Prev	a = 0.5 a of Feat. Baseline
Fixed	Conj.	No	a = 0.5 a of Feat. Baseline
Fixed	Conj.	Prev	a = 0.5 a of Feat. Baseline

If participants can use the preview information perfectly, both groups should be able to search through only one half of all elements and carry out a feature search there, which should result in a slope which is halved compared to the feature search baseline. However, it may be the case, that participants cannot exclude all old elements from search in the feature preview condition, since old and new stimuli cannot be separated when all elements have entered the display. This may lead to rechecking some positions if participants cannot remember all old locations. In conjunction search temporal asynchrony of old and new elements is complemented by a separation based on color, so that both color and spatial guidance may be possible in conjunction search. The half-slope prediction should thus be clearer fulfilled in conjunction than in feature search.

3.3.5 Apparatus and Stimuli

The experiment was carried out with Matlab. Stimuli were presented on NEC Spectra View 2090 at resolution of 1600 × 1200 and a refresh rate of 60 Hz. The light-green and orange triangles had an isoluminance of 59 cd/m^2 with a ColorCal Colorimeter (Cambridge Research Systems, Rochester, UK). No gamma corrections were utilized. Participants sat a distance of 70 cm from the display and viewed it binocularly. The stimulus items were triangle shapes, which measured 46 × 55 pixels, corresponding to $0.98° \times 1.15°$ visual angle. They had a line thickness of 2 pixels, the thicker line comprised 5 pixels. Positions of the stimuli were on a regular n-gon ($n = [8, 12, 16]$). Center-distance from each vertex was 308 pixels, corresponding to 6.97° visual angle. The center of the polygon was marked with a fixation cross. All triangles were randomly tilted 45° visual angle to either the right or left. A distance marker, but no chin rest was used. Participants responded via a computer keyboard and received acoustical feedback via headphones. While a "tacktack"-tone indicated an error, a "tack"-tone signaled a correct response.

3.3.6 Procedure

As in study I, I used a Yes/No forced choice task. Each experimental condition was shown in an experimental block, which contained 18 target absent and 18 target present trials for each set size. In total, these were 108 trials. Within a block, all trials appeared in random order. The color search baseline was measured by the randomly selected subjects at either the beginning or end of the experiment, which was randomly chosen. Each subject was tested in one session with a maximum length of one hour. All participants were informed that set sizes varied across trials, that target absent and present trials were equally frequent and that the target could never appear at a previewed location. Furthermore, participants of the fixed target group were informed about their chosen target. Subjects were told to attend to speed and accuracy and to use the given acoustical feedback. 12 practice trials per condition were performed to make sure that the task was apprehended by the subjects. The trial sequence for the preview conditions was fixation mark (at 500 ms) - preview (+ 750 ms) - search array (+ 2000 ms, until response). The trial sequence for the baseline conditions was fixation mark (at 500 ms) - search array (+ 750 ms, until response)

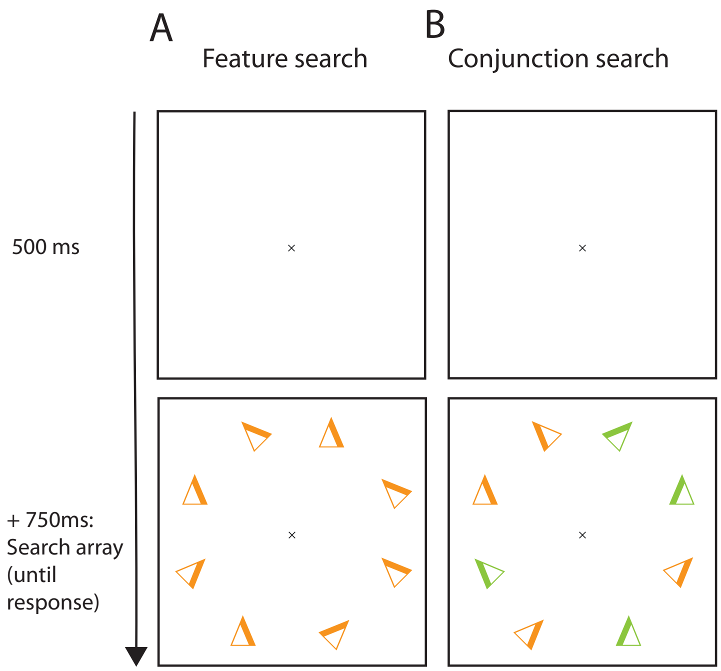


Figure 3.1: Examples of trials for the feature (A) and conjunction (B) baselines. The examples illustrate displays with a size of 8 elements. The target is an orange triangle with a thicker left leg. The item orientation alternates randomly across positions between $-45°$, $0°$, and $45°$.

3.3.7 Data analysis

Measures were accuracy and reaction times of correct responses. Data were analysed with mixed factor ANOVA with target type as grouping factor and condition, trial type (absent/present) and set size (8,12,16). To test if the slopes of the RT $\times$ Set Size functions of two conditions were parallel, I again used the procedure proposed by Watson and Humphreys (2002). By entering the two conditions in an ANOVA, if the Condition $\times$ Set Size interaction is revealed to be significant, this implies that the slopes are not parallel. Furthermore, I calculated slope ratios for all conditions in reference to the feature baseline. Furthermore, the ratios for fixed against random target search and conjunction against feature search were investigated. All data analysis was executed with STATISTICA 13 software.

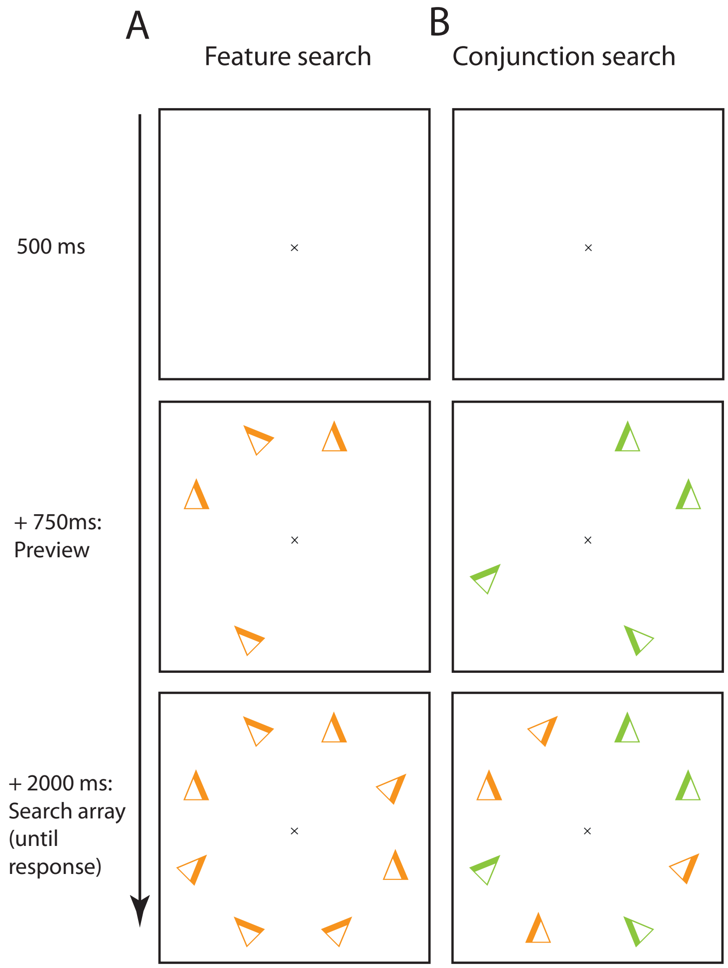


Figure 3.2: Examples of trials for the feature (A) and conjunction (B) preview conditions with a set size of 8 elements. In both conditions the target is an orange triangle with a thicker left leg. The item orientation alternates randomly across positions between −45°, 0°, and 45°. (A) Example display for feature search with preview of half the elements. (B) Example display for conjunction search with preview of one distractor family (all green elements).

3.4 Results

3.4.1 Accuracy

Table 3.2 shows the accuracy results. Accuracy was the same for the fixed and random target group ($F(1, 34) = 0.78, p = 0.38$). Accuracy decreased with increasing set size ($F(2, 68) = 13.61, p < 0.001$) and was lower in target present than target absent trials ($F(1, 34) = 51.81, p < 0.001$). Furthermore, there was also a significant main effect of condition ($F(3, 102) = 12.34, p < 0.001$), which interacted with target type (Condition × Target Type ($F(3, 102) = 8.94, p < 0.001$)) and trial type (Condition × Trial Type ($F(3, 102) = 7.12, p < 0.001$)).

Yet, these significant interactions can be explained by the significant Condition × Trial Type × Target Type interaction ($F(3, 102) = 3.94, p < 0.05$): While the lower accuracy in target present than absent trials is equal for all conditions in the random target group, this is not the case in the fixed target group: Here, accuracy in target present trials is higher for the conjunction baseline and the conjunction preview condition than for the other conditions.

Table 3.2: Mean percentage accuracy rates.

			Target absent			Target present		
Target	Search	Preview	8	12	16	8	12	16
Random	Color	No	0.99	0.97	1	0.96	0.95	0.95
Random	Feat.	No	0.98	0.98	0.97	0.86	0.86	0.83
Random	Feat.	Prev	0.97	0.98	0.96	0.86	0.82	0.75
Random	Conj.	No	0.98	0.98	0.96	0.82	0.82	0.82
Random	Conj.	Prev	0.97	0.98	0.97	0.85	0.83	0.84
Fixed	Feat.	No	0.97	0.97	0.96	0.87	0.83	0.82
Fixed	Feat.	Prev	0.98	0.97	0.95	0.88	0.82	0.75
Fixed	Conj.	No	0.98	0.98	0.98	0.88	0.91	0.87
Fixed	Conj.	Prev	0.98	0.99	0.98	0.91	0.92	0.93

There were also significant interactions of Condition × Set Size ($F(6, 204) = 6.32, p < 0.001$) and Set Size × Trial Type ($F(2, 68) = 3.48, p < 0.05$). These can be explained by taking a look at the significant interaction of Condition × Set Size × Trial Type ($F(6, 204) = 3.34, p < 0.05$): In target absent trials accuracy decreased with increasing set size at the same level for all conditions, whereas in target present trials accuracy decreased most for the feature preview condition. Typical errors in the experiment were that participants tended to overlook the target if it was present rather than giving a false alarm when it was absent.

3.4.2 Reaction Times

Figure 3.3 depicts the mean correct reaction times for all conditions. As can be seen there, the slopes for the pilot measurement of the color search baseline were flat with $a = 4.19$ for target absent trials and $a = -1.79$ for target present trials. This indicates that color targets can be found effortlessly, thus providing the best prerequisite for guidance by color.

Reaction times were influenced by target type ($F(1, 34) = 4.78, p < 0.05$), since participants of the fixed target group responded overall faster than participants of the random target group. Moreover, reaction times rose with increasing set size ($F(2, 68) = 376.14, p < 0.001$) and participants took longer to respond if the target was absent compared to when it was present ($F(1, 34) = 256.78, p < 0.001$). Furthermore, reaction times were different for the different conditions ($F(3, 102) = 144.14, p < 0.001$).

Moreover, this interacted also with target type (Condition × Target Type, $F(3, 102) = 73.86, p < 0.001$) and trial type (Condition × Trial Type, $F(3, 102) = 47.28, p < 0.001$; Condition × Trial Type × Target Type, $F(3, 102) = 24.47, p < 0.001$). This means that the shorter reaction times in target present than absent trials were equal for all conditions for both the random and fixed target group, except for the conjunction baseline. Here, participants of the random target group needed longer to respond and the difference in reaction time between target absent and present trials is higher for this condition in the random than the fixed target group.

Furthermore, condition interacted also with set size (Condition × Set Size, $F(6, 204) = 34.3, p < 0.001$, Condition × Set Size × Target Type, $F(6, 204) = 16.19, p < 0.001$): This indicates that the increasing reaction times with increased set size were equal for both groups in all conditions except for the conjunction baseline condition. Here, the increase in the random target group was higher than in the fixed target group.

Last but not least, the significant interactions of Set Size × Trial Type ($F(2, 68) = 101.58, p < 0.001$) and Condition × Set Size × Trial Type ($F(6, 204) = 11.6, p < 0.001$) show that the increase in reaction times with increasing set size is larger in target absent than in target present trials and this was highest for the feature and conjunction baselines.

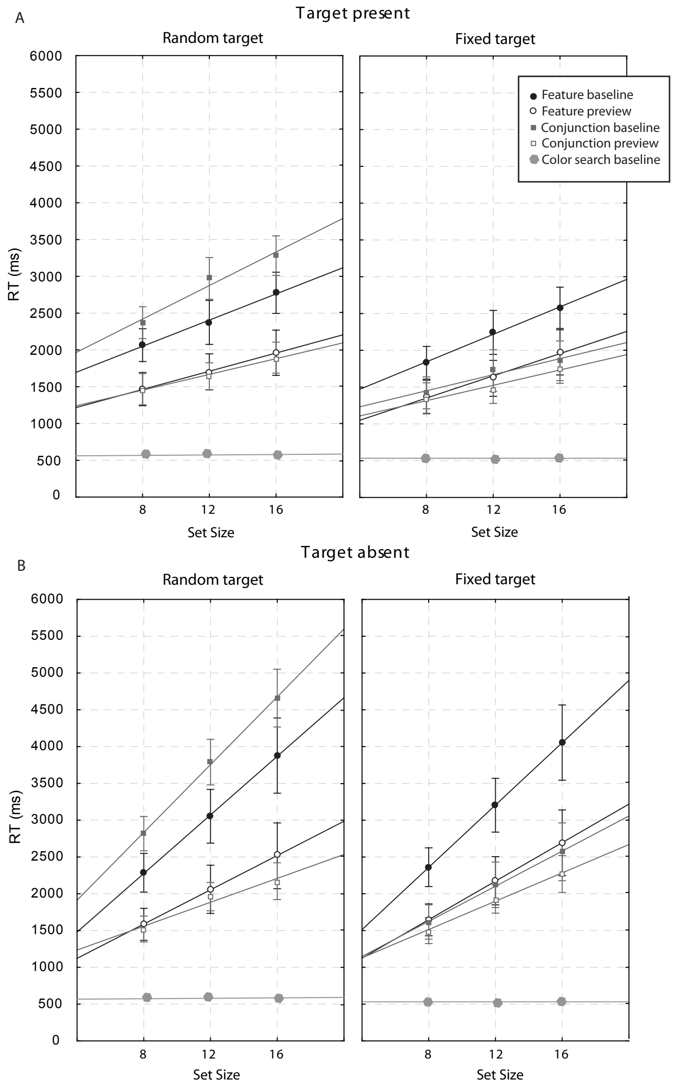


Figure 3.3: Mean correct reaction times, as a function of set size for all conditions for target present (A) and target absent trials (B). Filled symbols indicate baseline conditions, while open symbols indicate preview conditions. The error bars indicate the average 95 % confidence intervals of the means for all mean reaction times.

Since the omnibus ANOVA reveals only mean differences and gives no information whether two search functions are parallel, I tested with the Condition × Set Size interaction of all pairs of two combinations whether the slopes were parallel. Further, I calculated slope ratios to evaluate whether the half-slope prediction of spatial and feature guidance was fulfilled. Slopes and slope ratios are presented in table 3.3. Overall, the agreement of the slope ratios of target present and absent trials with a 1:2 ratio suggests that search was serial and self-terminated in all conditions for both target groups.

In the random target group conjunction baseline search was more inefficient than feature baseline search, since its slope is significantly higher than that of

Table 3.3: Slope estimates for the search functions. The table lists the slope estimates (search rates), a and the slope ratios of each condition with the feature baseline, q_p. The last column shows the slope ratios of target present and absent trials, q_t. All ratios are listed as percent (%) values.

			Target present		Target absent		
Target	Search	Preview	a	q_p	a	q_p	q_t
Random	Feat.	No	88.89		207.10		42.9
Random	Feat.	Prev	61.80	69.5	116.51	56.3	53.0
Random	Conj.	No	113.92	128.2	230.32	111.2	49.5
Random	Conj.	Prev	53.48	60.2	81.20	39.2	65.9
Fixed	Feat.	No	99.94		201.08		49.7
Fixed	Feat.	Prev	75.31	75.4	132.70	66.0	56.8
Fixed	Conj.	No	57.35	57.4	118.76	59.1	48.3
Fixed	Conj.	Prev	50.75	50.8	98.33	48.9	51.6

the feature baseline (target present: $F(2,34) = 3.56, p < 0.05$, target absent: $F(2,34) = 6.13, p < 0.01$, see table 3.3). Yet, this was not the case in the fixed target group (see table 3.3): Here, search was more efficient in the conjunction baseline than the feature baseline, since the slopes lie slightly above the predicted ideal of half the search rate of the feature baseline (target present: $F(2,34) = 7.6, p < 0.01$, target absent: $F(2,34) = 15.86, p < 0.001$). This suggests that color could be used to effectively guide search to only the target color items.

Table 3.4: Ratios of search rates for search with a fixed target compared to search with a random target. The table shows the slope ratios, q_s, as percent values, as well as F- ratio and p- value for testing the corresponding Condition × Set Size interaction. The F- tests have 2 denominator and 68 nominator degrees of freedom.

		Target present			Target absent		
Search	Preview	q_s	F	p	q_s	F	p
Feat.	No	112.4	0.58	0.564	97.1	0.19	0.825
Feat.	Prev	121.9	0.81	0.449	113.9	0.33	0.722
Conj.	No	50.3	11.73	< 0.001	51.6	29.17	< 0.001
Conj.	Prev	94.9	0.45	0.638	121.1	2.41	0.097

Moreover, I also found evidence for spatial guidance: In feature search significant effects and slopes fulfilling the half-slope prediction were found for target absent trials for both random target search ($F(2, 34) = 43.23, p < 0.001$) and fixed target search ($F(2, 34) = 14.28, p < 0.001$), while the half-slope prediction was not fulfilled in target present trials (see table 3.3, random target: $F(2, 34) = 3.17, p = 0.055$, fixed target: ($F(2, 34) = 1.66, p = 0.206$).

Yet, for conjunction preview search, the half-slope prediction was fulfilled for both trial types for random target search (target present: $F(2, 34) = 7.73, p < 0.01$, target absent: $F(2, 34) = 94.00, p < 0.001$) as well as fixed target search (target present: $F(2, 34) = 8.11, p < 0.01$, target absent: $F(2, 34) = 21.98, p < 0.001$).

Moreover, preview search was faster in conjunction than feature search, which is shown by the ratio $a_{\text{conj}}/a_{\text{feat}}$ for the used preview conditions (see table 3.5). Significant results were observed for target absent trials of fixed target search (target present: $F(2, 34) = 2.22, p = 0.124$, target absent: $F(2, 34) = 3.70, p < 0.05$). Furthermore, there was a significant advantage for random target search in target absent, but not target present trials (target present: $F(2, 34) = 0.76, p = 0.475$, target absent: $F(2, 34) = 12.32, p < 0.001$).

Furthermore, conjunction search with preview had an advantage over conjunction search without preview for both fixed target search (target present: $a_{\text{prev}}/a_{\text{base}} = 0.88, F(2, 34) = 3.77, p < .05$, target absent: $a_{\text{prev}}/a_{\text{base}} = 0.83, F(2, 34) = 4.04, p < 0.05$) and random target search (target present: $a_{\text{prev}}/a_{\text{base}} = 0.47, F(2, 34) = 15.91, p < 0.001$, target absent: $a_{\text{prev}}/a_{\text{base}} = 0.35, F(2, 34) = 98.17, p < 0.001$).

Table 3.5: Comparison of the slopes of conjunction and feature search. The table shows the slope ratios, q_v as percent values.

			Target present	Target absent
Target	Search	Prev	q_v	q_v
Random	Conj.	No	128.2	111.2
Random	Conj.	Prev	86.5	69.7
Fixed	Conj.	No	57.4	59.1
Fixed	Conj.	Prev	67.4	74.1

I also compared the search rates for all conditions between the fixed and random target group, which are shown in table 3.4. In both the feature baseline and the feature preview condition slopes were equal for both target types. Moreover, there was also no significant difference between the slopes of the conjunction preview condition for both groups. The only difference was found for the conjunction baseline condition where the slope for the fixed target group was halved compared to that of the random target group. This supports the notion that when participants know the target beforehand, they can search through only the elements which have the target color.

3.5 Discussion

I discovered evidence that in highly difficult form search color can be used to guide attention to only the target color items. Overall, search was serial and self-terminated in my experiment, since I observed a 1:2 ratio of target present to target absent trials. Form search was highly difficult, which did not differ between the target groups. Yet, it became more efficient due to spatial guidance: Slopes of the preview conditions which were halved compared to feature search with all elements for all trial types except fixed target search in target present trials indicated that observers were able to use the location information provided by the preview to search only through the new elements and this was not different for fixed and random target search.

Furthermore, participants of the fixed target group could use their knowledge about the target to search only through those elements containing the target color, which is indicated by a slope of conjunction baseline search, which is halved compared to the feature baseline. Feature guidance was complemented by spatial guidance, which was even more efficient than conjunction search without preview in the fixed target group. This improvement was also observed for random target search and it did not differ between both groups.

Overall, my results indicate that observers can use both spatial and feature guidance to improve search performance during a highly difficult search task, but search is most efficient if both mechanisms are combined.

3.5.1 Feature guidance facilitates conjunction search

Wolfe and colleagues illustrate in their Guided Search Theory how observers can include foreknowledge about target features to guide their search to only those elements containing those features, thus increasing search efficiency (Wolfe et al., 1989). After presentation of their theory the abilities of different features to guide search have been investigated (Wolfe and Horowitz, 2004). Color has been termed an undoubted guiding feature, whereas form is supposed to be a probable guiding feature (Wolfe and Horowitz, 2004), yet, as described in the introduction, the combination of those features led to controversial and discrepant results, particularly the results of Treisman and Gelade (1980) and Wolfe et al. (1989) (see also section "Theoretical background" for a broader description).

Efforts to provide evidence for color selective subset search have been made earlier. For example, Egeth et al. (1984) let their subjects search for either a color or an orientation target. If an equal number of distractors was shown, they observed slopes of 19 ms/item in target present and 34 ms/item in target absent trials, if observers were instructed to search for a red target. If participants searched for an orientation target, slopes of 17 ms/item in target present and 27 ms/item in target absent trials were observed. When the number of relevant distractors was held constant at three elements, while the number of irrelevant distractors increased, this led to flat slopes of the Reaction Time × Set Size function. The authors explained their results by color selective subset search, yet, they can also be explained by a distractor ratio effect, meaning that search becomes more effective the more different the ratios of distractors are (Bacon and Egeth, 1997; Zohary and Hochstein, 1989). Moreover, the colors green and red of the distractors in the study of Egeth et al. (1984) were not equally salient, so that their results could be due to different saliency of the distractors.

Kaptein et al. (1995) took this as a reason to solve the problems posed by the study of Egeth et al. (1984) by using equally salient stimuli and by varying the distractor ratios orthogonally. Furthermore, stimuli in their study were only presented for 150 ms. The target was a red vertical line, distractors were tilted red and vertical green lines. The authors assumed that differentiating the orientations of slightly tilted and vertical lines should not be effective enough to provide guidance, so that subset search should only be possible by color. The reaction time function for red elements showed steep slopes for both trial types and the slope for the reaction time function of green elements was equal in target absent trials. However, a flat slope of the reaction time function for green elements was observed if a target was present. The authors thus assumed that their results indicated search among only the red elements. However, the equal slopes for reaction time based on the number of green elements in target absent trials cannot be explained by this. Note that the slopes were about 25-30 ms/item. It is possible that search was still efficient enough, so that the use of color guidance was not necessary. In addition to this, the fact that no 1:2 ratio of target present to target absent trials was observed indicates that participants did not have to look at every element, but could search larger areas, which makes it hard to interpret and compare different search rates.

I solved these aspects by combining color, as a feature, which was shown in a pre-test to be searched efficiently, with a configural form. This form configuration made search really difficult, since the slopes were about 200 ms/item in target absent and ca. 90-100 ms/item in target present trials. Moreover, I observed a 1:2 ratio of present to absent trials, which indicates that participants needed to search element-wise.

What slope should be expected if color guidance is possible? If participants can search through only the elements of the target color, a slope which is halved compared to the feature search baseline should be observed in conjunction search for the fixed target group. Since all distractors of the target color share their color, participants can also perform a feature search among these items.

Indeed, I observed half-slopes in conjunction search which indicates that participants could use color to guide their attention to likely target elements. Without foreknowledge of the target color conjunction search was highly inefficient, since the conjunction search baseline slopes for the random target group were about 230 ms/item in target absent and 114 ms/item in target present trials. The difference between both groups highlights the role of feature guidance based on color in my experiment, since participants of the random target group had no information about likely target features.

3.5.2 Both feature and conjunction search gain from showing a preview of stimuli

Participants cannot only use features to guide their search, but guidance can also be based on the history of search, such as in the preview benefit (Wolfe and Horowitz, 2017): Watson and Humphreys (1997) investigated the ability of observers to guide their attention to only the "new" elements if half of all elements are shown as a preview 1 second before the remaining elements. They found that the search rate for conjunction search with preview was equal to the search rate of feature search with half of all elements and explained this "preview benefit" by visual marking (Watson and Humphreys, 1997): Visual marking means that the positions of the old stimuli can be inhibited during the preview, so that new elements are prioritized (Watson and Humphreys, 1997), however, other studies indicated that feature information is also used in the preview effect (Braithwaite and Humphreys, 2003; Braithwaite et al., 2003).

A preview benefit is indicated in my experiment if the slopes of the preview conditions are halved compared to their respective feature search baselines, since participants only need to search through the second item half and can perform a feature search there, since all new items share their color.

For feature search the half-slope prediction was nearly reached, yet the ideal of .5 was not fulfilled. However, significant results for all comparisons except target present trials in the fixed target group as well as clearly reduced slopes compared to feature search with all elements hint that observers could use the preview to guide their search to only the new stimuli. Since the slopes do not differ significantly between the fixed and random target group, target knowledge had no impact on feature search, so that it was the spatial information provided by the preview which the observers used to search through less elements.

A possible reason why the half-slope prediction was not clearly fulfilled in feature search is that once all elements are present in the search display, participants cannot distinguish both item halves. Memory is thus necessary in feature search to differentiate old and new items when the new items have entered the display (Jiang and Wang, 2004). This means that observers have to remember all old locations, otherwise they search through more elements than necessary. The high difficulty of feature search in this experiment could have interfered with remembering all old locations, so that the slope ratios higher than .5 likely indicate a failure of remembering all positions of the preview, so that some positions are revisited.

Remembering old item positions is not necessary in conjunction search, since old and new items can still be distinguished based on their different colors if all elements have entered the search display (Theeuwes et al., 1998). This means that the half-slope prediction should be clearer fulfilled in conjunction search and indeed, this was the case, since the slope ratios for conjunction preview search lie between .39 and .6 in my experiment. Moreover, conjunction search with preview was not different for the fixed and random target group (see table 3.4). This is interesting, since in the fixed target group, slopes are already halved due to feature guidance, but still, there is small improvement due to the preview, which means that the combination of spatial and feature guidance is most effective in search. That the slopes for the conjunction preview conditions were not different for the fixed and random target group hints that even if the target varies in random manner from one trial to the next, observers can use the information about likely target features provided by the preview to guide their attention to only the elements which have the target color.

Interestingly, my results for conjunction search stand in contrast to results for conjunction search in letter search tasks: both in the studies of Meinhardt and Persike (2015) and study 1 the preview benefit was disrupted in conjunction search with random item positioning, while it was intact in feature search irrespective of item positioning. Note that the slopes both in the study of Meinhardt and Persike (2015) and my own experiment were clearly shallower than in this experiment: They lie in a range of 23-27 ms/item in target present trials for feature baseline search and 19-70 ms/item in target present trials for conjunction baseline search. Thus, search was clearly more difficult in the presented experiment with triangle stimuli than in the named letter search tasks. Results for the preview benefit and feature guidance hint that participants are more likely to use the given information to guide their attention to likely target elements when they have more incentive to do so, thus, when the search task is highly difficult compared to a lower degree of difficulty.

Due to the physical differences of the described stimuli it would be advantageous to gradually change the difficulty of a search task using the same stimuli. However, this poses a problem for the currently used triangle stimuli, since the spatial configuration cannot be made easier. Thus, in my next study, I chose stimuli which could be gradually changed to increase or decrease target-distractor similarity and thus task difficulty. I investigated the impact of task difficulty on the utilization of feature and spatial guidance in study 3.

Chapter 4

The role of stimulus similarity in guiding search

4.1 Synopsis

Feature guidance to specific target features is built on both bottom-up and top-down activations computed in an activation map (Wolfe et al., 1989) and different features possess different abilities to provide guidance (Wolfe and Horowitz, 2004, 2017). Studies indicate that color is especially suited to guide search (Anderson et al., 2010), yet, conflicting results for color $\times$ form search have arisen (see e.g. results of Treisman and Gelade (1980) vs. those of Wolfe et al. (1989)). A study by Sobel and Cave (2002) hints that the critical factor in determining whether search is more controlled by bottom-up or top-down factors is the discriminability of target and distractors. I used four degrees of target-distractor form discriminability to investigate the effect on the usage of feature guidance as well as spatial guidance provided by a preview. For feature search guidance was observed with efficient form search, while for conjunction search guidance was only found with highly inefficient form search. A preview benefit was observed for feature search irrespective of target-distractor discriminability, while it was only fully observed for conjunction search with the highest target-distractor similarity. My results indicate that feature guidance can only operate if one efficiently searched feature can be used for guidance, but not two. With two efficient features, however, repetition priming can facilitate conjunction search. Moreover, the influence of attentional capture can be diminished by increasing target-distractor similarity.

4.2 Introduction

Search for a target depends on how salient a target is compared to its surrounding distractors (Itti and Koch, 2001). Search efficiency increases if the target and distractors differ to a high degree and search becomes less efficient if target-distractor similarity increases (Duncan and Humphreys, 1989). If the target differs in a singular feature from the surrounding context, it shows 'pop out' (Itti and Koch, 2001), so that reaction times are independent of the number of elements presented in the search display (Treisman, 1988). This automatic capture of attention perceived as pop-out is based on a large saliency contrast of the target compared to the context in which it is embedded and is thus bottom-up controlled (Itti and Koch, 2001). Underlying this phenomenon is the assumption of a topographically organized saliency map incorporating the locations which elicit different degrees of activation due to saliency, independent of the underlying feature dimension. Attention is then directed to the location that elicits the highest activity in the map (Itti and Koch, 2001).

Whereas saliency can be used to find a target rapidly in feature search, this is not possible in conjunction search, where the target is defined by a specific combination of two features. In conjunction search the target is not the most salient item in the display. It differs from both types of distractors in one feature, whereas the distractors are differentiated by two features. For example, imagine a color $\times$ form conjunction search for a green H among orange Hs and green As. While the green H differs from the H distractors in color it differs from the green distractors in form, whereas orange Hs and green As differ in both their color and their form, meaning that the green H does not pop out of the search display. Here, reaction times increase linearly with the number of display elements (Treisman, 1988). Yet, top-down factors can lead to more efficient conjunction search, such as guidance to specific features based on target knowledge (Wolfe et al., 1989).

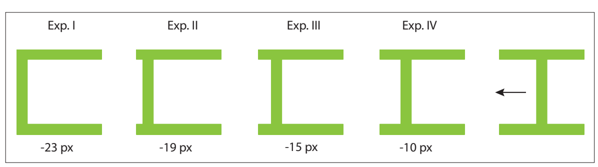
The Guided Search Theory (Wolfe et al., 1989) describes how observers can use knowledge about target features to restrict search to only the elements exhibiting those features (see section 'Theories' of chapter 1 for a detailed description of Wolfe and colleagues' Guided Search Theory). Although the Guided Search Theory has been investigated especially in conjunction search, guidance is not exclusive to it, but can also be used in feature search (Wolfe et al., 1989). In feature search the target can be distinguished in a single feature from the distractors (Treisman and Gelade, 1980). How salient the target is compared to the distractors decides about how efficiently guidance works (Wolfe et al., 1989). Moreover, the theory states that search efficiency depends on the amount of information that can be used in the parallel stage to conduct the search to likely target candidates (Wolfe et al., 1989). For example, Wolfe and colleagues showed in their seminal study that conjunction search was more efficient if target and distractors differed in two features than if they only differed in one feature (Wolfe et al., 1989).

How can we determine whether search is guided or not? First of all, guidance is only possible if observers know which feature the target contains. Without target knowledge feature guidance cannot be executed. This means, as evidence for feature guidance, that search performance should be better if subjects know the target than if they do not. For this, all conditions in my study were performed for both a known, not changing target as well as randomly changing targets which the subjects did not know in advance.

Second, in conjunction search observers can exclude elements from their search, so that one can take a look at the slope of the Reaction Time $\times$ Set Size function. Coming back to the example of search for a green H among orange Hs and green As, subjects know that they need not search through the orange elements, since these do not contain the target color. Perfect color guidance would mean, that they can conduct a feature search on only half the items (the green items), which would be indicated by a slope ratio of conjunction to feature search of 0.5. Ratios higher than 0.5, but less than 1 would hint that guidance could be used, but did not work perfectly. Ratios of 1 or higher would show that color guidance was not applicable. Yet, in the mentioned example, observers could also separate the search display based on form instead of color, since both form and color have been shown to be usable for guidance (Wolfe and Horowitz, 2004, 2017). Studies using two such efficiently searched features led to conflicting results concerning conjunction search, e.g. in the studies of Treisman and Gelade (1980) and Wolfe et al. (1989) (see section 'Controversies' for a detailed overview). This hints that if both used features in conjunction search are salient and can be searched efficiently, it remains unclear, which of the features is used to guide attention to a subset of elements in the search display, since observers are not aware which of the features they should prioritize. This implies, that one should establish a situation where it is clear, which feature should be prioritized for guidance and which should be used to make the final distinction between target and distractors.

One way to manipulate search efficiency is by varying target-distractor similarity, since search becomes more efficient with decreasing target-distractor similarity (Duncan and Humphreys, 1989). In agreement with this, Sobel and Cave (2002) manipulated search efficiency of the feature orientation by varying the orientation differences between target and distractor items, while combining it with the feature color. They showed that observers used guidance to items containing the target color, if target and distractors were highly similar and differed only in an orientation shift of 20 degrees, but that observers based search on bottom-up saliency differences if target and distractor items were highly different in their orientations. The aim of my study was to systematically vary the search efficiency of the feature form, while keeping the efficiency of the feature color constant and examine effects on feature and conjunction search. I implemented this by increasing the form similarity between target and distractors across the experiments, while the chosen colors orange and green remained the same. The chosen stimuli are presented in figures 4.1 and 4.2. As can be seen there, the vertical bar of the letter I was moved by 23, 19, 15 and 10 pixels, thus creating a C with increasing similarity to the I.

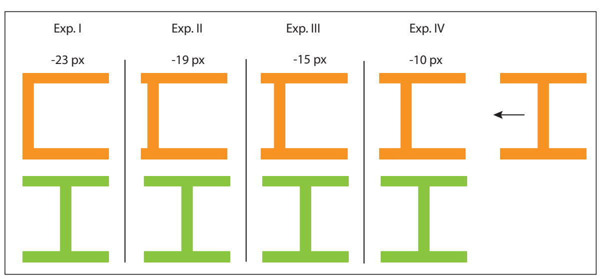
Figure 4.1: Examples of stimuli for feature search of study 3. The figure shows the shift of the vertical bar of the I to C in different pixels across the four experiments.



In feature search all letters have the same color, while the target has the alternative form than the distractors. Since color cannot be used to minimize the number of items to be searched, only form should be able to guide search and the amount of guidance should depend on how different the two forms C and I are. This means that fixed target search should be more efficient than random target search, the higher the difference between both letters. This can be computed as a ratio $a_{\text{fixed}}/a_{\text{random}}$. The smaller the ratio is, the higher is the difference in efficiency between search for both target types. The largest difference between C and I is established by moving the bar by 23 pixels, the smallest difference by moving it 10 pixels. Accordingly, the ratio $a_{\text{fixed}}/a_{\text{random}}$ should advance near 1 with higher target-distractor similarity.

In conjunction search both color and form can principally guide attention. Whereas color was kept constant in its target-distractor similarity in my study, this varied for form. This means that across the different pixel shifts of the bar, color was either combined with an efficiently searched form feature, e.g. at 23 pixels shift, or an inefficiently searched form feature, e.g. at 10 pixels shift. To that effect, feature guidance should be more clearly observed, the more different the two search efficiencies of the features color and form are. I thus predict that a) the ratio $a_{\text{fixed}}/a_{\text{random}}$ decreases and b) the ratio of conjunction to feature search comes nearer to 0.5, which indicates perfect guidance, with increased similarity of the target and distractor forms. At such an arrangement, it should be clear to observers that color can be used for guidance and form cannot. If both color and form are equal in search efficiency, like should be the case with 23 pixels shift, the ratio should come nearer 1, since then, no clear priority can be built for one feature over the other.

Figure 4.2: Examples of stimuli for conjunction search of study 3. The figure shows the shift of the vertical bar of the I to C in different pixels across the four experiments. Underneath, the corresponding distractor is shown for each experiment, although the classification of target and distractor could vary across letters.



Attention cannot only be guided by feature foreknowledge, but also by knowledge about positions of items. Watson and Humphreys (1997) introduced an experimental paradigm where half of all items in conjunction search, all of the same color, were shown as a preview 1000 ms before the remaining elements. The slope of the RT × Set Size function of this preview condition was equal to the slope for the feature baseline with only half the elements. From this, the authors concluded that their participants were able to encode and inhibit the previewed locations and search only through the "new" items.

The preview benefit in feature search relies on memory, since the preview and the new elements cannot be separated once the new elements are added to the search display (Jiang and Wang, 2004). Jiang and Wang (2004) propose that the memory for new positions has a limited capacity and that the memory for the temporal asynchrony of both groups deteriorates fast. This hints, that the preview benefit in feature search should be diminished the longer search takes and the harder it becomes. While a full preview benefit is indicated by a ratio of the feature preview condition to the feature baseline condition of 0.5, I thus predict that the ratio rises across the four experiments.

In conjunction search on the other hand, new and old items are also separable due to their different colors (Theeuwes et al., 1998), meaning that conjunction preview search should be less influenced by memory limitations. However, study 1 and 2 hinted that the preview benefit with randomly positioned elements depends on the choice of stimuli in conjunction search and their search efficiency. In study 1, with green and orange A and H letters, I did not observe a preview benefit in conjunction search with randomly positioned letters. Search efficiency of form search was higher than in study 2, where subjects searched for green and orange triangles with a thick bar on either the right or left. Yet, in study 2, where form search was highly inefficient, a conjunction preview benefit was existent. This hints that there is a factor which impedes the emergence of a preview benefit with efficient, but not inefficient search.

A possible reason is the catching of attention due to salient and matching items in conjunction search. Note that the target matches the preview in form in conjunction search. Several authors provided evidence for attentional capture of salient items (Kim and Cave, 1999; Lamy and Zoaris, 2009; Theeuwes, 1992, 2004) and this has also been found for matching elements (Folk et al., 1992; Remington et al., 2001). Yet, as form differences get less salient, less attentional capture should happen. Thus, the half-slope prediction of a potential visual marking mechanism should be clearer fulfilled, the harder form search gets.

In the following I present four experiments which illustrate that the emergence of feature guidance and the preview benefit in feature and conjunction search is dependent on the difference between target and distractor features and thus the search efficiency of feature search.

4.3 Experiment I

4.3.1 Methods

Ethics Statement

Observers received information about the expected duration and course of the experiment prior to participation. The general purpose of the study was explained, but no specific outcome expectations were given. Every participant had to sign a written consent form according to the Declaration of Helsinki. Participants were told that withdrawal from participation in the experiment was possible during the whole experiment and without penalty. Every participant received a summary of their data, which was explained according to the purpose of the experiment after completion of the experiment.

Sample

25 undergraduate students from the university of Mainz participated in the experiment. Mean age was 22.05 (age range 18-30) and 23 were female participants. All observers had normal or corrected-to-normal visual acuity. For participation, observers received course credit.

Experimental Outline and Design

With this experiment I wanted to investigate how feature guidance and the preview benefit are influenced by the search efficiencies of the used features. To vary search efficiency systematically, the stimuli I and C were used and the vertical bar of the I was offset to the left toward the form C. In experiment I the vertical bar of the I was shifted 23 pixels to the left so that this led to the form of a C.

Participants searched for two different target types: randomly varying target and fixed target. For the first, the target and distractor colors and forms varied randomly between trials, this means, that no knowledge about the target could be gained based on a previous trial. For the fixed target type a target was chosen for each participant and the participants were told that the target would always have this form and color and would remain the same in the fixed target conditions of the experiment. 8, 12 or 16 elements appeared on the display.

Since the colors and luminances were the same as in study 2, where it was shown that color targets led to flat slopes, indicating pop-out, I assumed that color could be searched as efficiently in this study as in study 2.

In the following the different conditions will be described:

Feature baseline with random target: All elements in the search display had the same color, but target and distractor colors and forms varied from trial to trial. The target had the alternative form than the distractors, so that it could be a C between Is or vice versa. Since the color and form assignments varied from trial to trial no knowledge about the upcoming target could be gained due to the previous trials. Figure 4.1 shows stimulus examples, an example of a trial is presented in panel A of figure 4.3.

Feature preview condition with random target: Half of the distractors were shown 2000 ms before the rest of the elements entered the search display. The target, if present, could only appear at one of the "new" positions and it had the alternative form than the previewed distractors (see figure 4.1 for stimulus examples and panel A of figure 4.4 for a trial example).

Conjunction baseline with random target: Both Cs and Is appeared and while the Cs had one color, the Is had the alternative color. The color and form assignments could vary from trial to trial. The target could appear among either the green or orange elements and had the alternative form than the same colored distractors (see figure 4.2 and panel B of figure 4.3).

Conjunction preview condition with random target: All distractors of one color were shown 2000 ms before the elements of the other color made the search display complete. The target could only appear among the "new" items and, since it had the same form as the previewed distractors, its form could be deduced based on the preview (see figure 4.2 and panel B of figure 4.4).

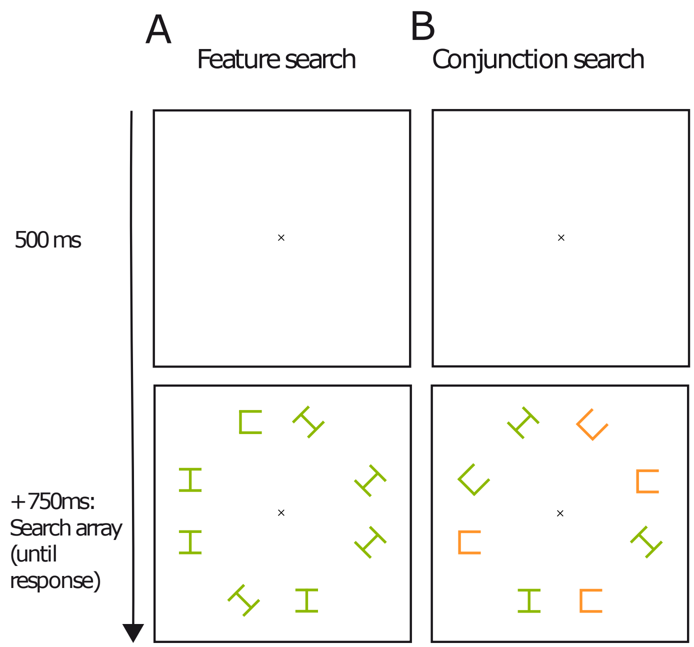
Feature baseline with fixed target: The target form and color were fixed and known to the participant. The distractors always appeared in the same color as the target and had the alternative form (see figure 4.1 and panel A of figure 4.3).

Feature preview condition with fixed target: The target was the same as in the other fixed target conditions and could only appear among the "new" elements, which appeared 2000 ms after a preview of same colored distractors (see figure 4.1 and panel A of figure 4.4).

Conjunction baseline with fixed target: Both Cs and Is appeared in the search display. The target form and color was again the same as in the other fixed target conditions. This meant that the other colored distractors had the same form as the target, whereas the same colored distractors had the alternative form. Stimulus examples are presented in figure 4.2 and a trial example is depicted in panel B of figure 4.3.

Conjunction preview condition with fixed target: The distractor color items were shown 2000 ms before the remaining elements, which had the target color and which could contain the target. Again, the target was fixed and known to the participants (see figure 4.2 and panel B of figure 4.4).

Figure 4.3: Examples of trials for the feature (A) and conjunction (B) baseline conditions with a set size of 8 elements. In both conditions, the target is a green C. The item orientation alternates randomly across positions between −45°, 0°, and 45°.

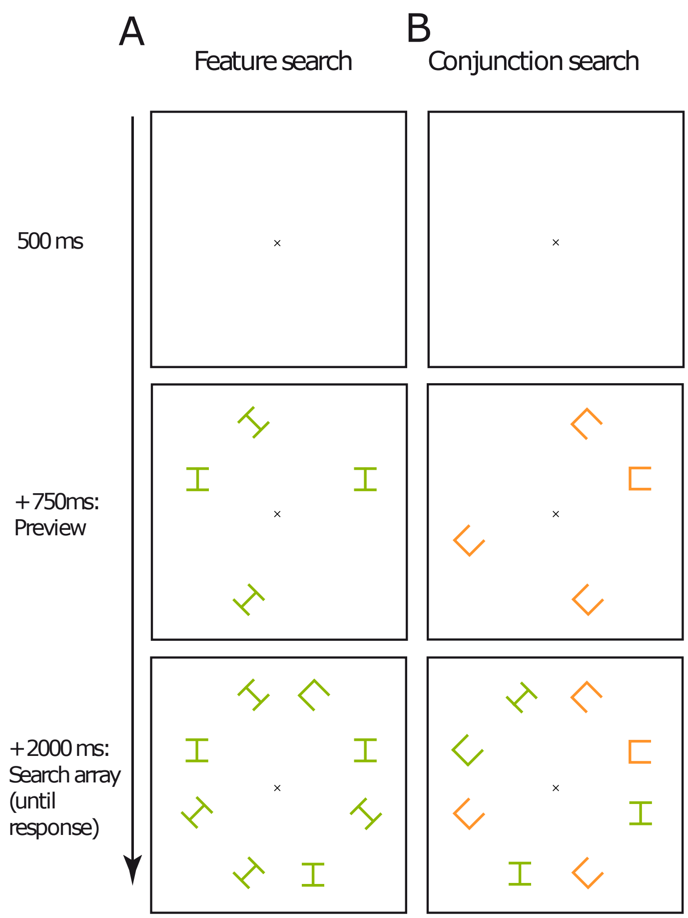


Experimental Predictions

The predictions for the experimental conditions with offset 23 pixels are the following:

Offsetting the vertical bar of the I by 23 pixels leads to a C, which is the maximum difference between both forms. Since all elements have the same color in feature search and the target differs only from the distractors in its highly dissimilar form, guidance should be observed in feature search, meaning that the ratio $a_{\text{fixed}}/a_{\text{random}}$ should be near 0.5. In conjunction search however, two efficienty searched features are present, so that the ratio $a_{\text{fixed}}/a_{\text{random}}$ should be nearer 1 and the half-slope prediction should also not be fulfilled. For the feature and the conjunction preview conditions slope ratios of the preview condition and the feature baseline should be near 0.5, since only half of all elements have to be searched if the preview can be used.

Figure 4.4: Examples of trials for the feature (A) and conjunction (B) preview conditions with a set size of 8 elements. In both conditions, the target is a green C. The item orientation alternates randomly across positions between −45°, 0°, and 45°. (A) Example display for feature search with preview of half the elements. (B) Example display for conjunction search with preview of one distractor family (all orange elements).



Apparatus and Stimuli

The experiment was run with Matlab. Participants saw patterns on NEC Spectra View 2090 screens at a resolution of 1600 × 1200, which had a refresh rate of 60 Hz. The colors orange and light-green were used. Calibration for isoluminance at 59 cd/m^2 was done with a ColorCal Colorimeter of Cambridge Research Systems (Rochester, UK) without the usage of gamma corrections. Observers sat in front of a binocularly viewed display at a distance of 70 cm. To create the stimulus micropatterns I used Adobe Illustrator. To build the stimuli I combined horizontal and vertical bars which had a line thickness of 7 pixels. Every stimulus item measured overall 53 × 53 pixels. For creating the stimuli the vertical central line of the I stimulus was moved to the left by 23 pixels, so that this transformation led to the form of a C. Stimuli were displayed in a regular n-gon (n=8,12,16). Each vertex possessed a center-distance of 308 pixels, corresponding to 6.97 ° visual angle. At the center of the polygon sat a fixation cross. The stimulus orientations varied randomly between 0 and 45 ° visual angle to either the left or right. A distance marker, but no chin rest was used. Participants responded by pushing different buttons on a computer keyboard. They received acoustical feedback via headphones, where a "tack" showed a correct response and a "tacktack" showed that the response was incorrect.

Procedure

As in the experiments before I used a Yes/No forced choice task. The experiment contained eight experimental conditions, of which each was measured in a separate experimental block. Each block contained 108 trials in total, which comprised 18 target absent and 18 target present trials for each of the three set sizes. Each subject was tested in a single experimental session, which lasted for about one and a half hours. Participants were instructed that the target could vary randomly from trial to trial in the random target conditions. In the fixed target conditions each subject was told about the chosen target. Choice of one of the four possible targets (green C, green I, orange C, orange I) was counterbalanced over all subjects. Moreover, observers were informed that different set sizes of elements would appear, that the target could never be present on previewed locations and that target absent and target present trials would be equally frequent. Participants were told to pay attention to both fast and correct responses and to use the given feedback. 12 practice trials were carried out by the subjects to make sure that they understood the task. The trial sequence for baseline conditions was the following: fixation mark (at 500 ms) - search array (+ 750 ms, until response). For the preview conditions the trial sequence was fixation mark (at 500 ms) - preview (+ 750 ms) - search array (+ 2000 ms, until response).

Data analysis

Measures were reaction times of correct responses and accuracy (proportion correct). For data analysis I used Microsoft Excel and Statistica 13.1. I analyzed all data with mixed factor ANOVA. Condition (feature baseline, feature preview condition, conjunction baseline, conjunction preview condition), set size (8,12,16), target type (random/fixed) and trial type (absent/present) were entered as factors into the ANOVA. Moreover, by entering two conditions into an ANOVA and analyzing the Condition × Set Size interaction I could evaluate whether two slopes of the Reaction Time × Set Size function differed from parallelism. A significant result of the interaction indicates that two search functions are not parallel. Furthermore, I computed slope ratios of all conditions to their respective feature search baseline as well as the ratios of the conjunction preview condition against the conjunction baseline condition and of fixed to random target search.

4.3.2 Results of experiment I

Accuracy

Accuracy was overall high. Testing with an ANOVA revealed effects of Target ($F(1, 24) = 24.72, p < 0.001$), Condition ($F(3, 72) = 9.42, p < 0.001$), Set Size ($F(2, 48) = 12.07, p < 0.001$) and Trial Type ($F(1, 24) = 58.86, p < 0.001$). Moreover, target type interacted also with condition (Target × Condition ($F(3, 72) = 7.41, p < 0.001$) and trial type (Target × Trial Type ($F(1, 24) = 9.55, p < 0.05$). For fixed target search accuracy was not different for the different conditions. For random target search accuracy was equal for all conditions except the conjunction baseline, for which accuracy was lower. While accuracy was equal in both trial types for fixed target search, accuracy in target present trials was lower than in target absent trials for random target search.

Moreover, a significant interaction of Condition × Trial Type ($F(3, 72) = 2.85, p < 0.05$) indicates, that although accuracy is not different for the conditions in target absent trials, accuracy is lower for the conjunction baseline than the other conditions in target present trials.

Furthermore, set size interacted also with trial type (Set Size × Trial Type $(2, 48) = 9.23, p < 0.001$), meaning that overall accuracy did not decrease with increasing set size in target absent, but in target present trials.

Last but not least, ANOVA showed a significant three-way interaction of Target × Condition × Set Size ($F(6, 144) = 2.93, p < 0.05$): Accuracy was higher for fixed than random target search and for fixed target search, the decrease in accuracy with increasing set size is equal for all conditions. For random target search accuracy is lower than for fixed target search and decreases with increasing set size. The highest decrease is observed for the conjunction baseline condition (see table 4.1).

Table 4.1: Mean percentage accuracy rates for experiment I.

			Target present			Target absent		
Target	Search	Preview	8	12	16	8	12	16
Random	Feat.	No	0.91	0.92	0.89	0.95	0.96	0.95
Random	Feat.	Prev	0.91	0.91	0.91	0.97	0.97	0.98
Random	Conj.	No	0.88	0.87	0.82	0.97	0.92	0.94
Random	Conj.	Prev	0.94	0.92	0.90	0.97	0.97	0.98
Fixed	Feat.	No	0.97	0.97	0.94	0.99	0.98	0.98
Fixed	Feat.	Prev	0.96	0.96	0.93	0.98	0.98	0.99
Fixed	Conj.	No	0.94	0.95	0.93	0.98	0.99	0.98
Fixed	Conj.	Prev	0.98	0.93	0.94	0.99	0.99	0.98

Reaction Times

Reaction times are presented in figure 4.5. Testing reaction times with an ANOVA revealed significant main effects of Target ($F(1, 24) = 145.52, p < 0.001$), Condition ($F(3, 72) = 187.79, p < 0.001$), Set Size ($F(2, 48) = 234.55, p < 0.001$) and Trial Type ($F(1, 24) = 82.3, p < 0.001$). These factors also interacted and all following interactions must be explained by looking at the significant four-way interaction of Target × Condition × Set Size × Trial Type ($F(6, 144) = 3.19, p < 0.05$): Target interacted with Condition (Target × Condition ($F(3, 72) = 135.75, p < 0.001$) and Set Size (Target × Set Size ($F(2, 48) = 48.61, p < 0.001$; Target × Condition × Set Size ($F(6, 144) = 19.18, p < 0.001$): Reaction times increased with increasing set size and this increase was higher

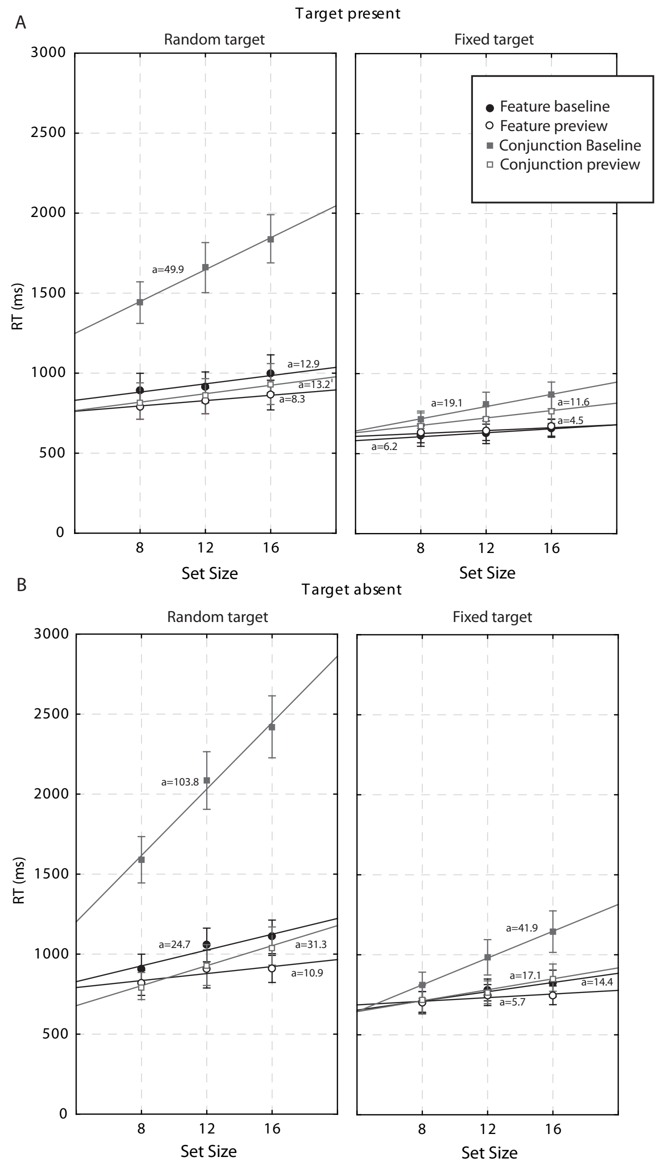


Figure 4.5: Mean correct reaction times for experiment I as a function of set size for all conditions for target present (A) and target absent trials (B). Filled symbols indicate baseline conditions, while open symbols indicate preview conditions. The error bars indicate the average 95 % confidence intervals of the means for all mean reaction times. The slopes of the RT × Set Size functions, a, are also presented.

for random than fixed target search and here especially for the conjunction baseline.

Furthermore, there were significant interactions of Condition × Set Size ($F(6, 144) = 66.33, p < 0.001$), Condition × Trial Type ($F(3, 72) = 42.27, p < 0.001$) and Set Size × Trial Type ($F(2, 48) = 39.68, p < 0.001$), which can be explained by the significant three-way interaction of Condition × Set Size × Trial Type ($F(6, 144) = 16.87, p < 0.001$): Reaction times increase with increasing set size more for the conjunction baseline than for the other conditions and this is more pronounced in target absent than target present trials.

The interactions of Target × Condition × Trial Type ($F(3, 72) = 16.08, p < 0.001$) and Target × Set Size × Trial Type ($F(2, 48) = 6.92, p < 0.05$) were also shown to be significant.

Overall, all results can be explained by the aforementioned significant interaction of Target × Condition × Set Size × Trial Type ($F(6, 144) = 3.19, p < 0.05$): The increase in reaction times with increasing set size is higher for the conjunction baseline than for the other conditions and this is more pronounced in target absent than target present trials. Furthermore, this difference between the trial types is more pronounced for random than fixed target search.

Since I wanted to know if the slopes of the Reaction Time × Set Size function differ from parallelism, I tested this with the Condition × Set Size interaction. Moreover, I computed ratios of all conditions and the feature baseline to evaluate whether the half-slope prediction was fulfilled (see table 4.2). I also calculated the slope ratios of the conjunction preview condition and the conjunction baseline (see table 4.3), as well as the ratios $a_{\text{fixed}}/a_{\text{random}}$ for all conditions (see table 4.4).

First of all, as can be seen in the last column of table 4.2, a 1:2 ratio of target present to target absent trials suggests serial self-terminating search in all conditions except the feature preview condition in both random and fixed target search and the conjunction preview condition of fixed target search. In these conditions the ratio is less than 1, but not halved, which indicates that observers tend to scan in mean more than half of all elements in target present trials.

For random target search feature baseline search slopes indicate that search could be performed efficiently (see table 4.2). For the feature preview condition the half-slope prediction was fulfilled in target absent trials, which was supported by a significant result of the test of the Condition × Set Size interaction ($F(2, 48) = 4.45, p < 0.05$). In target present trials the half-slope prediction was slightly missed, since the ratio was about .65 and the F-test showed no significant result ($F(2, 48) = 0.93, p = 0.401$).

Conjunction baseline search was apparently a lot harder for participants, since the slopes were about 3.9 (target present trials) to 4.2 (target absent trials) times the size of the feature baseline and this is substantiated by significant results of the F-test (target present: $F(2, 48) = 17.35, p < 0.001$, target absent: $F(2, 48) = 78.64, p < 0.001$).

Table 4.2: Slope estimates for the search functions obtained in experiment I. The table lists the slope estimates (search rates), a, and the slope ratios of each preview condition with the feature search baseline, q_p. The last column shows the slope ratios of target present and absent trials, q_t. All ratios are listed as percent (%) values.

			Target present		Target absent		
Target	Search	Preview	a	q_p	a	q_p	q_t
Random	Feat.	No	12.9		24.7		52.1
Random	Feat.	Prev	8.3	64.7	10.9	44.3	76.2
Random	Conj.	No	49.9	387.7	103.8	420.7	48.1
Random	Conj.	Prev	13.2	102.9	31.3	126.6	42.4
Fixed	Feat.	No	6.2		14.4	43.0	
Fixed	Feat.	Prev	4.5	73.1	5.7	39.2	80.2
Fixed	Conj.	No	19.1	308.2	41.9	291.0	45.6
Fixed	Conj.	Prev	11.6	187.0	17.1	118.8	67.7

For conjunction preview search the slopes do not differ significantly from the feature baseline (target present: $F(2, 48) = 0.05, p = 0.947$, target absent: $F(2, 48) = 2.06, p = 0.139$).

Testing the conjunction preview condition against the conjunction baseline again fortified the notion that conjunction baseline search was really difficult, since the ratios are about .3 (see table 4.3), thus indicating an advantage due to the preview (see table 4.3). Since the half-slope prediction is not fulfilled for the conjunction preview condition (see table 4.2), this ratio is mostly due to the high baseline search rates.

As can be seen in table 4.2, for fixed target search, feature baseline search is efficient. For feature search with preview the slope was reduced compared to the feature baseline in target present trials, but the half-slope prediction was not fulfilled and the F-test showed no deviations from parallelism ($F(2, 48) = 0.34, p = 0.710$). In target absent trials the slope was more than halved compared to the feature baseline and the Condition × Set Size interaction was significant ($F(2, 48) = 6.40, p < 0.01$).

The conjunction baseline slopes were significantly different from the feature baseline slopes and were about 3 times the feature baseline slopes (target present: $F(2, 48) = 11.12, p < 0.001$, target absent: $F(2, 48) = 30.0, p < 0.001$).

Conjunction preview search slopes did not differ significantly from the feature baseline slopes (target present: $F(2, 48) = 2.80, p = 0.070$, target absent: $F(2, 48) = 1.97, p = 0.151$), although the ratios are 1.87 (target present trials) and 1.18 (target absent trials).

As is presented in table 4.3, conjunction preview search was advantageous to conjunction baseline search, which is indicated by ratios of 0.6 (target present trials) and 0.4 (target absent trials) and by significant Condition × Set Size interactions (see table 4.3) . As for random target search, this is likely due to the high conjunction baseline search slopes, since the half-slope prediction for the conjunction preview condition is not fulfilled and the slopes for the conjunction preview condition are higher than the feature baseline slopes.

Table 4.3: Ratios of search rates for the conjunction preview condition against the conjunction baseline condition. The table shows the slope ratios, q_x, as percent values, as well as F- ratio and p- value for testing the corresponding Condition × Set Size interaction. The F- tests have 2 denominator and 48 nominator degrees of freedom.

	Target present			Target absent		
Target	q_x	F	p	q_x	F	p
Random	26.5	17.79	< 0.001	30.1	73.89	< 0.001
Fixed	60.7	4.15	< 0.05	40.8	17.28	< 0.001

I have also investigated whether fixed target search is advantageous to random target search due to target knowledge. As can be seen in table 4.4, this is the case for conjunction baseline search, since the ratios $a_{\text{fixed}}/a_{\text{random}}$ are about .4 and the slopes of this conditions differ significantly between the targets.

For conjunction preview search slopes differ also significantly in target absent trials and the ratio is about .5, while for target present trials, the slope is only slightly reduced and no significant deviations from parallelism were observed. For feature search the ratios are about .5 for both the feature baseline and the feature preview condition, yet the Condition × Set Size interaction was only significant for the feature baseline in target absent, but not target present trials.

Table 4.4: Ratios of search rates for search with a fixed target compared to search with a random target of experiment I. The table shows the slope ratios, q_s, as percent values, as well as F- ratio and p- value for testing the corresponding Condition × Set Size interaction. The F- tests have 2 denominator and 48 nominator degrees of freedom.

		Target present			Target absent		
Search	Preview	q_s	F	p	q_s	F	p
Feat.	No	48.1	2.09	0.135	58.3	3.7	< 0.05
Conj.	No	38.2	16.58	< 0.001	40.3	49.33	< 0.001
Feat.	Prev	54.4	0.52	0.599	51.7	1.05	0.357
Conj.	Prev	87.4	0.23	0.793	54.7	6.97	< 0.01

4.3.3 Discussion of experiment I

In experiment I two highly different forms were used. Feature search was shown to be efficient, both for random and fixed target search. The half-slope prediction of visual marking was fulfilled for both target types for the feature preview condition in trials when the target was absent. In target present trials the slopes of the RT × Set Size function for these conditions were reduced compared to the feature baseline, but not completely halved. Conjunction baseline search slopes were 3-4 times the size of the feature baseline search slopes, indicating rather inefficient search. With preview, conjunction search was more efficient than without, yet, these slopes did not differ from the feature baseline, indicating that even with preview, observers were not able to utilize the given information to restrict search to less elements. Nonetheless, fixed target search was more efficient than random target search in all conditions.

The Guided Search Theory predicts that attention can be guided by efficiently searched features (Wolfe and Horowitz, 2004) with a sufficient difference in feature level (Wolfe et al., 1989; Wolfe, 1994). The target is most different from the distractors due to its possessing a unique feature (Itti and Koch, 2001). Thus, it receives the highest bottom-up activation as well as high top-down activation due to knowledge about the target (Sobel et al., 2009). In the feature conditions of experiment I, target and distractors could be differentiated by an efficiently searched form difference, whereas they all had the same color. Guidance is indicated by the ratio $^{a_{\text{fixed}}}/_{a_{\text{random}}}$. The farther below 1 this ratio is, the more efficient fixed target search is compared to random target search. The ratio was ca. 48 % in target present and 58 % in target absent trials, hinting at guidance.

In conjunction search both color and form could principally guide attention in this experiment, since both could be searched efficiently. However, results for conjunction search with two efficiently searched features varied across studies (see e.g. results of Treisman and Gelade (1980) vs. those of Wolfe et al. (1989)). Moreover, with two features able to guide search, it remains unclear which feature is prioritized and used for guidance. Thus, I predicted that no guidance should be observed in conjunction search if participants searched for a fixed target, thus meaning that the half-slope prediction $^{a}/_{a_{\text{feature}}}$ should not be fulfilled. Indeed, this is what I observed, since the slopes of the RT $\times$ Set Size function were steeper than those of feature search. Thus, conjunction search was less efficient than feature search.

Although feature search was already efficient, it was made even more efficient, if it was presented with a preview. Here, one half of the distractors was shown 2 seconds before the remaining elements. The slopes were significantly different from the feature baseline in target absent trials and were halved. This half-slope indicates that participants could effectively separate both item halves and exclude the old items from search by inhibiting their locations (Watson and Humphreys, 1997). In target present trials search was already efficient, with slopes of 6.2 (fixed target) and 12.9 (random target), so that, although the ratios indicate a reduction, there was apparently no leeway for further improvement, so that the slopes of the feature preview conditions are not completely halved in trials when a target was present.

In conjunction search no preview effect was observed, since the search rates for conjunction search did not differ from those for feature baseline search. The target item matches one half of the items in color and the other half in form. Since not only color differences, but also form differences were highly salient in experiment I, a likely reason for the failure to comply with the half-slope prediction was potential attentional capture by distractor items containing the target form. Folk et al. (1992) showed that the ability to control attentional capture depends on contingency of the singleton's features to task demands: If the singleton had a task relevant feature, it captured attention, but it did not capture attention if it did not share the target-defining feature. This supports the assumption that attentional capture of the distractor items sharing the target form occured in the conjunction search conditions of this experiment. Yet, attentional capture should be less likely to occur, if target and distractors become more similar, since these displays require scrutiny of every item one after another to differentiate target from distractors and lead to less bottom-up saliency differences.

I compared search efficiency for fixed target search to efficiency if the target varied from one trial to the next in random fashion to investigate the establishing of feature guidance. Evidence for guidance was found in feature search. Although the ratio of the conjunction baseline to the feature baseline indicates that no feature guidance could be used in conjunction search, fixed target search had an advantage compared to random target search in conjunction search, as well as all other conditions (see table 4.4). One possible explanation for this efficiency advantage is priming, which is independent of target knowledge, but manifests itself in more efficient search if features of a target are repeated (Kristjánsson et al., 2002). Since evidence for priming in conjunction search has been presented by several authors (Geyer et al., 2006; Kristjánsson et al., 2002), the efficiency advantage for fixed target search without evidence for feature guidance can be explained by repetition priming. Decreasing the search efficiency of one feature, while keeping the other feature efficient should offer better prerequisites for guidance in conjunction search. I investigated the influences of increasing form similarity on both feature guidance and the preview benefit in the following experiments.

4.4 Experiment II

4.4.1 Methods

Ethics Statement

The same procedure as in experiment I was used to fulfill ethical standards.

Sample

38 observers participated in the experiment, who had normal or corrected-to-normal visual acuity and were undergraduate students of psychology from the university of Mainz, who received course credit for participating in the experiment. Of the random target group 18 participants were female. The mean age

was 24.32 with a range of 18 to 38 years. The fixed target group had 18 female observers. Overall mean age was 22.16 years (age range 19-27).

Experimental Outline and Design

In this experiment form similarity was increased by using a smaller offset than in experiment I. Here, the vertical line of the I was shifted 19 pixels to the left, so that both stimuli were more similar than in experiment I.

Participants searched for both a fixed, known target, which did not change in the fixed target conditions, as well as randomly varying targets from trial to trial. Furthermore, set size was 8, 12 or 16 elements.

The conditions were the same as in experiment I with 23 pixels offset.

Experimental Predictions

Feature search should be more difficult in this group than with 23 pixels offset due to increased form similarity, so that the search function for feature search should be higher than with 23 pixels. Feature guidance in feature search should be less pronounced with lower search efficiency of feature search, so that the ratio $a_{\text{fixed}}/a_{\text{random}}$ should be higher than in experiment I and thus nearer 1. In conjunction search observers should be more able to use feature guidance, since the search efficiencies of color and form should differ. For preview search the ratios of preview to feature baseline condition should be higher than in experiment I.

Apparatus and Stimuli

Apparatus and stimuli were the same as in experiment I except for the following change: Offset from the letter I to the left was 19 pixels, so that the C and I became more similar than in experiment I.

Procedure

The procedure was the same as in experiment I, except that one group of participants performed the conditions for random target search, whereas another group performed the fixed target search conditions. Stimuli examples are shown in figures 4.1 and 4.2, the trial sequences were the same as those depicted in figures 4.3 and 4.4.

Data analysis

Data was analyzed in the same way as the data from experiment I, except for the following change: Since different participants performed the random and fixed target search conditions, Target Type was entered as a grouping factor into the omnibus ANOVA.

4.4.2 Results of experiment II

Accuracy

I analyzed accuracy with a repeated measurements ANOVA with Target Type as grouping factor. Accuracy was modulated by Target Type ($F(1,36) = 6.98, p < 0.05$), Condition ($F(3,108) = 7.97, p < 0.001$), Set Size ($F(2,72) = 25.9, p < 0.001$) and Trial Type ($F(1,36) = 138.86, p < 0.001$).

Furthermore, these factors also interacted: Target Type interacted with Trial Type (Trial Type $\times$ Target Type ($F(1,36) = 8.74, p < 0.05$), indicating that while accuracy was equal for both target types in target absent trials, it was lower for random than fixed target search in target present trials.

Furthermore, the significant interaction of Set Size $\times$ Target Type ($F(2,72) = 6.2, p < 0.05$) indicates that accuracy decreased more with increasing set size if participants searched for a random target than if they searched for a fixed target.

Table 4.5: Mean percentage accuracy rates for experiment II.

			Target present			Target absent		
Target	Search	Preview	8	12	16	8	12	16
Random	Feat.	No	0.94	0.94	0.89	0.99	0.99	0.98
Random	Feat.	Prev	0.96	0.91	0.86	0.98	1.00	0.99
Random	Conj.	No	0.92	0.91	0.86	0.96	0.95	0.95
Random	Conj.	Prev	0.96	0.94	0.91	0.99	0.97	0.97
Fixed	Feat.	No	0.95	0.97	0.94	0.98	0.99	1.00
Fixed	Feat.	Prev	0.96	0.94	0.90	0.96	0.99	0.99
Fixed	Conj.	No	0.96	0.94	0.93	0.98	0.99	0.96
Fixed	Conj.	Prev	0.96	0.96	0.95	0.99	0.99	0.98

Moreover, there were significant two-way interactions of Condition $\times$ Trial Type ($F(3,108) = 3.55, p < 0.05$) and Set Size $\times$ Trial Type ($F(2,72) =$

$24.51, p < 0.001$), yet, for interpreting these interactions one has to keep in mind the significant three-way interaction of Condition × Set Size × Trial Type ($F(6, 216) = 3.6, p < 0.05$): Accuracy was higher in target absent than target present trials and decreased with increasing set size. This decrease was more distinctive in target present than absent trials and especially for the feature preview condition.

Reaction Times

Reaction times were influenced by Target Type ($F(1, 36) = 46.31, p < 0.001$), Condition ($F(3, 108) = 154.84, p < 0.001$), Set Size ($F(2, 72) = 309.24, p < 0.001$) and Trial Type ($F(1, 36) = 187.46, p < 0.001$).

Furthermore, the factors Condition, Target Type and Set Size also interacted, since there were significant interactions of Condition × Target Type ($F(3, 108) = 88.11, p < 0.001$), Set Size × Target Type ($F(2, 72) = 27.56, p < 0.001$) and Condition × Set Size ($F(6, 216) = 42.22, p < 0.001$) . Yet, these can be explained by the significant three-way interaction of Condition × Set Size × Target Type ($F(6, 216) = 8.17, p < 0.001$): Reaction times increased with increasing set size and this increase was higher for random than fixed target search and while it was about equal for all conditions for the fixed target group, for the random target group reaction times increased most for the conjunction baseline condition.

Furthermore, the factors Condition and Trial Type interacted (Condition × Trial Type ($F(3, 108) = 19.58, p < 0.001$), yet one has to take into consideration the significant three-way interaction of Condition × Trial Type × Target Type ($F(3, 108) = 4.4, p < 0.05$) to explain this: Reaction times were shorter in target present than target absent trials and conjunction baseline search had higher reaction times than the other conditions in random than fixed target search. Moreover, while the difference between both trial types was about equal for all conditions in fixed target search, it was larger for the conjunction baseline condition than the other conditions in random target search.

Other significant interactions were Set Size × Trial Type ($F(2, 72) = 107.74$, $p < 0.001$) and Set Size × Trial Type × Target Type ($F(2, 72) = 13.13, p < 0.001$): In target absent trials reaction times increased more with increasing set size than in target present trials and this was more pronounced for random than fixed target search. Last but not least, the significant three-way interaction of Condition × Set Size × Trial Type ($F(6, 216) = 8.12, p < 0.001$) signifies that the higher increase in reaction times with increasing set size in target absent compared to target present trials was most pronounced for the conjunction baseline condition.

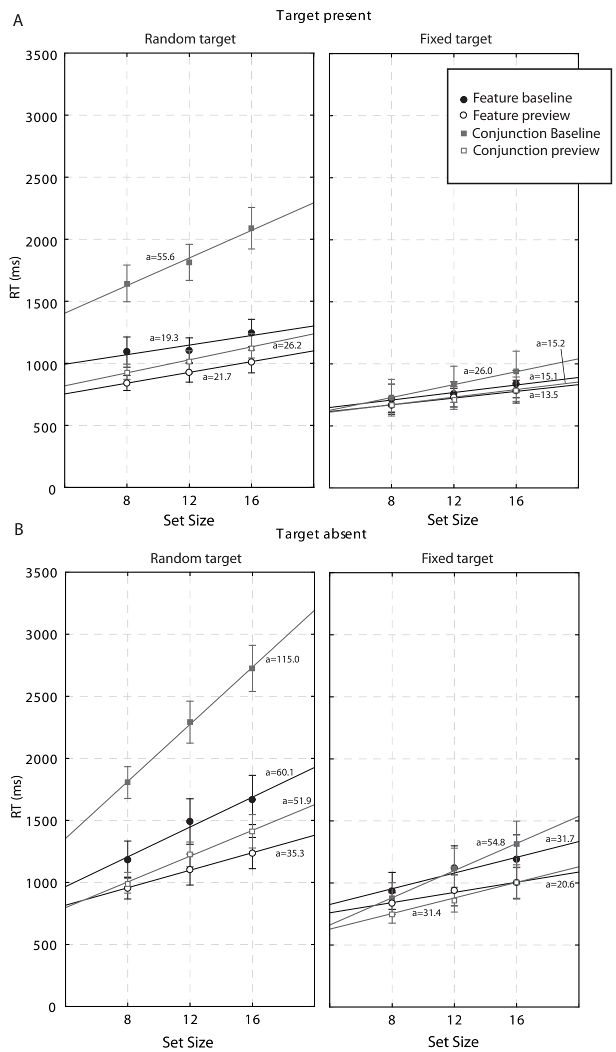


Figure 4.6: Mean correct reaction times for experiment II, as a function of set size for all conditions for target present (A) and target absent trials (B). Filled symbols indicate baseline conditions, while open symbols indicate preview conditions. The error bars indicate the average 95 % confidence intervals of the means for all mean reaction times. The slopes of the RT × Set Size functions, a, are also presented.

I also took the slopes of the Reaction Time × Set Size function into consideration, since the omnibus ANOVA shows only mean differences.

First of all, for the random target group, the search function was steeper than in experiment I, showing that feature search was more difficult than in experiment I, so that the experimental manipulation of changing the offset was successful.

Table 4.6: Slope estimates for the search functions obtained in experiment II. The table lists the slope estimates (search rates), a, and the slope ratios of each preview condition with the feature search baseline, q_p. The last column shows the slope ratios of target present and absent trials, q_t. All ratios are listed as percent (%) values.

			Target present		Target absent		
Target	Search	Preview	a	q_p	a	q_p	q_t
Random	Feat.	No	19.3		60.1		32.1
Random	Feat.	Prev	21.7	112.7	35.3	58.8	61.6
Random	Conj.	No	55.6	288.3	115.0	191.5	48.4
Random	Conj.	Prev	26.2	135.8	51.9	86.4	50.5
Fixed	Feat.	No	15.1		31.7		47.7
Fixed	Feat.	Prev	13.5	89.6	20.6	64.9	65.9
Fixed	Conj.	No	26.0	171.7	54.8	172.8	47.4
Fixed	Conj.	Prev	15.2	100.5	31.4	99.1	48.4

With the Condition × Set Size interaction I evaluated whether the slopes of the other conditions differed significantly from the slope of the feature baseline and also computed the ratios a/a_{feature}.

As can be seen in table 4.6, the slope was nearly halved for the feature preview condition in target absent trials, which was substantiated by a significant value of the F-test ($F(2, 36) = 14.85, p < 0.001$), while the slopes were parallel in target present trials ($F(2, 36) = 1.00, p = 0.377$).

Conjunction search was less efficient than feature search, since the slopes were not parallel to the feature baseline slopes and ratios ranged from 191% (target absent trials, $F(2, 36) = 25.46, p < 0.001$) to 288% (target present trials, $F(2, 36) = 14.15, p < 0.001$).

The slopes for the conjunction preview conditions were not significantly different from the feature baseline slopes, both in target present and target absent trials (target present: $F(2, 36) = 0.88, p = 0.422$, target absent: $F(2, 36) = 1.25, p = 0.300$).

I also analyzed with the ratio $a_{\text{conjprev}}/a_{\text{conjbase}}$ whether conjunction preview search was more efficient than conjunction baseline search and indeed this was the case: For both trial types the slopes of the conjunction preview condition were halved compared to the conjunction baseline condition and this was supported by significant Condition × Set Size interactions (see table 4.7).

Table 4.7: Ratios of search rates for the conjunction preview condition against the conjunction baseline condition. The table shows the slope ratios, q_x, as percent values, as well as F- ratio and p- value for testing the corresponding Condition × Set Size interaction. The F- tests have 2 denominator and 36 nominator degrees of freedom.

	Target present			Target absent		
Target	q_x	F	p	q_x	F	p
Random	47.1	17.08	< 0.001	45.1	21.06	< 0.001
Fixed	58.5	10.13	< 0.001	57.4	29.15	< 0.001

For the fixed target group the slopes of the Reaction Time × Set Size function for the feature baseline were higher than in experiment I, again indicating higher task difficulty (see table 4.6). Slopes for the feature preview condition were nearly halved compared to the baseline condition in target absent trials and the Condition × Set Size interaction was significant ($F(2, 36) = 3.54, p < 0.05$). In target present trials the slope was not significantly different from the feature baseline search rate ($F(2, 36) = 1.01, p = 0.375$).

As for random target search the conjunction baseline search rates were significantly different from the feature baseline search rates in both trial types, since the ratio was ca. 172% in both trial types (target present: $F(2, 36) = 8.85, p < 0.001$, target absent: $F(2, 36) = 14.99, p < 0.001$).

The search rate of conjunction preview search differed significantly from the feature baseline search rate in target absent ($F(2, 36) = 3.53, p < 0.05$), but not target present trials ($F(2, 36) = 0.16, p = 0.857$). The ratio $a_{\text{conjprev}}/a_{\text{conjbase}}$ showed again a ratio of nearly .5 and the F-test showed significant results for both trial types, so that conjunction preview search was more efficient than conjunction baseline search (see table 4.7).

To evaluate whether target knowledge (fixed target group) had an efficiency advantage against random target search, I investigated the Set Size × Target Type interaction for all conditions and computed the ratios $a_{\text{fixed}}/a_{\text{random}}$. A significant result would indicate that the search rates for the same condition were not parallel for both target types. Results are presented in table 4.8. For the feature baseline the slope of fixed target search differed significantly from that of random target search in target absent trials and the slope ratio was about .5. In target present trials the slopes were parallel. Slopes were nearly halved for the feature preview condition, yet the F-test only showed a significant result in target absent trials. Fixed target search was more efficient than random target search for the conjunction baseline, since the slopes were halved and the Condition × Set Size interactions were significant for both trial types. Last but not least, the search rates for the conjunction preview condition nearly reached the half-slope prediction, a significant Condition × Set Size interaction was however only found in target absent trials (see table 4.8).

Table 4.8: Ratios of search rates for search with a fixed target compared to search with a random target of experiment II. The table shows the slope ratios, q_s, as percent values, as well as F- ratio and p- value for testing the corresponding Set Size × Target Type interaction. The F- tests have 2 denominator and 72 nominator degrees of freedom.

		Target present			Target absent		
Search	Preview	q_s	F	p	q_s	F	p
Feat.	No	78.4	1.19	0.309	52.8	9.71	< 0.001
Conj.	No	46.7	14.7	< 0.001	47.6	33.17	< 0.001
Feat.	Prev	62.3	1.79	0.174	58.3	3.34	< 0.05
Conj.	Prev	58.0	2.56	0.084	60.6	4.9	< 0.05

4.4.3 Discussion of experiment II

In experiment II the vertical bar of the I was moved by 19 pixels in direction of a C, thus creating more similar stimuli than in experiment I. Feature baseline search was less efficient than in experiment I, since the slopes of the RT × Set Size function were steeper in experiment II. Target present to absent ratios of 1:2 in all conditions except the feature preview condition for both target types indicated serial self-terminated search. In feature preview search slopes were nearly halved in target absent trials, whereas slopes in conjunction preview search compared to the feature baseline. Conjunction baseline search was less efficient than in experiment I and also more difficult than feature search. For all conditions, fixed target search showed a search advantage compared to random target search.

Feature search rates were higher in experiment II than in experiment I. Since the bar was only moved 19 and not 23 pixels from the I to the C stimulus, this indicates that feature search was more difficult for participants since stimulus discrimination was harder and search becomes less efficient if distractors and target become more similar (Duncan and Humphreys, 1989). Since form search became less efficient, feature guidance should be observed in a smaller degree in feature search, indicated by a higher ratio of fixed to random target search than in experiment I. This could be clearly observed in target present trials, whereas the ratio was, although only slightly, smaller than in experiment I for target absent trials.

In conjunction search for a fixed target increasing form search similarity should make observers more likely to use feature guidance to facilitate their search, since the search efficiencies of color and form differed. Yet, although the ratio of conjunction to feature search was smaller than in experiment I, conjunction search clearly was still less efficient than feature search, since the ratios were ca. 1.7. Thus, color guidance was apparently hindered from getting effective.

With more difficult feature search the preview benefit should be reduced in feature search, since memory capacity is limited (Jiang and Wang, 2004) and it should be harder for observers to remember all positions correctly. Nevertheless, search rates for the feature preview conditions were nearly halved in target absent trials, which shows that observers could use the temporal asynchrony as well as the location information provided by the preview to search through less items (Jiang et al., 2002b; Watson and Humphreys, 1997). In target present trials, however, no half-slopes were found. This, as well as the observation that the half-slope prediction was not completely fulfilled in target absent trials, shows, that this mechanism did not work perfectly, so that assumedly some old items were rechecked by the observers due to the higher demands on memory.

Memory restrictions should have less influence on the preview benefit in conjunction search, since old and new items can still be told apart due to their different colors if all items have entered the search display. However, the target shares a salient feature, namely its form, with the distractors of the alternative color. Several studies showed evidence for attentional capture by salient stimuli (Folk et al., 1992; Kim and Cave, 1999; Lamy and Zoaris, 2009; Theeuwes, 1992, 2004). Such attentional capture could hinder the preview benefit in conjunction search. Yet, the slope ratios of conjunction preview to feature search are overall reduced compared to experiment I. This indicates that, although the preview could apparently not yet be used to search only through half of all items, potential capture effected conjunction preview search less than in experiment I, which is likely due to the decreased saliency of the feature form.

As in experiment I the ratio $a_{\text{fixed}}/a_{\text{random}}$ was less than 1 in all conditions. This search advantage can be explained by feature guidance in feature search. In conjunction search repetition priming could have facilitated fixed target search.

4.5 Experiment III

4.5.1 Methods

Ethics Statement

The same measures as in the previous experiments were used to fulfill ethical standards.

Sample

Participants were 20 undergraduate students of psychology from the university of Mainz. All had normal or corrected-to normal visual acuity and received course credit for participation. 15 participants were female, 5 male. Overall mean age was 22.79 (age range 18-28).

Experimental Outline and Design

Form similarity was further increased compared to experiments I and II by decreasing the offset of the vertical bar of the letter I to 15 pixels. Participants executed both random and fixed target search conditions and, as before, set sizes could vary between 8, 12 or 16 elements. The same conditions as in experiments I and II were performed.

Experimental Predictions

Due to the higher similarity of both forms, feature search should be less efficient than with offset 19 pixels. Moreover, due to less form search efficiency, feature guidance should develop less in feature search, but more in conjunction search. This means that the ratio $a_{\text{fixed}}/a_{\text{random}}$ for feature search should be higher than in experiments I and II, the ratio of conjunction baseline to feature baseline search for fixed target search should come nearer 0.5. Moreover, the preview benefit should be less pronounced due to increased task difficulty.

Apparatus and Stimuli

The same apparatus and stimuli were used in experiment III as in experiments I and II except for the following changes: The vertical line of the I was offset 15 pixels to the left, so that the letters C and I were more similar than in the experiments before.

Procedure

The procedure was the same as in experiment I. Stimuli examples are presented in figures 4.1 and 4.2. Examples for both baseline and preview trials are shown in figures 4.3 and 4.4.

Data analysis

All data was analyzed in the same way as in experiment I.

4.5.2 Results of experiment III

Accuracy

Accuracy depended on Target ($F(1, 19) = 22.11, p < 0.001$), Set Size ($F(2, 38) = 37.79, p < 0.001$) and Trial Type ($F(1, 19) = 129.54, p < 0.001$) and these factors also interacted: Target interacted with Condition (Target × Condition ($F(3, 57) = 9.5, p < 0.001$)) and Trial Type (Target × Trial Type ($F(1, 19) = 28.65, p < 0.001$); Target × Condition × Trial Type ($F(3, 57) = 4.39, p < 0.05$). This means that while accuracy was overall equal for fixed and random target search in target absent trials, it was lower for random target search than fixed target search in target present trials. The biggest difference between accuracy in both trial types for random target search was observed in the feature preview condition.

The interactions of Condition × Trial Type ($F(3, 57) = 3.8, p < 0.05$), Set Size × Trial Type ($F(2, 38) = 38.66, p < 0.001$) as well as the three-way interaction Condition × Set Size × Trial Type ($F(6, 114) = 2.58, p < 0.05$) were also shown to be significant: Overall, accuracy is higher in trials where no target was present compared to trials when a target was present. In target absent trials accuracy is overall equal for the three set sizes, while accuracy decreases with increasing set size in target present trials. The decrease of accuracy with increasing set size in target present trials is different for the conditions, it is most pronounced for the feature preview condition (see table 4.9).

Table 4.9: Mean percentage accuracy rates for experiment III.

			Target present			Target absent		
Target	Search	Preview	8	12	16	8	12	16
Random	Feat.	No	0.89	0.88	0.86	0.99	0.98	0.99
Random	Feat.	Prev	0.96	0.89	0.82	0.98	0.99	0.98
Random	Conj.	No	0.91	0.89	0.85	0.98	0.96	0.96
Random	Conj.	Prev	0.94	0.95	0.91	0.98	0.99	0.98
Fixed	Feat.	No	0.96	0.94	0.88	0.99	0.99	0.99
Fixed	Feat.	Prev	0.98	0.94	0.88	0.98	0.98	0.97
Fixed	Conj.	No	0.97	0.96	0.91	0.99	0.99	0.98
Fixed	Conj.	Prev	0.93	0.93	0.89	0.99	0.98	0.98

Reaction Times

Results are depicted in figure 4.7. In the ANOVA, the main effects of Target ($F(1, 19) = 58.86, p < 0.001$), Condition ($F(3, 57) = 75.46, p < 0.001$), Set Size ($F(2, 38) = 256.55, p < 0.001$) and Trial Type ($F(1, 19) = 123.69, p < 0.001$) became significant. Yet, the results can only be explained by looking at the observed significant interactions and one has to bear in mind that the four-way interaction of Target × Condition × Set Size × Trial Type ($F(6, 114) = 5.46, p < 0.001$) was also significant.

The factor Target showed interactions with Condition (Target × Condition ($F(3, 57) = 71.19, p < 0.001$) and Set Size (Target × Set Size (F$(2, 38) = 15.03, p < 0.001$); Target × Condition × Set Size ($F(6, 114) = 24.34, p < 0.001$)): Reaction times are higher for random than fixed target search and they increase with increasing set size. This increase is higher for random target search and here especially for the conjunction baseline, while the increase is equal for all conditions in fixed target search.

Furthermore, there were significant interactions of Condition × Set Size ($F(6, 114) = 25.7, p < 0.001$), Condition × Trial Type ($F(3, 57) = 36.09, p < 0.001$), Set Size × Trial Type ($F(2, 38) = 92.66, p < 0.001$) as well as Condition × Set Size × Trial Type ($F(6, 114) = 8.25, p < 0.001$): The increase of reaction times with increasing set size was higher for target absent than target present trials and this increase was highest for the conjunction baseline.

The three-way interaction Target × Condition × Trial Type ($F(3, 57) = 35.07, p < 0.001$) was significant, yet, like all effects and interactions this can

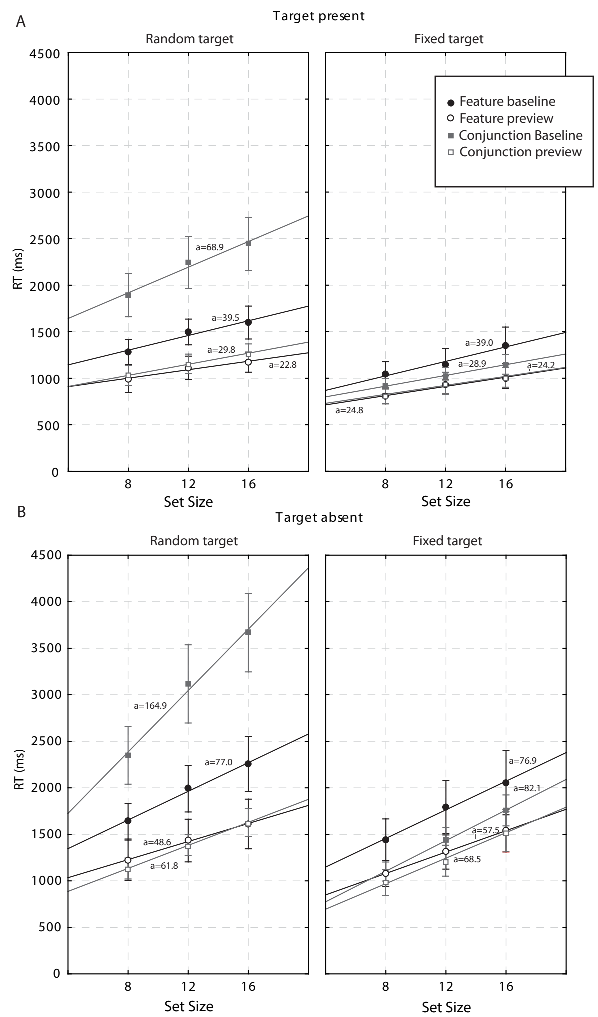


Figure 4.7: Mean correct reaction times for experiment III, as a function of set size for all conditions for target present (A) and target absent trials (B). Filled symbols indicate baseline conditions, while open symbols indicate preview conditions. The error bars indicate the average 95 % confidence intervals of the means for all mean reaction times. The slopes of the RT × Set Size functions, a, are also presented.

be explained by the aforementioned significant four-way interaction of Target × Condition × Set Size × Trial Type ($F(6, 114) = 5.46, p < 0.001$): For both targets reaction times increase with increasing set size and are higher for target absent than target present trials. For fixed target search both the increase in reaction times with increasing set size and the difference between target absent and present trials are smaller than for random target search. The highest increase is observed for the feature baseline for this target. For random target search reaction times are overall higher, increase more with increasing set size and show a bigger difference between both trial types. Last but not least, reaction times increase most for the conjunction baseline condition, if participants search for a random target.

The omnibus ANOVA does not reveal if the slopes of different conditions are parallel, so I analyzed this with the Condition × Set Size interactions. As can be seen in the last column of table 4.10, all slopes agree well with a 1:2 ratio of target present to target absent trials, which indicates that search for all conditions was serial and self-terminated.

Table 4.10: Slope estimates for the search functions obtained in experiment III. The table lists the slope estimates (search rates), a and the slope ratios of each preview condition with the feature search baseline, q_p. The last column shows the slope ratios of target present and absent trials, q_t. All ratios are listed as percent (%) values.

			Target present		Target absent		
Target	Search	Preview	a	q_p	a	q_p	q_t
Random	Feat.	No	39.5		77.0		51.3
Random	Feat.	Prev	22.8	57.7	48.6	63.1	46.9
Random	Conj.	No	68.9	174.7	164.9	214.1	41.8
Random	Conj.	Prev	29.8	75.4	61.8	80.3	48.2
Fixed	Feat.	No	39.0		76.9		50.7
Fixed	Feat.	Prev	24.8	63.7	57.5	74.8	43.2
Fixed	Conj.	No	28.9	74.1	82.1	106.8	35.2
Fixed	Conj.	Prev	24.2	62.0	68.5	89.1	35.3

For random target search a preview benefit was observed for feature, but not conjunction search. Slopes of the feature preview condition differed significantly from the feature baseline in both trial types and were nearly halved (see table 4.10, target present: $F(2, 38) = 3.69, p < 0.05$, target absent: $F(2, 38) = 4.74, p < 0.05$).

For the conjunction preview condition slopes were reduced in comparison to the feature baseline, but they were not halved and the results of the F-test also showed no significant results (target present: $F(2, 38) = 1.69, p = 0.199$, target absent: $F(2, 38) = 2.55, p = 0.092$).

The slopes of the Reaction Time × Set Size function of the conjunction baseline were not parallel to the slopes of the feature baseline and the ratios were ca. 175% (target present trials, $F(2, 38) = 6.38, p < 0.01$) and 214% (target absent trials, $F(2, 38) = 40.79, p < 0.001$), indicating the high difficulty of conjunction search.

I also computed the ratio of the conjunction preview condition against the conjunction baseline and tested for parallelism. As can be seen in table 4.11, slopes of the conjunction preview condition were halved compared to the conjunction baseline in both trial types and this was substantiated by significant results of the F-test. Thus, conjunction preview search had an advantage compared to baseline search.

A preview benefit for feature search was also found if participants searched for a fixed target (see table 4.10): Slopes were reduced in comparison to the feature baseline and, although not reaching the ideal of .5 assumed by the half-slope prediction of visual marking, the F-test showed significant deviations from parallelism (target present: $F(2, 38) = 7.98, p < 0.01$, target absent: $F(2, 38) = 5.72, p < 0.01$).

For the conjunction preview condition the half-slope prediction was failed in target absent trials, which also showed no deviation from parallelism ($F(2, 38) = 3.24, p = 0.050$), while the ratio was .62 in target present trials and the slopes were significantly different ($F(2, 38) = 7.33, p < 0.01$).

The slopes for the search function of the conjunction baseline showed no significant deviations from parallelism in comparison to the feature baseline in both trial types (target present: $F(2, 38) = 1.92, p = 0.160$, target absent: $F(2, 38) = 0.54, p = 0.587$). In target absent trials the slope was only slightly steeper than that of the feature baseline, while it was shallower in target present trials (see table 4.10).

As presented in table 4.11, the ratio $a_{\text{conjprev}}/a_{\text{conjbase}}$ was lower than 1, so that slopes of the conjunction preview condition were shallower than for the conjunction baseline condition, but the F-test only showed a significant result in target absent trials.

I also compared search rates for fixed and random target search and ratios as well as the results of the F-test are presented in table 4.12. The only significant deviations were observed for the conjunction baseline conditions and ratios were below .5, showing that the slopes for fixed target search were halved compared to random target search. For the other conditions the F-tests showed no significant differences of the slopes.

Table 4.11: Ratios of search rates for the conjunction preview condition against the conjunction baseline condition. The table shows the slope ratios, q_x, as percent values, as well as F- ratio and p- value for testing the corresponding Condition × Set Size interaction. The F- tests have 2 denominator and 38 nominator degrees of freedom.

	Target present			Target absent		
Target	q_x	F	p	q_x	F	p
Random	43.2	10.16	< 0.001	37.5	83.41	< 0.001
Fixed	83.7	0.98	0.384	83.4	6.47	< 0.01

Table 4.12: Ratios of search rates for search with a fixed target compared to search with a random target of experiment III. The table shows the slope ratios, q_s, as percent values, as well as F- ratio and p- value for testing the corresponding Condition × Set Size interaction. The F- tests have 2 denominator and 38 nominator degrees of freedom.

		Target present			Target absent		
Search	Preview	q_s	F	p	q_s	F	p
Feat.	No	98.7	3.05	0.059	99.8	0.00	0.999
Conj.	No	41.9	13.28	< 0.001	49.8	64.16	< 0.001
Feat.	Prev	109.1	0.08	0.927	118.4	0.97	0.387
Conj.	Prev	81.1	1.32	0.278	110.8	1.92	0.160

4.5.3 Discussion of experiment III

In experiment III the bar from I to C was offset by 15 pixels and feature search was less efficient than in experiment II. Ratios of target present to absent trials agreed with the prediction of a 1:2 ratio, indicating serial self-terminated search in all conditions. No evidence for guidance was found in feature search and, although the search rate was reduced for target present trials of the conjunction baseline for fixed target search, the half-slope prediction was not fulfilled. A preview effect was observed for feature search, since the slopes of the feature preview conditions were nearly halved. For conjunction preview search slopes were nearly halved in target present and reduced in target absent trials.

Reaction times increase with increased target-distractor similarity (Duncan and Humphreys, 1989), which explains why feature search rates were higher in experiment III than in experiments I and II. It was more difficult for participants to discriminate both types of stimuli, so that the target did not pop out from its surrounding context, as would be expected if the target differs from the distractors in a unique feature (Itti and Koch, 2001). Rather, observers had to scan every element one by one to evaluate whether it was the target or not.

Due to less form search efficiency no guidance should be possible in feature search. Indeed this is what I observed, since the ratios $a_{\text{fixed}}/a_{\text{random}}$ were near 100 %. Thus, fixed target search had no efficiency advantage over random target search in the feature baseline and also feature preview condition.

Concerning guidance in the conjunction baseline of fixed target search, the slope of the RT $\times$ Set Size function was reduced in target present trials, but not yet halved. In target absent trials no reduction was observed. This hints that form search was not yet inefficient enough to induce full color guidance.

For feature search I anticipated a reduced preview benefit due to higher memory demands in search which takes more time. The ratios a/a_{feature} were, in target absent trials, higher than in experiment II, yet, slopes are still nearly halved, also in target present trials. This hints that, although observers apparently recheck some items, they can still reduce the number of elements to sift through to a large extent.

In conjunction preview search slopes of the RT $\times$ Set Size functions were reduced, but not halved. Thus, the preview facilitates search by reducing the part of the search display, which has to be investigated, but this works apparently not to full extent, so that a bit more than half of all items are searched. Yet the ratios of conjunction preview to feature search are clearly smaller than in experiment II, indicating that due to lower form search efficiency, a probable negative effect of salient form stimuli can be reduced in contrast to the earlier experiments.

It seems important to note that with more similar stimuli, the efficiency advantage of fixed to random target search, which was observed in experiments I and II, vanishes for all conditions except the conjunction baseline. This could still be either due to priming or to a building up effect of feature guidance. Apparently, the similarity between the stimuli was not yet large enough to fully bring observers to use color to guide their search, thus hindering the establishing of complete feature guidance. However, with even more similar form stimuli, the difference in efficiency for color and form should be sufficient to establish color guidance. This is investigated in the following experiment.

4.6 Experiment IV

4.6.1 Methods

Ethics Statement

The same measures as in the previous experiments were taken to comply with the ethical standards.

Sample

The sample consisted of 20 undergraduate students of psychology from the university of Mainz, who received course credit for participating in the experiment. The mean age was 23.2 with a range of 20-30 years. 15 were female observers. All participants in the experiment had normal or corrected-to-normal visual acuity.

Experimental Outline and Design

By decreasing the offset from I to C to 10 pixels both letters became most similar in this experiment compared to the three experiments before. Both fixed and random target conditions again used search displays which appeared with either 8,12 or 16 elements. Again, I used the same conditions as in experiments I, II and III.

Experimental Predictions

Feature search should be most difficult in this experiment, since both forms are most similar. Full color guidance should be possible in the conjunction baseline with fixed target, because the search efficiencies of the features form and color should be most different in this group, thus providing the best prerequisite for color guidance. Moreover, the ratio $a_{\text{fixed}}/a_{\text{random}}$ should be nearer 1 than in the experiments I to III, since feature guidance by form should not be possible in this experiment due to low form search efficiency. Furthermore, the preview benefit should be reduced due to memory fading with large reaction times.

Apparatus and Stimuli

I used the same apparatus and stimuli as in experiments I, II and III. The following difference was made: Offset of the vertical line of the letter stimulus I to the left was 10 pixels, thus leading to the greatest similarity of both stimuli in the four experiments.

Procedure

Procedure was not varied from the other experiments and thus remained the same as in experiments I and III. As for the other experiments, stimuli examples can be gathered from figures 4.1 and 4.2 and trial examples from figures 4.3 and 4.4.

Data analysis

I analyzed all data in the same way as in experiments I and III.

4.6.2 Results of experiment IV

Accuracy

As presented in table 4.13, accuracy in the experiment was overall high. Testing with an ANOVA revealed that accuracy was modulated by Target Type ($F(1, 19) = 15.88, p < 0.001$), which indicates that participants made more errors if they searched for a randomly varying target compared to a fixed target. Furthermore, percent correct were also influenced by Condition ($F(3, 57) = 13.76, p < 0.001$), Set Size ($F(2, 38) = 61.65, p < 0.001$) and Trial Type ($F(1, 19) = 73.69, p < 0.001$). These factors also interacted, since there were significant two-way interactions of Condition × Set Size ($F(6, 114) = 5.2, p < 0.001$), Condition × Trial Type ($F(3, 57) = 12.57, p < 0.001$) and Set Size × Trial Type ($F(2, 38) = 36.12, p < 0.001$) as well as the significant three-way interaction Condition × Set Size × Trial Type ($F(6, 114) = 3.99, p < 0.05$). Accuracy is lower in target present than target absent trials. It decreases overall with increasing set size in target present, but not target absent trials. This decrease in accuracy with increasing set size in target present trials is most pronounced for the feature preview condition.

Table 4.13: Mean percentage accuracy rates for experiment IV.

			Target present			Target absent		
Target	Search	Preview	8	12	16	8	12	16
Random	Feat.	No	0.85	0.78	0.74	0.96	0.95	0.93
Random	Feat.	Prev	0.88	0.79	0.69	0.96	0.93	0.95
Random	Conj.	No	0.86	0.83	0.81	0.95	0.94	0.93
Random	Conj.	Prev	0.89	0.90	0.81	0.94	0.95	0.97
Fixed	Feat.	No	0.88	0.84	0.78	1.00	0.99	0.98
Fixed	Feat.	Prev	0.91	0.81	0.76	0.98	0.98	0.98
Fixed	Conj.	No	0.90	0.91	0.86	1.00	0.99	0.98
Fixed	Conj.	Prev	0.94	0.93	0.90	0.98	0.99	0.99

Reaction Times

Mean correct reaction times are shown in figure 4.8. The omnibus ANOVA showed that reaction times were influenced by Target Type ($F(1,19) = 25.20, p < 0.001$), Condition ($F(3,57) = 142.22, p < 0.001$), Set Size ($F(2,38) = 171.13, p < 0.001$) and Trial Type ($F(1,19) = 90.67, p < 0.001$). Yet, these factors also interacted and results must be evaluated by considering the significant four-way interaction of Target Type × Condition × Set Size × Trial Type ($F(6,114) = 3.24, p < 0.05$).

There were significant interactions of Target Type × Condition ($F(3,57) = 92.02, p < 0.001$) as well as Target Type × Condition × Set Size ($F(6,114) = 11.31, p < 0.001$): Reaction times increased with increasing set size and this increase was the same for fixed and random target search for all conditions except the conjunction baseline, for which reaction times increased more for search for a random target than for a fixed target.

There was also a significant interaction of Condition × Trial Type ($F(3,57) = 38.86, p < 0.001$) as well as Target Type × Condition × Trial Type ($F(3,57) = 29.79, p < 0.001$). Reaction times were higher in target absent than target present trials and while the difference between both trial types was highest for the feature baseline in fixed target search, it was highest for the conjunction baseline in random target search.

Other significant interactions were Condition × Set Size ($F(6,114) = 10.97, p$ < 0.001), Set Size × Trial Type ($F(2,38) = 61.53, p < 0.001$) and Condition ×

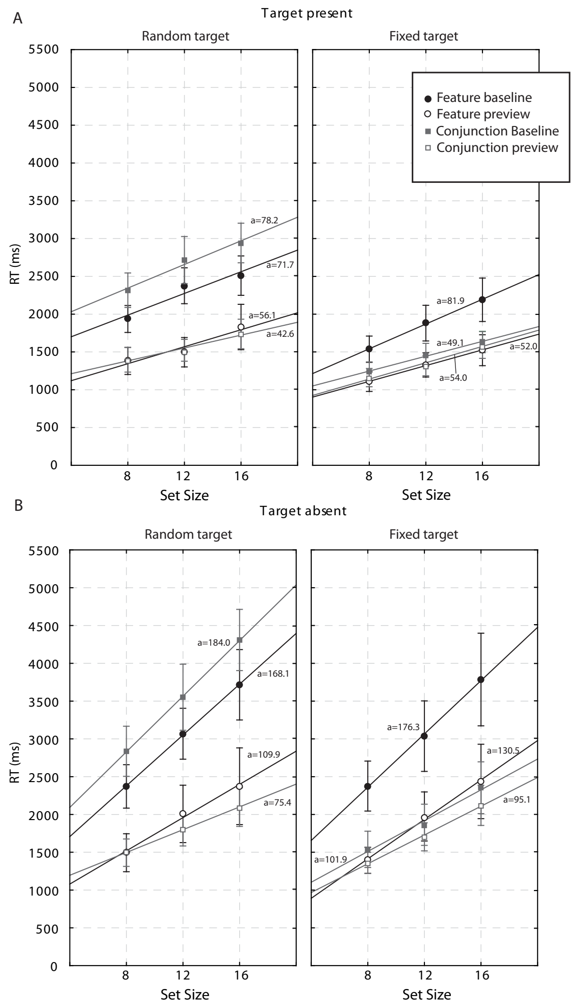


Figure 4.8: Mean correct reaction times for experiment IV, as a function of set size for all conditions for target present (A) and target absent trials (B). Filled symbols indicate baseline conditions, while open symbols indicate preview conditions. The error bars indicate the average 95 % confidence intervals of the means for all mean reaction times. The slopes of the RT × Set Size functions, a, are also presented.

Set Size × Trial Type ($F(6, 114) = 7.12, p < 0.001$), indicating that reaction times increased more with increasing set size in target absent than target present trials, especially for the feature and conjunction baseline.

Yet, as the aforementioned four-way interaction of Target Type × Condition × Set Size × Trial Type ($F(6, 114) = 3.24, p < 0.05$) was shown to be significant, this differs for both trial types: While the conjunction baseline shows the highest reaction times and increase for random target search, the feature baseline takes this part for fixed target search.

I also analyzed the Condition × Set Size interactions of the search rates of all conditions and the feature baseline, since the omnibus ANOVA shows only mean differences and not whether the slopes show deviations from parallelism. I also computed the ratios $a_{\text{conjprev}}/a_{\text{conjbase}}$ and $a_{\text{fixed}}/a_{\text{random}}$ as well as the matching significance tests to evaluate whether the slopes were parallel.

Table 4.14: Slope estimates for the search functions obtained in experiment IV. The table lists the slope estimates (search rates), a, and the slope ratios of each preview condition with the feature search baseline, q_p. The last column shows the slope ratios of target present and absent trials, q_t. All ratios are listed as percent (%) values.

			Target present		Target absent		
Target	Search	Preview	a	q_p	a	q_p	q_t
Random	Feat.	No	71.7		168.1		42.7
Random	Feat.	Prev	56.1	78.3	109.9	65.4	51.1
Random	Conj.	No	78.2	109.0	184.0	109.5	42.5
Random	Conj.	Prev	42.6	59.4	75.4	44.9	56.5
Fixed	Feat.	No	81.9		176.3		46.4
Fixed	Feat.	Prev	52.0	63.6	130.5	74.0	39.9
Fixed	Conj.	No	49.1	60.0	101.9	57.8	48.2
Fixed	Conj.	Prev	54.0	66.0	95.1	54.0	56.8

As shown in table 4.14, search functions for feature search were higher than in experiment III, both for random and fixed target search, which indicates that the manipulation of offset to achieve higher task difficulty was successful. Overall, ratios agree with a prediction of 1:2 of target present to absent trials, so that serial self-terminated search can be assumed.

For random target search slopes of the feature preview condition were reduced to 78% (target presence) and 65% (target absence) and both results were significant in the F-test (target present: $F(2, 38) = 5.02, p < 0.05$, target absent:

$F(2, 38) = 11.06, p < 0.001$, see table 4.14).

Conjunction baseline search slopes were not significantly different from the feature baseline search slopes (target present: $F(2, 38) = 0.29, p = 0.750$, target absent: $F(2, 38) = 0.53, p = 0.592$).

In contrast to this slopes were halved (target absent trials) or nearly halved (target present trials) for the conjunction preview condition compared to the feature baseline and this was substantiated by significant deviations from parallelism in both trial types (target present: $F(2, 38) = 6.30, p < 0.01$, target absent: $F(2, 38) = 30.33, p < 0.001$).

Conjunction preview search was also more efficient than conjunction baseline search, since the ratios $^{a_{\text{conjprev}}}/_{a_{\text{conjbase}}}$ lay between .41 to .54 (see table 4.15).

Table 4.15: Ratios of search rates for the conjunction preview condition against the conjunction baseline condition. The table shows the slope ratios, q_x, as percent values, as well as F- ratio and p- value for testing the corresponding Condition × Set Size interaction. The F- tests have 2 denominator and 38 nominator degrees of freedom.

	Target present			Target absent		
Target	q_x	F	p	q_x	F	p
Random	54.4	5.98	< 0.01	41.0	36.05	< 0.001
Fixed	110.0	2.06	0.141	93.3	0.70	0.501

For fixed target search results are also presented in table 4.14. The slopes for the feature preview condition were significantly reduced compared to the feature baseline, although the ideal of .5 was not reached (target present: $F(2, 38) = 3.33, p < 0.05$, target absent: $F(2, 38) = 10.23, p < 0.001$) .

In contrast to random target search the slopes of the conjunction baseline condition were nearly halved compared to the feature baseline and the F-test also indicated significant deviations from parallelism (target present: $F(2, 38) = 6.59, p < 0.01$, target absent: $F(2, 38) = 18.74, p < 0.001$).

The conjunction preview slopes were also significantly reduced compared to feature baseline search, with ratios ranging from 66% (target present trials, $F(2, 38) = 4.11, p < 0.05$) to 54% (target absent trials, $F(2, 38) = 24.42, p < 0.001$).

Furthermore, I analyzed with the ratio $^{a_{\text{fixed}}}/_{a_{\text{random}}}$ whether fixed target search was more efficient than random target search. Results are depicted in table 4.16: For all conditions except the conjunction baseline slopes were not significantly different between random and fixed target search, so that search efficiency did not differ between the target types. For the conjunction baseline ratios were 62% (target present trials) and 55% (target absent trials) and this was substantiated by significant results of the F-test (see table 4.16). Thus, conjunction baseline search for fixed target search was advantageous compared to random target search.

Table 4.16: Ratios of search rates for search with a fixed target compared to search with a random target of experiment IV. The table shows the slope ratios, q_s, as percent values, as well as F- ratio and p- value for testing the corresponding Condition × Set Size interaction. The F- tests have 2 denominator and 38 nominator degrees of freedom.

		Target present			Target absent		
Search	Preview	q_s	F	p	q_s	F	p
Feat.	No	114.2	1.83	0.175	104.9	0.50	0.608
Conj.	No	62.8	5.19	< 0.05	55.4	20.68	< 0.001
Feat.	Prev	92.7	1.51	0.235	118.7	2.44	0.100
Conj.	Prev	127.0	1.41	0.257	126.2	3.18	0.053

4.6.3 Discussion of experiment IV

In experiment IV the slopes of the Reaction Time × Set Size function for the feature baselines were the highest of all four experiments. This supports the assumption, that search was most inefficient with the least form feature difference between target and distractors. A 1:2 ratio of target present to target absent trials for all conditions indicates that search was serial and self-terminated. I found evidence for feature guidance in conjunction search, since the search rates for the conjunction baseline for fixed target search were about halved compared to the feature baseline. In feature search guidance could not be used. Conjunction baseline search was as efficient as feature search if participants searched for a random target, since the search rates of both conditions were parallel. A preview benefit was found for both feature and conjunction search for both target types.

Search is difficult if target and distractors are very similar (Duncan and Humphreys, 1989). This was the case in experiment IV: The vertical bar of the C and I stimuli was only moved 10 pixels, leading to a minimum difference between the stimuli (see e.g. figure 4.1). This manifests itself in the high search rates for the feature baselines, independent of target type.

In the baseline conditions of random target search observers do not have foreknowledge about the target features, since the target varies randomly from one trial to the next. Thus, the observer has to scan every element serially until the target is either found or search is terminated by deciding that no target is present.

For target knowledge, however, the Guided Search Theory (Wolfe et al., 1989) predicts a parallel segmentation of the search display based on basic features. Within the items supposed to be likely target candidates, a serial search is then performed to find the target (Wolfe et al., 1989). Color is supposed to be an undoubted guiding feature (Wolfe and Horowitz, 2004, 2017) and evidence for color selective subset search has previously been presented (Egeth et al., 1984; Kaptein et al., 1995). If guidance is possible, then the search rate of color $\times$ form search should be halved compared to the feature baseline. This is assumed, since only the elements containing the target color, which are half of all items in color $\times$ form search, have to be searched in a feature search comparing the stimulus forms. This is indeed what I observed. My results are in accordance with the findings of Kaptein et al. (1995), who combined color and a small orientation difference and concluded that guidance could only be possible by color, but not orientation in their experiment.

In feature search, however, no guidance is possible due to the high similarity of the forms C and I, since thus, form cannot be used to search through less items in the color homogeneous display.

Moreover, participants are not only able to use color guidance, but to use the information provided by the preview: Both for the feature preview conditions and the conjunction preview conditions, slopes fulfill the half-slope prediction of a potential visual marking mechanism, indicating that participants were able to tag the locations of the old stimuli and inhibit them at search, leaving them to search only through the new items (Watson and Humphreys, 1997).

Whereas new and old items are only separated by temporal asynchrony in feature search (Jiang et al., 2002b), a second grouping mechanism enters in conjunction search: a possible grouping based on the different colors of new and old elements (Meinhardt and Persike, 2015; Theeuwes et al., 1998). Memory has only a limited capacity (Jiang and Wang, 2004). This means that the preview benefit in feature search should be reduced, the longer search takes. This is indicated if the ratio of the feature preview condition to the feature baseline approaches 1, since observers recheck some positions. Although this ratio is higher for random target search in experiment IV than experiment III, the slopes are still nearly halved or clearly reduced. This indicates that memory seems to have no large restrictive effect on the preview effect in feature search.

The fact that another cue for grouping is present in conjunction search suggests that conjunction preview search could be even more efficient than feature preview search. Comparing the search rates presented in table 4.14 confirms this assumption. However, conjunction preview search had no efficiency advantage compared to conjunction baseline search, if participants had target foreknowledge and thus searched for a fixed target. This leads to the assumption that the temporal segregation due to a preview is not necessary to restrict search to one half of the items in a color × form search, if observers have target foreknowledge and can thus guide their attention to only those items containing a specific target feature.

This is complemented by the result that search efficiency did not differ between fixed and random target search except for the conjunction baseline, where fixed target search slopes were nearly halved compared to random target search slopes.

These results indicate that the full extent of feature guidance in conjunction search is only exploited when the search efficiencies of both used features differ to a large extent, with one feature guiding attention to likely target elements, where the elements have to be scrutinized one by one for the difference in the inefficiently searched feature.

4.7 General discussion

4.7.1 The preview benefit

Watson and Humphreys (1997) postulate that observers can encode previewed distractors and inhibit them later at search, a mechanism which they termed „visual marking“. Evidence for visual marking has been presented by a variety of studies (Olivers and Humphreys, 2002; Meinhardt and Persike, 2015; Watson and Humphreys, 2000, 2002; Watson et al., 2008).

In my study a preview consisting of distractors was presented 2000 ms before the remaining elements entered the search display in either feature preview conditions or conjunction preview conditions in all four experiments.

A full preview benefit is indicated if the search rate of the RT × Set Size function for the preview condition is halved compared to its corresponding baseline, since observers only have to search among the second item half and can perform a feature search there, since for both the feature and the conjunction preview conditions, the "new" elements differ only in the feature form, but not in color. Overall, for feature search, search rates were reduced compared to the feature baseline across all experiments. This indicates that observers could use the preview to search only through the new items and perform a feature search among them. The preview benefit in feature search depends on memory (Jiang and Wang, 2004). I predicted that the preview effect should be reduced in feature search, the longer it takes, since memory for positions has only a limited capacity and the memory for temporal asynchrony fades fast (Jiang and Wang, 2004). Although the slope ratios increased mostly for target absent trials of both fixed and random target search with increasing form search inefficiency, a clear slope reduction was still observed with the highest task difficulty. This hints that memory limitations only seem to have a small diminishing effect on the preview benefit.

In conjunction search a second grouping principle enters to separate old from new items: their different colors (Theeuwes et al., 1998). This means that conjunction preview search offers more advantageous prerequisites to establish a preview benefit than feature search (Meinhardt and Persike, 2015). Conjunction preview search was in most cases not more efficient than feature preview search though. The only exception are the results observed for experiment IV. Furthermore, no preview benefit was observed in experiments I and II. In experiment III slopes for the conjunction preview conditions were reduced compared to the feature baselines, but they were not near halved except for target present trials for fixed target search.

Thus, observers could only use the preview to search through the new items when search was really difficult (experiment IV), but not, when it was easy (experiments I and II). The results indicate that the establishing of a preview benefit in conjunction search does not follow a continuum based on increased target-distractor similarity, since a preview benefit was only observed for color $\times$ form search when search was really inefficient, but not gradually across decreasing discriminability of the stimulus forms.

The preview works not only because of top-down influences, but search among the new items can also be influenced by onset capture (Donk and Theeuwes, 2001, 2003). Onset capture works directly when the new items enter the display (Donk, 2006) and cannot be controlled top-down (Jonides and Yantis, 1988;

Yantis and Jonides, 1984). That no preview benefit for conjunction search was observed except in experiment IV indicates that another powerful bottom-up principle could hinder participants from attending to only the new elements.

Since both color and form differences were highly salient in experiment I and the distractors which have the alternative color in conjunction search also share the target form, attentional capture by distractors in both feature and conjunction search seems a reasonable explanation why no preview benefit for conjunction search and no full preview benefit in target present trials for feature search was observed if form search was easy. Evidence for attentional capture by salient distractors has been provided by several authors (Kim and Cave, 1999; Lamy and Zoaris, 2009; Theeuwes, 1992, 2004, for further discussion see section "Attentional capture can hamper search performance in conjunction search" in the General Discussion).

If form search was difficult, no attentional capture was possible by the form of the distractors, since form was not salient, so that a preview benefit could be established in conjunction search as well as feature search. My results indicate that not even grouping of the old and new items by temporal asynchrony could hinder attentional capture by the distractors if forms differed to a high degree.

4.7.2 Feature guidance is influenced by the efficiency of the used features

The Guided Search Theory assumes that attention can be guided to only a subset of elements in a search task due to them possessing the same features as the target (Wolfe et al., 1989). According to the model guidance consists of both bottom-up and top-down mechanisms: Bottom-up guidance is based on salience differences between different stimuli (Wolfe, 2012). This bottom-up process gives information about the salience of an item compared to the context in which it occurs, thus in comparison to the other distractors presented in the search display (Wolfe, 1994). Guidance consists not only of bottom-up, but also top-down activation based on knowledge about the target features (Wolfe, 1994). Guidance rests upon an activation map, which calculates both forms of activation, which can be weighted to different degrees (Cave and Wolfe, 1990; Wolfe, 1994). For two efficiently searched features the Guided Search Model would predict flat search function slopes, since the target should be the item getting the highest top-down activation (Wolfe et al., 1989; Wolfe, 1994).

While color remained the same for all four experiments of the current chapter, form search difficulty varied: Form search was easier if the bar from I to C was moved 23 and 19 pixels than if it was moved to a lesser degree, which is hinted by the flat or very shallow slopes of the RT × Set Size functions for feature baseline search. Guided Search Theory (Wolfe et al., 1989) would predict flat slopes in that instant, since the top-down activations for the target should be highest with two efficiently searched features. Thus, the target should be the item to be examined first, leading to immediate detection of the target.

In feature search of my experiments all items in the search display had the same color, so that the target differed only from the distractors in its form. Guidance in feature search can be assessed by computing the ratio $a_{\text{fixed}}/a_{\text{random}}$. The smaller this ratio is, the higher is the advantage that fixed target search has to random target search. These results are presented for the feature baseline condition in table 4.17. As can be seen there, the ratio $a_{\text{fixed}}/a_{\text{random}}$ lies between 48.1 % and 78.4 % in experiments I and II. This search advantage for fixed target search hints that observers could use guidance to search through less elements if they knew the target form beforehand. In experiments III and IV the ratios show no efficiency gain of fixed to random search. Since form was highly inefficient in these experiments, no feature guidance could be exerted by the observers.

Table 4.17: Ratios of search rates for search with a fixed target compared to search with a random target for the feature baseline conditions of all experiments. The table shows the slopes, the slope ratios, q_s, as percent values, as well as p- value for testing the corresponding Condition × Set Size interaction (experiments I, III and IV) or Set Size × Target Type interaction (experiment II).

				Target present			Target absent		
Exp.	Target	Search	Prev	a	q_s	p	a	q_s	p
I	Random	Feat.	No	12.9			24.7		
I	Fixed	Feat.	No	6.2	48.1	0.135	14.4	58.3	< 0.05
II	Random	Feat.	No	19.3			60.1		
II	Fixed	Feat.	No	15.1	78.4	0.309	31.7	52.8	< 0.001
III	Random	Feat.	No	39.5			77.0		
III	Fixed	Feat.	No	39.0	98.7	0.059	76.9	99.8	0.999
IV	Random	Feat.	No	71.7			168.1		
IV	Fixed	Feat.	No	81.9	114.2	0.175	176.3	104.9	0.608

In color × form search both color and form can principally guide search (Wolfe and Horowitz, 2004). Yet, with two such efficiently searched features it remains unclear which feature to prioritize and conflicting results have arisen (e.g. those of Treisman and Gelade (1980) and Wolfe et al. (1989)). This means that evidence of guidance should be found if one efficiently searched feature is combined with one inefficiently searched feature, since then, only the efficient feature can be used for guidance. In my experiment color remained the same for all experiments, while form search efficiency was reduced across the four experiments. This means that evidence for color guidance should only be found with highly inefficient form search.

What are indicators for guidance in conjunction search? First of all, as for feature search, the ratio $a_{\text{fixed}}/a_{\text{random}}$ can show a search advantage of fixed to random target search if it is less than 1. Second, if subjects can search through only the items of the target color, this means that only half of all items have to be searched and can be compared in a feature search for form. Thus, if the ratio a/a_{feature} is near to 0.5 this indicates perfect color guidance. If it is higher, but still less than 1, this indicates that guidance can be used, but does not work perfectly.

Table 4.18: Ratios of search rates for search with a fixed target compared to search with a random target for the conjunction baseline conditions of all experiments. The table shows the slopes, the slope ratios, q_s, as percent values, as well as p- value for testing the corresponding Condition × Set Size interaction (experiments I, III and IV) or Set Size × Target Type interaction (experiment II).

				Target present			Target absent		
Exp.	Target	Search	Prev	a	q_s	p	a	q_s	p
I	Random	Conj.	No	49.9			103.8		
I	Fixed	Conj.	No	19.1	38.2	< 0.001	41.9	40.3	< 0.001
II	Random	Conj.	No	55.6			115.0		
II	Fixed	Conj.	No	26.0	46.7	< 0.001	54.8	47.6	< 0.001
III	Random	Conj.	No	68.9			164.9		
III	Fixed	Conj.	No	28.9	41.9	< 0.001	82.1	49.8	< 0.001
IV	Random	Conj.	No	78.2			184.0		
IV	Fixed	Conj.	No	49.1	62.8	< 0.05	101.9	55.4	< 0.001

As shown in table 4.18 fixed target search was more efficient than random target search in all conditions. However, the ratio ${}^{a_{\text{fixed}}}/{}_{a_{\text{random}}}$ does not drop with decreased form search efficiency, but rises, even though it is still nearly halved with the highest form similarity. Moreover, the ratio ${}^{a}/{}_{a_{\text{feature}}}$ for fixed target search only shows a reduced slope of the conjunction baseline in target present trials of experiment III and for both trial types in experiment IV. This hints that only the results for experiment IV and present trials of experiment III can be explained by color guidance. The better search performance for target knowledge in the other experiments must thus be caused by another mechanism.

Moreover, the activation map uses both bottom-up and top-down activation (Wolfe, 1994). In conjunction search the distractors should have a smaller degree of top-down activation than the target, since every distractor contains only one of both target features, while the target contains both. The only other influence on the activation map are bottom-up differences in salience between stimuli (Wolfe, 1994). Both distractor types differ in both features (for example, if the distractors are green Cs and orange Is), which leads to a higher distractor-distractor dissimilarity. The target, however, differs from both types of distractors only in one feature, leading to a higher similarity of target and distractors.

Search becomes less efficient if distractors differ to a high degree, but target and distractors differ to a smaller degree (Duncan and Humphreys, 1989).

All in all, the failure to observe guidance with efficient form search is thus likely due to a higher salience of the distractors compared to the target, so that bottom-up activations seem stronger than top-down activations in influencing the allocation of attention in these tasks.

4.7.3 Attentional capture can hamper search performance in conjunction search

Studies suggest that attention can be captured by salient stimuli (Kim and Cave, 1999; Lamy and Zoaris, 2009; Theeuwes, 1992, 2004, although see Yantis and Egeth, 1999 for a conflicting view). Moreover, studies indicate that attentional capture can also be contingent on the goals of an observer (Bacon and Egeth, 1994; Folk et al., 1992; Gibson and Amelio, 2000; Remington et al., 2001).

In experiment I not only color differences were salient, but also differences in the feature form, since the letters C and I differed to the highest degree (23 pixels difference). While the target receives both the highest bottom-up and top-down activations in feature search, which leads to fast target detection (Sobel et al., 2009), this is not the case in conjunction search: Here, local differences between distractors attract the observer's attention (Sobel et al., 2009). Moreover, since the form differences were salient in experiments I and II and furthermore, the distractors in the alternative color than the target shared the target form, it seems likely that the failure to observe guidance as well as a preview benefit in conjunction search in experiments I and II is due to attentional capture by distractors. Thus, the influence of attentional capture is higher in conjunction than feature search of my study due to an overall higher bottom-up activation of distractors as well as the matching of distractor and target form.

As feature search becomes less efficient, however, saliency differences between both stimulus forms decrease and evidence for feature guidance is observed. Thus, with more similar forms, the observer's top-down set leads to higher top-down activations of elements containing the target's color which are supported by lower bottom-up activations of the feature form due to target's and distractors higher similarity in form. Theeuwes et al. (2010) as well as Theeuwes (2010) suggest that inefficient search, as was the case in experiments III and IV, can prevent attention from getting caught due to the need to search focused through complex items. Additionally, my results are in line with results from Sobel and Cave (2002): They showed that observers tended to base their search on bottom-up mechanisms like searching through the elements building up a smaller group in the search display if target and distractors were highly discriminable, but searched for an instructed feature if target and distractors were more similar in their orientation and thus harder to differentiate. Other evidence that target-distractor similarity decides whether search is influenced by attentional capture has been provided by Proulx and Egeth (2006).

Since the features form and color competed for my observers' attention in experiment I, but not in experiments III and IV, where color differences were more salient than form differences, it seems likely that participants became more able to use top-down strategies like feature and spatial guidance in conjunction search the less discriminable the used stimuli became in the feature form.

4.7.4 Repetition priming

Fixed target search had an efficiency advantage to random target search in all four experiments: In experiments I and II the ratio was reduced for all conditions, whereas in experiment III and IV, an efficiency advantage was only observed for the conjunction baseline. For the feature baselines and feature preview conditions of experiment I and II this advantage can be explained by the usage of feature guidance. Feature guidance in conjunction search is the expected cause for the advantage for the conjunction baseline in experiment IV as well as target present trials of experiment III. Yet, how can the other search advantages be explained?

A possible reason for shallower slopes of the RT $\times$ Set Size functions if observers searched for a fixed target compared to if they searched for a random target is priming. Priming signifies an easier detection or identification of a target stimulus if its location or features are repeated (Kristjánsson and Campana, 2010). Priming has been demonstrated in both pop-out search (Maljkovic and Nakayama, 1994) and conjunction search (Geyer et al., 2006; Kristjánsson et al., 2002; Hillstrom, 2000; Kristjánsson and Driver, 2008), as well as a target's location (Kristjánsson et al., 2005; Maljkovic and Nakayama, 1996).

For example, Kristjánsson et al. (2002) investigated priming in a conjunction search task with red and green horizontal and vertical bars as stimuli with different orientations. In different conditions the target could either be known and remain the same (conjunction condition), change its orientation between trials (switch condition), have the same orientation for some following trials (streak condition) or vary its orientation in random manner (random condition). The authors observed the shortest reaction times for the conjunction condition, followed by the streak and the random condition. If the target switched its orientation, observers gave the slowest responses. Thus, search was faster if the target was repeated over several trials than if it changed. Furthermore, priming effects were also observed for target absent trials, indicating that priming cannot only operate on the target stimulus, but also on distractors. This is in line with a study by Kristjánsson and Driver (2008), who showed a priming effect for both target and distractors for both conjunction and feature search as well as a study by Geyer et al. (2006): They observed the highest priming effect when both target and distractors were repeated, but also, that repeating distractors alone led to the same benefit as repeating target and distractors together. These findings indicate that priming can operate on several levels (Kristjánsson and Campana, 2010). Neural evidence for priming has also been provided for both single neurons (Bichot and Schall, 1999, 2002) and whole regions in the brain (Kristjánsson et al., 2007; Vuilleumier et al., 2005; Wig et al., 2005).

The mentioned studies hint that better search performance for fixed than random target search cannot only be based upon utilizing target knowledge to guide attention to a subset of elements containing the target feature, but that the repetition of the same target and distractor features in the fixed target condition could lead to priming independently of actually knowing the target features. The feature color seems to be especially suited for priming, since Kristjánsson (2006) observed color priming effects even if color was not relevant for the task which observers had to conduct. Priming has also been observed for the feature form (Fecteau, 2007).

A better search performance for fixed than random target search was observed for combinations of different degrees of efficiency for the used features: First, conditions, where one efficiently searched feature (form) could potentially be used for guidance, because the other feature (color) was the same for all items. This was the case in the feature baselines and feature preview conditions of experiment I and II. Second, conditions, where one efficiently searched feature (color) was combined with an inefficiently searched feature (form), which was the case in the conjunction baseline conditions in experiments III and IV. Last but not least, conditions, where two efficiently searched features were combined as in the conjunction baseline and the conjunction preview condition in experiments I and II.

I propose the following: In cases when only one efficiently searched feature can offer guidance, such as in the first and second option, observers are able to use feature guidance to search through less elements. In the third option, however, where two features could potentially offer guidance, subjects cannot build a clear top-down priority for one feature to guide their search. Yet, as priming can work due to the mere repetition of the target, but target knowledge is not necessary, priming could also operate in a case where the subject cannot use feature guidance and thus lead to more efficient fixed than random target search.

Chapter 5

General Discussion

5.1 The preview benefit in feature search

A vast body of evidence suggests that visual search can be facilitated by presenting a preview of distractors before the rest of the search display (Humphreys et al., 2002; Kunar et al., 2003a,b; Watson and Humphreys, 1997, 2000, 2002; Watson et al., 2003; Watson and Humphreys, 2005). This facilitation is often explained by visual marking (Watson and Humphreys, 1997), which means that observers can inhibit the locations of the previewed stimuli at later search, so that the new items are prioritized.

A preview benefit is indicated if the slope of the Reaction Time × Set Size function is halved compared to the feature baseline. This is assumed, since, if observers can use the preview to limit their search to just the new items, only half of all items need to be searched. Moreover, these stimuli are feature homogeneous in one feature, so that the target differs only in one feature from the distractors, making it possible to employ feature search mode (Meinhardt and Persike, 2015).

I investigated whether observers could use the information provided by the preview with both feature and conjunction search and different kinds of stimuli. For feature search I found a preview benefit for letter search if the stimuli in feature search appeared with two different, heterogeneous colors (Study 1). For letter search target knowledge had no great influence on feature search compared to when the target and distractor features varied in random fashion trial after trial. Furthermore, a preview benefit was also discerned with triangle stimuli for both random and fixed target search and it did not differ for both target types (Study 2).

Last but not least, I detected a preview benefit for feature search with letter stimuli with varying degrees of distractor-target similarity (Study 3). A clear slope reduction was observed for all experiments except for target present trials for random target search of experiment II. In experiment I and II fixed target search rates were reduced compared to random target search rates. With increased distractor-target similarity and thus increased task difficulty (Exp. III and IV) the efficiency advantage for fixed target search disappeared.

My findings indicate that the preview benefit in feature search does not depend on stimulus type and is not influenced by irrelevant features, such as the heterogeneous colors in the letter search task of study 1. Observers can apparently use the preview to search only through the new items, although search rates, which are often not completely halved, indicate that observers sometimes search through some old items. This is likely due to the fact that memory is mandatory to separate old from new items in feature search, since no other grouping cue can be used when the search display is completed with stimuli (Jiang and Wang, 2004). If subjects cannot remember all old locations correctly, they can sometimes revisit locations of the preview. This hinders the perfect fulfillment of the half-slope prediction of potential visual marking. However, this influence does not seem to hinder observers from decreasing the number of to-be-searched elements to a great extent, since even in highly inefficient feature search the search rates are still clearly reduced.

5.2 The preview benefit in conjunction search

Results for conjunction preview search were different than for feature search. For letter search (Study 1) no preview benefit was observed with a heterogeneous conjunction preview.

In highly inefficient search among triangle stimuli a full preview benefit was observed with random item positioning (Study 2).

Last but not least, study 3 combined different degrees of distractor-target similarity for the feature form with the feature color. A preview benefit in conjunction search was observed if form search was inefficient (experiments III and IV), but not, if form search was easy (experiments I and II).

My results show that target-distractor similarity plays a crucial role in establishing a preview benefit in conjunction search. For overview, the feature search baseline rates for all experiments with random item positioning are shown in table 5.1. A preview benefit with randomly positioned items was only observed if target and distractors were highly similar and feature search thus inefficient (Duncan and Humphreys, 1989), as was the case in study 2 and experiments III and IV of study 3. With more efficient feature search (Study 1 and experiments I and II of study 3) no evidence for a preview effect in conjunction search for randomly positioned items was found.

This suggests that efficient search prevents the establishing of a preview benefit for randomly positioned items in conjunction search. How can this be explained?

Table 5.1: Search rates for the feature baseline conditions of all three studies for random item positioning and homogeneous colors. For better view, trial type (target present, target absent) is named abbreviated.

		Random target		Fixed target	
Study	Experiment	present	absent	present	absent
Study I		23.2	55.2	23.1	41.0
Study II		88.9	207.1	99.9	201.1
Study III	Exp I	12.9	24.7	6.2	14.4
Study III	Exp II	19.3	60.1	15.1	31.7
Study III	Exp III	39.5	77	39	76.9
Study III	Exp IV	71.7	168.1	81.9	176.3

5.3 Attentional capture in conjunction search

In feature search the target is defined by a unique form compared to the distractors, who share their form. In contrast to this, the target shares the form of the distractors, which appear in the conjunction preview. Studies showed that salient elements can catch an observer's attention (Kim and Cave, 1999; Lamy and Zoaris, 2009; Theeuwes, 1992, 2004) and this has also been found for stimuli that match the stimulus that the observer is looking for (Folk et al., 1992; Gibson and Amelio, 2000; Remington et al., 2001).

Since form was the feature that differentiated target from distractors in feature search and no preview benefit was found in conjunction search with flatter feature search rates, the idea that the salient form of the distractors, which additionally matched that of the target, attracts the observer's attention seems convincing. If, however, the form of the distractors was not salient, but hard to separate from the target form, as in study 2 and also experiments III and IV of study 3, a preview benefit emerged.

Observers can use top-down strategies to hinder their attention from getting caught (Proulx and Egeth, 2006). My results are in accordance with this, since with highly similar stimuli, top-down influences apparently have a larger influence in participants search than the bottom-up activations of the stimuli.

5.4 Feature guidance depends on search efficiency of the used features

Another aspect that I investigated in my thesis is the contribution of feature guidance to visual search. The Guided Search Theory (Wolfe et al., 1989) predicts that search can be guided to only a subgroup of elements that comprise specific target features. It originates from the finding that conjunction search slopes do not have to be steep, but can also be flat (e.g.McLeod et al., 1988; Sagi, 1988; Wolfe et al., 1989), which cannot be reconciled with the highly influential Feature Integration Theory (FIT,Treisman and Gelade, 1980). Guided Search Theory assumes that guidance works due to both bottom-up activations, based on saliency differences between the target and its neighboring elements in the search display as well as guidance by top-down activations based on knowledge about the target's features (Wolfe, 1994). Both are summed and weighted in an activation map, which guides attention to the location eliciting the overall highest activation (Wolfe, 1994).

Not all features have the ability to lead to feature guidance. For example, while spatial configurations, such as intersections, are not considered to be features able to guide attention (Wolfe and DiMase, 2003), features which lead to pop-out and are searched efficiently are considered good guiding features, for example color (Wolfe and Horowitz, 2004; Wolfe, 2000). However, choosing two efficiently searched features for guidance led to conflicting results, since the search rates observed by Wolfe et al. (1989) were a lot shallower than the steep slopes observed by Treisman and Gelade (1980) (see section "Controversies" for an overview).

To gain clear evidence for feature guidance, in study 2 I combined color, as a supposed guiding feature, with spatial configuration, which should not be able to offer guidance. Feature baseline search rates showed that form, here as the spatial configuration, led to inefficient search, since slopes of the Reaction Time $\times$ Set Size function were about ca. 200.1 ms/item in target absent and 99.9 ms/item in target present trials. Color targets (color search baseline), however, led to flat search functions and thus fast target detection. Thus, two features with different search efficiencies were combined.

The search rate for the conjunction search baseline for fixed target search was about halved compared to the feature search baseline. This hints that only half of all elements, specifically those sharing the target color, were searched for the target form.

Yet, to show that the different search efficiencies affected the occurrence of guidance, a systematical manipulation of search efficiency by distractor-target similarity was needed. Search efficiency depends on distractor-target similarity, since search is inefficient if target and distractors become similar, but not, when they are easy to discriminate (Duncan and Humphreys, 1989). Yet, the triangle stimuli with one thick bar could not be systematically varied.

Thus, in study 3 I created stimuli whose target-distractor similarity could be systematically varied by moving the vertical bar from an I to a C by varying pixels. The feature baseline search rates indicate how efficient search is, since target and distractors are differentiated by their form. As can be seen in table 4.17, search was efficient in experiments I and II of study 3, where the bar was moved by 23 and 19 pixels, thus leading to a high target-distractor difference. In contrast to this, slopes of the RT $\times$ Set Size function were steep with a low difference between target and distractors (Exp. III and IV, 15 and 10 pixels difference).

Evidence for feature guidance was found in feature search of experiments I and II, where search could be guided by the efficiently searched form feature. Here, the ratio of $^{a_{\text{fixed}}}/_{a_{\text{random}}}$ showed a search advantage for fixed target search compared to random target search.

For conjunction search evidence of feature guidance was only gained in experiment IV and target present trials of experiment III, when search was highly inefficient. This hints that there is no continuum in observing degrees of feature guidance with decreasing search efficiency, since feature guidance was only completely observed if search was highly inefficient, such as in study 2 and experiment IV of study 3, but not, when search was inefficient, such as with a 15 pixels difference (experiment III of study 3).

But what lies underneath the observation that guidance is only observed in inefficient, but not efficient search? A probable reason is the same as for hindering the preview in conjunction search from becoming effective: In conjunction search the target cannot be found solely on bottom-up activations of the stimuli, since it is not the most salient element: It matches in one distractor feature with both half the distractors, while the distractors differ in both. Thus, it may be possible that items that have a higher saliency could catch the observer's attention (Kim and Cave, 1999; Lamy and Zoaris, 2009; Theeuwes, 1992, 2004). In addition to this the target form is the same as for half the distractors, which fits the finding that attentional capture by salient distractors can also depend on the observer's search goals (Folk et al., 1992; Gibson and Amelio, 2000; Remington et al., 2001).

Attentional capture by salient stimuli is a likely reason why feature guidance in conjunction search was only observed with high distractor-target similarity, but not with low similarity. Proulx and Egeth (2006) varied distractor-target similarity by varying degrees of orientation of the elements. A bright singleton could appear at different locations. Their results showed that search proceeded fast among items with low similarity if the singleton appeared at the target's location and was faster than if the target was not the singleton. This difference did not emerge if target and distractors were highly similar. Thus, one can infer from the finding that high target-distractor similarity can prevent attentional capture. This was also found by Lu and Han (2009). Evidence for search for specific target features with high target-distractor similarity was also provided by Sobel and Cave (2002).

5.5 Both priming and feature guidance can contribute to search

In my studies fixed target search had, in some conditions, a search advantage compared to random target search.

In study 1 fixed target search had a significant advantage compared to random target search for the conjunction heterogeneous condition with heterogeneous preview.

Fixed target search was also more efficient than random target search in the conjunction baseline of study 2.

Last but not least, the ratio $a_{\text{fixed}}/a_{\text{random}}$ shows more efficient search for a fixed target than random targets in several conditions and trial types in study 3: In experiment I (23 px difference) and experiment II (19 px difference) fixed target search rates were shallower than for random target search in all conditions (see tables 4.17 and 4.18). This search advantage vanishes for all conditions except the conjunction baseline condition in experiments III (15 px difference) and experiment IV (10 px difference).

If search shows a higher efficiency if a target is repeated compared to if it changes, this is called priming (Kristjánsson et al., 2002). Priming does not depend on target knowledge (Kristjánsson et al., 2002). In the fixed target search conditions of my experiment, although participants know the target's identity, the target still remains the same and is repeated for all trials.

Priming effects can appear in both pop-out search (Maljkovic and Nakayama, 1994) and conjunction search (Geyer et al., 2006; Kristjánsson et al., 2002; Hillstrom, 2000; Kristjánsson and Driver, 2008).

The Guided Search Model (Wolfe et al., 1989) also predicts more efficient search if observers know the target's identity compared to when they do not. How can we then decide whether the search advantage for fixed target search is due to bottom-up repetition priming or top-down feature guidance?

First of all, guidance should be possible by an efficiently searched feature, but not by an inefficiently searched one or if both features are searched efficiently. Color is supposed to be able to provide guidance (Wolfe and Horowitz, 2004, 2017), while spatial configurations are not (Wolfe and DiMase, 2003). Thus, guidance in conjunction search should only be possible by color in conjunction search of study 2 and experiments III and IV of study 3, since there, one efficiently searched feature (color) was paired with an inefficiently searched configuration cue. In feature search of experiment I and II of study 3 feature guidance by form could also be possible, since only form is an efficiently searched feature there, which differentiates target from distractors and all elements are of the same color.

This, in combination with a ratio $a_{\text{fixed}}/a_{\text{random}}$ which is clearly reduced and less than 1, can hint at feature guidance.

In addition to this, feature guidance in conjunction search is indicated by a reduced conjunction baseline slope of the RT $\times$ Set Size function in comparison to the feature baseline if observers search for a fixed target: If this ratio is about 0.5, perfect guidance is suggested, since then, only half the items present in the search display (those containing the target color) need to be searched and can then be compared in a feature search for the other feature (spatial configuration). If this ratio is lower than 1, but higher than 0.5, this hints that guidance is possible, but not perfect. If conjunction baseline search is not more, but less efficient than feature baseline search if observers look for a fixed target, then no evidence for feature guidance in conjunction search is gained.

Bringing this all together it can be assumed that feature guidance worked in the fixed target conjunction conditions of study 2 and experiment IV and also target present trials of experiment III (study 3). There, all the named suppositions were met.

Moreover, the distinctly better search performance for fixed than random target feature search in experiments I and II of study 3 can be explained by feature guidance, since there, an efficiently searched form feature could assumedly be used for guidance.

Repetition priming on the other hand can account for the search advantage for fixed target conjunction search in the other experiments, where the ratio of the conjunction baseline to the feature baseline did not indicate guidance and also two efficiently searched features were combined.

This hints that repetition priming and feature guidance can also act together to facilitate search if the target does not change: In situations where a clear preference for one feature to use for guidance can be built, observers can use top-down guidance to only a subset of elements. Yet, in situations, where the difference in search efficiencies between the used features is not high enough to define one feature as the guiding feature, repetition priming is a mechanism that can speed up search if the target is repeated. Repetition priming is independent of actual target knowledge but works due to repetition of target features (Kristjánsson et al., 2002) and thus requires no conscious effort of the observers.

5.6 Conclusion

In three studies I investigated the constraints on the preview benefit and feature guidance in feature and conjunction search. Feature search is not always performed efficiently: It was found that feature search can be highly inefficient, whereas conjunction search can become more efficient than feature search.

Search efficiency can be strongly influenced by both bottom-up factors and top-down factors. First of all, saliency between different elements can play a huge part in deciding how efficient a visual search task can be performed. Studies 2 and 3 corroborate the findings of Duncan and Humphreys (1989).

Secondly, the occurrence of a preview benefit in feature search is independent of how efficient visual search can be performed: It was observed for letter search as well as inefficient search for triangle stimuli and varying degrees of distractor-target similarity of C and I stimuli.

Last but not least, color heterogeneous distractors did not influence the preview benefit in feature search.

Moreover, evidence for feature guidance in feature search was found if an efficiently searched form feature could be used to provide guidance, as was the case in experiments I and II of study 3.

In contrast to this both the preview benefit and feature guidance underlie several constraints in conjunction search: First of all, feature guidance depends on the efficiencies of both combined features. Only with one efficiently searched and one inefficiently searched feature clear evidence for guidance in conjunction search can be gained.

Moreover, since the target shares its form with half the distractors in conjunction search, the observation of both the preview benefit and feature guidance depends on stimulus similarity and saliency of the used stimuli: Only in highly inefficient search, where target and distractors are hard to distinguish, top-down influences like guidance and visual marking can take effect.

With a higher dissimilarity bottom-up attentional capture by salient elements can occur. Both feature guidance as well as a preview benefit in conjunction search were only observed with highly inefficient feature search. This hints that with inefficient and thus focused search attentional capture can be prevented as well as the facilitating role of priming can be replaced by the influence of feature guidance and visual marking, making it possible for observers to diminish their search to only about half of all items. Moreover, if temporal asynchrony and guidance are combined, this leads to more efficient search than if only temporal asynchrony can be used to reduce the search display. This is indicated since conjunction preview search is overall more efficient than feature preview search in highly inefficient search.

Yet, several questions remain open for future research: In the fixed target search conditions of my studies both the target and the distractor identities remained the same. Repetition priming effects have been shown for both target and distractor repetition (Geyer et al., 2006; Kristjánsson and Driver, 2008). Geyer et al. (2006) observed the largest priming effects for a repetition of both distractors and target, but that this did not differ from when only distractor identities were repeated. The authors inferred from those findings that conjunction search priming stems to the most part not from the repetition of the target, but of the distractors. However, we do not yet know whether this holds for feature search tasks in the same way. Moreover, the repetition of distractors could not only ease search due to priming, but also, if observers know the distractor identities beforehand, they could choose to inhibit the distractor features in a top-down way.

In addition to this, the distinction between priming effects and the effects of top-down guidance should be investigated further, for example by creating experimental designs which compare search performance for conditions in which observers know the target identity and the target remains the same to conditions in which the target is repeated for several trials, but observers do not know the target identity. Moreover, an alternative explanation for the interference in establishing a preview benefit in conjunction search was proposed in the discussion of study 1: The inhibition of the target form due its uniformity to the form presented in the preview. Although this explanation cannot definitely be rejected based on the present data, it seems less convincing than the idea of attentional capture by salient elements, mainly because if the target form gets inhibited in conjunction preview search, there is no reason to assume that this inhibition mechanism works more intensely in efficient conjunction than in inefficient conjunction search. Thus, in light of the present data, accepting the explanation of attentional capture which hinders efficient, but not inefficient conjunction search suggests itself. Yet, for future research, a clearer distinction between both mechanisms seems worthwile.

Finally, it was found that top-down strategies like visual marking and feature guidance can be used in conjunction search if search is highly inefficient, but not in efficient search. It was shown that continuously decreasing target-distractor dissimilarity does not lead to a continuous increase in the usage of feature guidance or visual marking in conjunction search. More studies investigating the exact point when observers can use feature guidance or visual marking to facilitate conjunction search, possibly in combination with biopsychological techniques, could help to clarify the relationship between search efficiency of feature search and the usage of top-down strategies in conjunction search.

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