Sources and time course of mechanisms biasing visual selection

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Synopsis

Theoretical background

There are two main mechanisms active during selection of visual input, namely a bottom-up, stimulus driven mechanism and a top-down, goal oriented control. The first is based on stimulus-induced saliency signals, i.e., coding of local contrasts (see, e.g., Wolfe, 1994) whereas the second is concerned with modulating those stimulus-related signals with respect to what is currently important (e.g., Bundesen, 1990; Wolfe, 1994). What is important for the perceptual system is related to many factors. For example, a piece of visually presented information might be important with respect to task at hand: “detect a shape target” (e.g., Bacon & Egeth, 1994; Chelazzi et al., 1998; Posner, 1980 and many others) or, also with respect to prepared action: “prepare for a particular movement type” (e.g., Craighero, et al., 1999; Fagioli et al, 2007; Hommel et al., 2001b). It is interesting to investigate how our perceptual system manages to modulate the processing stream. Several theories have postulated a biasing mechanism (e.g., Bundesen, 1990; Duncan, 2006) or a weighting process (e.g., Found & Müller, 1996) that acts on perceptual dimensions. Empirical data has provided evidence for such a weighting mechanism in behavioral terms (e.g., Bacon & Egeth, 1994; Found & Müller, 1996; Wolfe et al., 2003) as well as neurophysiological terms (Chelazzi et al., 1998; Luck et al., 1997, Moran & Desimone, 1985).

What needs to be answered, however, is not only what are the sources of modulation of processing but also what stages of processing can already be weighted with respect to particular types of bias. Does, for example, the action-related weighting affect early stages of processing such as detection of simple features or is it in power only at the level of processing of conjunctin of features (Bekkering & Neggers, 2002; Humphreys & Riddoch, 2001)? How are the weighting mechanisms that originate from different sources related? Müller and colleagues (Müller, Reimann & Krummenacher, 2003) investigated the issue of how top-down control is related to automatic priming processes. The authors found some interdependence between top-down control and automatic dimension priming effects, i.e., they observed that top-down control reduced automatic priming effects but did not abolish them completely. The question remains whether weighting mechanisms stemming from other sources are also inter-related: Is action-related weighting independent of task-relevance bias or do they form common weights on perceptual dimensions? How is the action-induced weighting mechanism related to bottom-up weighting through repetition?

The aim of the first part of this dissertation was to answer the above questions: Chapter 2 examined whether early stages of processing, such as simple feature detection can already be affected by action-induced weighting mechanism. Moreover, the action-related bias was investigated in relation to task-relevance modulatory mechanism and weighting through inter-trial repetition.

The above described issues are concerned with the modulatory mechanisms themselves. What also still remains unanswered, though, is related to the distinction of two main mechanisms of selection, namely the bottom-up, saliency driven selection and the top-down, goal-oriented control. The following questions, as not resolved so far, require further investigation: how potent is the top-down modulation mechanism. Are simple features processed in a bottom-up manner and are impenetrable to top-down control (e.g., Theeuwes, 1991; Theeuwes et al., 2000)? Or, does the top-down modulation take place already as early as detection of simple features? What is the exact time course of the top-down mechanisms?

The second part of this dissertation (Chapter 3 and Chapter 4) concentrated on answering these questions. With the use of ERP methodology, the precise time course of explicit top-down modulation of visual selection was examined. The issue of whether top-down modulation of attention allocation is potent enough to override the bottom-up induced saliency signals was undertaken.

Overview of the present studies

On the action-related weighting of perceptual dimensions

Chapter 2 describes three experiments in which action-relevance weighting of perceptual dimensions was investigated in a visual search task. Moreover, the inter-relations between action-induced bias, task-relevance weighting and inter-trial priming were examined.

First aim was to investigate whether intending to perform a particular type of movement (e.g., grasping or pointing) would result in influencing a visual search task, i.e., whether intending to move would result in weighting higher perceptual dimensions that might be relevant for that movement type (Experiment 2.1).

Subsequently, the task-relevance bias was manipulated in order to investigate whether the action-related effects are dependent on the general top-down control (Experiment 2.2 & Experiment 2.3). Moreover, the action-related influence on perceptual processing was examined with respect to priming through inter-trial repetition (Experiment 2.2 & Experiment 2.3).

All three experimental designs consisted of two tasks: a visual search task for a pop-out item (either size or luminance) and a movement task (grasping or pointing). Participants were instructed to prepare for a particular movement but execute it only after they would have completed the visual search task. The differences between experiments consisted in the degree to which task-relevance weighting was induced.

In Experiment 2.1, the target-defining dimension was blocked. Participants were to detect either size or luminance throughout the whole block of trials. Therefore, target detection was assumed to take place based on possibly two mechanisms: both the bottom-up driven attentional capture to the pop-out item and top-down weighting of the relevant dimension. The two types of movement (grasping and pointing) were intermixed across trials.

The results showed that detection of size was faster when participants were intending to grasp compared to when they were intending to point. In contrast, detection of luminance targets was faster when participants were intending to point relative to when they were intending to grasp.

These results constituted a straight-forward support for action-related weighting of perceptual dimensions. Such findings provided support for the Theory of Event Coding (Hommel et al., 2001b).

Experiment 2.2 was designed to examine relationship between the action-related weighting and explicit top-down task-relevance weighting. In Experiment 2.2, the two types of singletons (size and luminance) were intermixed across trials. Three types of displays could be presented: blank displays (no singleton), displays with a luminance singleton or displays with a size singleton. Participants were instructed to detect any item that would pop-out from the surrounding neutral distracters. The assumption was that in the case of Experiment 2.2, an explicit task-relevance weighting would be discouraged as, presumably, participants would detect the targets based on their bottom-up saliency signals. At the same time, however, weighting through inter-trial repetition should occur (see, e.g., Found & Müller, 1996). If the design of Experiment 2.2 would still yield action-related effects on processing of perceptual dimensions, it would suggest that these effects might be independent of the task-relevance weighting. If the action-related effects would not be present, it would suggest that they might be somehow related to, or dependent on, task-relevance weighting mechanism. Additionally, the design of Experiment 2.2 allowed for investigating the interdependency between action-related weighting and bottom-up weighting through inter-trial repetition. Since this type of bottom-up weighting was assumed to occur, any interaction between inter-trial repetition effects and action-related effects would suggest that these two types of weighting mechanism are related.

The results showed no action-related influences on target detection, i.e., neither the detection of size singletons nor the detection of luminance exhibited facilitation effects when coupled with congruent compared to the incongruent movement. This suggested that action-related weighting might depend on task-relevance bias. As expected, inter-trial repetition effects were observed. This result was in line with findings of, e.g., Found & Müller (1996); Müller et al. (1995). However, no interaction between inter-trial repetition of dimension and movement type was obtained. Even when only repeated-dimension trials were analyzed, movement-related effects did not occur.

This might suggest that action-related weighting and inter-trial priming are independent.

Experiment 2.3 was conducted in order to test these suggestions. In Experiment 2.3, two types of singleton were presented also in an intermixed manner. However, target assignment was blocked. That is, throughout a block, only one of the singleton types was assigned as target and the other was supposed to be rejected as irrelevant. Through such a design, task-relevance weighting was assumed to be induced, as the only one of the singletons was assigned task-relevant. The other singleton was supposed to be ignored and treated in the same way as blank trials. In all other aspects, Experiment 2.3 did not differ from Experiment 2.2.

Results of Experiment 2.3 revealed action-related influences on the search task. These effects were significant for luminance task and showed a similar tendency for the size task. Interestingly, no interaction between action-related effects and inter-trial priming was observed. This result was in line with the findings of Experiment 2.2. Therefore, action-related weighting seems to be indeed dependent on the occurrence of task-relevance bias. However, action-related effects might be independent from the inter-trial priming of perceptual dimensions.

Taken together, results of Experiments 2.1-2.3 show that movement-related weighting influences selection of perceptual dimensions already at the early stages of processing, i.e., in a task as simple as search for a single feature (for a discussion of single-feature search tasks see e.g., Treisman & Gelade, 1980; Wolfe, 1994). This weighting, though, might not directly affect the dimension maps (see e.g., Found & Müller, 1996; Krummenacher et al., 2002; Wolfe, 1994) but might modulate the explicit top-down task-relevance bias. Action-related bias and bottom-up weighting observed as inter-trial dimension repetition effects seem to be independent.

To account for these results, a model of processes involved in a visual search task was proposed at the end of Chapter 2. This model incorporates action-related weighting which might affect processing of perceptual dimensions indirectly through modulation of task-relevance bias.

On the time course of visual selection

Chapter 3 describes a study in which, using an ERP methodology, the time course of top-down guidance of focal attention and its potency with respect to irrelevant interfering salient signal was investigated.

The ERP methodology allows for examining attentional effects with high temporal resolution. Importantly, the ERP methodology allows for investigating particular temporal windows of the processing stream additionally to its end effects, i.e., response execution.

Therefore, analyzing ERPs as neurophysiological correlates of stimulus processing may allow for a detailed and precise examination of temporal dynamics of processes of interest, i.e., in this case, the top-down control of allocation of attention.

Experiment 3.1 consisted in a paradigm in which participants were instructed to perform two tasks: a visual search task and probe detection. The visual search required detection of a shape target, i.e., a blue circle presented among blue rectangular distracters. In some of the trials, an irrelevant rectangle of the red color was presented. Participants were asked to ignore the irrelevant singleton. The probe task required to detect, as fast as possible, a blue square probe that appeared subsequent to the search display with a variable SOA (134 ms or 234 ms). The probe was presented at a position of either one of the singletons ("On" position) or at a position of one of the neutral distracters ("Off" position). Two SOAs were introduced to investigate the time course of top-down control over attention allocation.

ERPs time-locked to the probe onset as well as probe responses were assumed to reflect effects of allocation of focal attention to items of the search display on probe processing. Any difference in processing of probe dependent on its position should allow for observing whether attention was allocated to the target item or the irrelevant singleton presented prior to probe.

The results showed that in the long SOA condition, P1 component (100-140 ms) time-locked to probe presentation was more enhanced for probes presented at former target positions relative to neutral distracters' positions. Also reaction times were faster to probes presented at the "On" position relative to the "Off" position in target trials, long SOA.

In the short SOA condition, reaction times to the "On" position were faster compared to the "Off" position for the irrelevant-singleton trials. No such effect was observed in the ERP data time-locked to probe presentation.

ERPs time-locked to the search display showed that only after a certain delay (ca. 300 ms after search display onset), the neural responses to particular singleton displays differed: in the interval 300 ms to 360 ms after search display presentation, ERPs elicited by target displays differed from ERPs to displays containing the irrelevant singleton.

These results showed that focal attention was efficiently guided by top-down control to the target item. However, influence of this top-down control needed time to develop as it was observed only in the long SOA condition. The ERPs time-locked to search display presentation might indicate that classification of search stimuli into target and non-target categories took some time. The bottom-up attentional capture did not obtain a strong support as it was observed only in reaction time data.

Various aspects of top-down control of visual selection

Chapter 4 describes a study (Experiment 4.1) which aimed at further investigation of potency and time-course of the top-down modulation with the ERP methodology. The goal of Experiment 4.1 was to compare ERPs which were evoked by physically identical stimuli in conditions that differed only with respect to relevance to the task at hand. Moreover, Experiment 4.1 aimed at investigating the task-relevance effects depending on stimuli of presumably different saliency intensity (shape vs. color). A paradigm similar to the one of Experiment 3.1 was used. Participants were to perform two tasks: detect a pre-defined target and discriminate orientation of a probe bar which was either left- or right- tilted. Two types of display were presented: a display containing a target and a display containing an irrelevant singleton. The singleton could be either a blue circle or a red rectangle among blue rectangles. The target assignment was blocked and changed after the first part of the experiment. That is, the singleton type that was to be detected in the first part (say, blue circle) was supposed to be rejected as irrelevant in the second. The short SOA was equal to 83 ms and the long was equal to 183 ms.

The results showed that N1 time-locked to search display (130-200 ms) was enhanced for target trials relative to irrelevant singleton trials. Such result speaks in favor of a top-down mechanism weighting stimuli with respect to task-relevance. Interestingly it occurred already at early stages of processing. Moreover, ERPs time-locked to probe presentation revealed that probes presented at target’s positions evoked more enhanced positivity within the 90-180 ms time-window compared to neutral distracters’ positions. Such effect of position was also observed for the irrelevant singleton items but was not as pronounced as for target trials. This interaction allows for a conclusion that allocation of attention was modulated in a top-down manner with respect to task-relevance. Behavioral data showed a similar pattern of results.

Finally, differential effects with respect to two singleton types were observed: P3 time-locked to search display (270-360 ms) was less enhanced for irrelevant color singleton displays compared to shape target displays. This effect did not occur in the color-task condition (shape target and color irrelevant) which indicates that color singletons might have been harder to reject as being more salient. Therefore, when presented as irrelevant, they might have required an additional inhibitory mechanism.

Taken together, results of Experiment 4.1 showed that visual selection might be modulated in a top-down manner already at early stages of processing. Such modulatory effects were observed within the N1 time window and extended over the later P2 time-window. Moreover, also ERPs time-locked to probes revealed that allocation of attention was top-down modulated.

Although the present results do not allow for decisive interpretation concerning the exact nature of the observed top-down modulatory mechanisms, some speculations can be put forward: The early N1 effects might reflect a sustained process of assigning weights to task-relevant dimensions for the whole block of trials with respect to experimental instructions. The later P3 effects might be related to an additional suppressive mechanism that is employed only when needed on a trial-by-trial basis.

Results of Experiment 4.1 show that the debate between the proponents of the *pure-capture* perspective (e.g., Theeuwes, 1992; Theeuwes et al., 2000) and the *contingent capture* stance (e.g., Folk & Remington, 1998, 2006) seems not to have a simple solution. Top-down mechanism might modulate processing even if attention is also allocated to the irrelevant items.

Conclusions

The series of studies presented in this dissertation were conducted in order to investigate the inter-relations between various sources of bias affecting early visual processing (Chapter 2) and the precise time course of a mechanism controlling visual selection with respect to task-relevance (Chapter 3 and Chapter 4). Results of the studies described in the present dissertation indicate that even such early perceptual processes as detection of pop-out can be efficiently modulated by top-down control. Such a control might stem not only from task-relevance but also from action intentions. Intending to act in a particular way might have an impact on selection of information potentially relevant to such intended action (Experiments 2.1 and 2.3). This is supportive of the Theory of Event Coding (TEC, Hommel et al., 2001b) that postulates a common code enabling binding across action and perception domains. According to TEC, when intending to move in a particular way, one activates an action-code which automatically primes dimensions that might potentially be relevant for that type of movement. In this way, action intentions might bias perception through intentional weighting (Hommel et al., 2001b). Such an action-related weighting mechanism might be due to learned anticipation of consequences of particular actions (an idea that has its origins in ideomotor theories postulated by, e.g., James, 1890). Moreover, results reported in Chapter 2 indicate that action-related intentional weighting is not independent of task-related weighting. Only if our perceptual system is attentionally set for a particular dimension (see e.g., Folk & Remington, 1992 for a discussion of attentional set), the action-related weighting occurs. That is, we assign intentional weights to perceptual dimensions when we search for a pre-defined target and not when we select any item that pops-out from the surrounding. This implies that the action-related intentional weighting serves a role of a modulatory mechanism acting on the attentional set. At the same time, the intentional weighting with respect to action-relevance is not dependent on bottom-up weighting observed as inter-trial repetition effects (Found & Müller, 1996; Müller et al., 1995).

Results reported in Chapter 3 and Chapter 4 showed that an explicit task-related top-down control of pop-out detection is powerful enough to guide allocation of attention to the target item although a salient singleton produces a distracting signal. The ERP methodology allowed for tracking the precise time course of development of top-down control of attention. Similarly to results of Kim&Cave (1999), the present results showed that such a control takes time to be fully in power (Chapter 3) but seems to be efficient enough to exhibit some modulatory effects already early (Chapter 4). Finally, Experiment 4.1 allowed for observing two aspects of target selection (Chapter 4). One might be sustained weighting mechanism for the whole block of trials with respect to experimental instructions. Another mechanism occurring later might be concerned with additional suppression of irrelevant items. This mechanism might be used in cases when target detection is more difficult or more prone to interference.

In summary, it can be concluded that human perceptual system has developed efficient ways of selecting relevant information and ignoring irrelevant signals. There are many sources of relevance, i.e., action-relevance or task-relevance and they can bias already early stages of processing. They are not independent and might interact to produce common weights on perceptual dimensions. Although the exact nature and potency of top-down control might be dependent on the temporal factor, already early stages of selection processes are modulated by a top-down bias.

Chapter 1: General Introduction

How and why do we select information? A thought experiment.

Imagine the following situation: you are asked to pick up somebody from an airport and you know they will be wearing a green jacket. You also know that you should help them carry a large luggage. You are a bit late and rushing through the crowds of people. You have to make sure that you will not miss the person at the same time trying to find a trolley that will help you to carry the luggage. Your perceptual system is, therefore, trying to act as efficiently as possible. You have to select the appropriate information and, at the same time, ignore an abundance of data that is not important at the moment. How does the perceptual system accomplish such task? Due to the knowledge it possesses, it can be tuned to react to green (the color of the jacket of the person that is to be picked up). Will, in such case, a person wearing a bright red coat capture your attention anyway and you will risk missing the person in green? Will a person with a big umbrella also capture your attention? Or, are you able to ignore all this input? Now, imagine that the person that you are looking for is exiting the gate together with a crowd of people (also together with person in bright red coat and the person with big umbrella). Where will your attention be focused first? To the bright-red jacket, the big umbrella or, will you be able to focus on the importance of the green jacket and pay attention immediately to the appropriate person? How will the time that passes from the moment when all of these people exited the gate influence what you will be attending to? Will you first broadly scan the scene and notice anything that is green and only then focus your attention to the relevant jacket? Do you need time to focus on the present green jacket? At the same time, you cannot forget about the second aim: Finding a trolley. How will you select that information? Here, you cannot select information based on how a trolley looks (they can be of different shapes, sizes and colors) but based on your intended action, i.e., pushing (or pulling) the luggage. Therefore your system might be biased to attend to anything that has wheels and is “pushable”.

This thought experiment illustrates an everyday situation for which our perceptual system has developed mechanisms that allow efficient functioning. The abundance of data that is received through our senses would be overwhelming and processing all of it would probably be impossible and certainly dysfunctional. Therefore, our perceptual system must have developed mechanisms of selection of relevant information. How efficient that selection is, what is its time course (in terms of brain events), what is selection based on and how susceptible it is to interference – these and other questions experimental psychologists investigate in laboratories.

Visual attention

Visual attention has been studied for many years now. General attention phenomenon has already been considered by William James in his Principles of Psychology (1890). First experiments on visual attention can be traced back to Hermann von Helmholtz in the XIX century who investigated the phenomenon of covert attention (attending to a part of the visual field while maintaining eye fixation in the middle of the field).

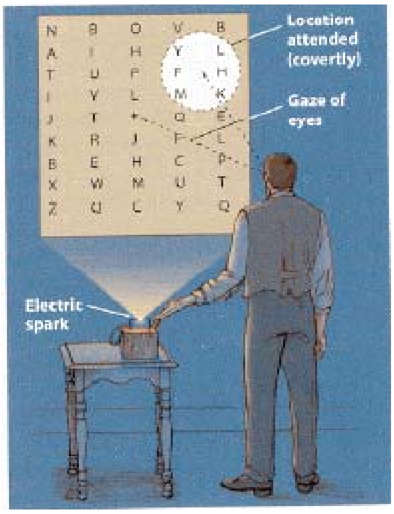

Figure 1.1. Experimental setup used by Helmholtz. The experimenter observed that during a short illumination of the tabloid, he could attend to a limited area in a periphery and detect the letters in that area while maintaining fixation of the eyes in the middle of the tabloid. At the same time, though, he could not read letters form other, unattended, locations. This

phenomenon can be described as allocation of covert attention. Picture taken from Gazzaniga, Ivry, & Mangun (2002).

In more modern times, visual attention has been studied in the context of more particular questions, such as, the questions raised earlier: What is the time course of selection (in terms of brain events); what mechanisms is selection based on; how susceptible is attention to interference. As the experimental cognitive psychologists now know, the answer to these questions depends on many various factors.

Mechanisms of selection

As illustrated in the earlier thought experiment, our attention might be driven to a particular stimulus by two processes. On the one hand, stimuli that are extremely salient in the environment will, most probably, capture our attention (bright red jacket in the example above). At the same time, our cognitive system is tuned to currently relevant, important information (green jacket of the relevant person). The first is called a bottom-up attentional capture effect. That is to say, in the case of bottom-up driven attentional capture, attention is driven to a particular stimulus depending on its physical characteristics. The more salient the stimulus is, i.e., the more it contrasts with the surrounding environment, the more likely it is that attention will be allocated there. Many models of visual attention incorporate this mechanism (e.g., Itti & Koch, 2000; Müller, Heller & Ziegler, 1995; Wolfe, 1994). The second mechanism that is related to selecting relevant information from abundance of input has been termed top-down, or goal-directed control mechanism. Again, many theories have stressed this mechanism which plays a role in the process of attention allocation (e.g., Bundesen, 1990; Müller, Heller & Ziegler, 1995; Posner, 1980; Wolfe, 1994; and many others).

Empirical data shows that indeed a salient stimulus captures attention and can be selected with no particular effort – as in the case of, e.g., pop-out elements that are significantly different from the surrounding with respect to only one feature (Müller, Heller &

Ziegler, 1995; Treisman & Gelade, 1980; Theeuwes, 1992; Wolfe, 1994). At the same time, many studies have provided evidence that bottom-up driven processing of information can be modulated by such factors like task-relevance (e.g., Bacon & Egeth, 1994; Bundesen, 1990; Folk & Remington, 1998, 2006; Kim & Cave, 1999; Posner, 1980; Wolfe, 1994; Wolfe, Butcher, Lee, & Hyle, 2003; see also Wolfe, 1998 for an overview), cueing (e.g., Chelazzi, Duncan, Miller & Desimone, 1998; Luck, Chelazzi, Hillyard & Desimone, 1997; Moran & Desimone, 1985; Posner & Cohen, 1984; Reynolds, Chelazzi & Desimone, 1999), priming by repetition across trials (e.g., Found & Müller, 1996; Maljkovic & Nakayama, 1994: Müller, et al., 1995) or action-relevance (e.g., Craighero, Fadiga, Rizzolatti, & Umilta, 1999; Deubel & Schneider, 1996; Fagioli, Hommel & Schubotz, 2007; Hommel, Müsseler, Aschersleben, & Prinz, 2001b; Humphreys & Riddoch, 2001; Rizzolatti, Riggio & Sheliga, 1994). It seems that the system is capable of weighting the incoming information with respect to the above factors. A weighting mechanism consists in prefereantial processing of some information over other. In this way, efficient selection of relevant information can be achieved and interference ignored.

Weighting mechanism: how visual selection might be modulated

Many authors agree that task requirements and behavioral relevance influence processing of visual features (e.g., Bacon & Egeth, 1994; Duncan, 2006; Egeth, Virzi & Garbart, 1984; Wolfe, 2001; Wolfe, Horowitz, Kenner, Hyle & Vasan, 2004). How can such influence be realized in a perceptual system? To account for this impact, several accounts have proposed a weighting mechanism (e.g., Müller et al., 1995; Wolfe, 1994). It seems that there are many possible sources of weighting that modulates selection when we perceive information from our environment and when we interact with it. As argued above, sensory input might be weighted with respect to task-relevance (“look for a green jacket”) or action-relevance ("I will need to carry the luggage"). This means that the relevant information is processed in a prioritized manner. Additionally, repeatedly presented stimulus can lead to preferred processing of that stimulus, as the system might be primed or tuned towards selecting it again. This might result in a facilitation of processing of repeated information. This phenomenon has been used in paradigms in which priming effects are investigated (Jacoby & Witherspoon, 1982; Schacter, 1987; Tulving, Schacter, & Stark, 1982). In the context of modulatory effects on early visual processes (i.e., processing of perceptual dimensions), priming phenomenon has been found in the form of inter-trial facilitation of simple feature detection (Found & Müller, 1996: Müller et al., 1995)

Weighting with respect to task-relevance

The earlier thought experiment illustrated a situation in which the perceptual system needs a specification of relevant information in order to complete the task. When searching for a particular person in a crowd of people, it would not be enough to detect any pop-out item or characteristic. The perceptual system needs to be biased towards the relevant information in order to find the person of interest and to ignore the irrelevant information. As described above, many theories incorporate a weighting mechanism that should account for such a selection process based on relevancy.

According to, for example, the Guided Search model (see Figure 1.2), information about a visual scene is processed as follows: first, information is coded in broadly tuned input channels from where it is transferred further in a form of feature maps that code local contrasts and top-down commands. Task demands modulate processing in a way that enables efficient detection of relevant information. Both the bottom-up saliency values as well as the top-down commands are computed. A weighted sum of activations is computed at the level of Activation Map. Here, attention is guided to locations in the order of decreasing activation.

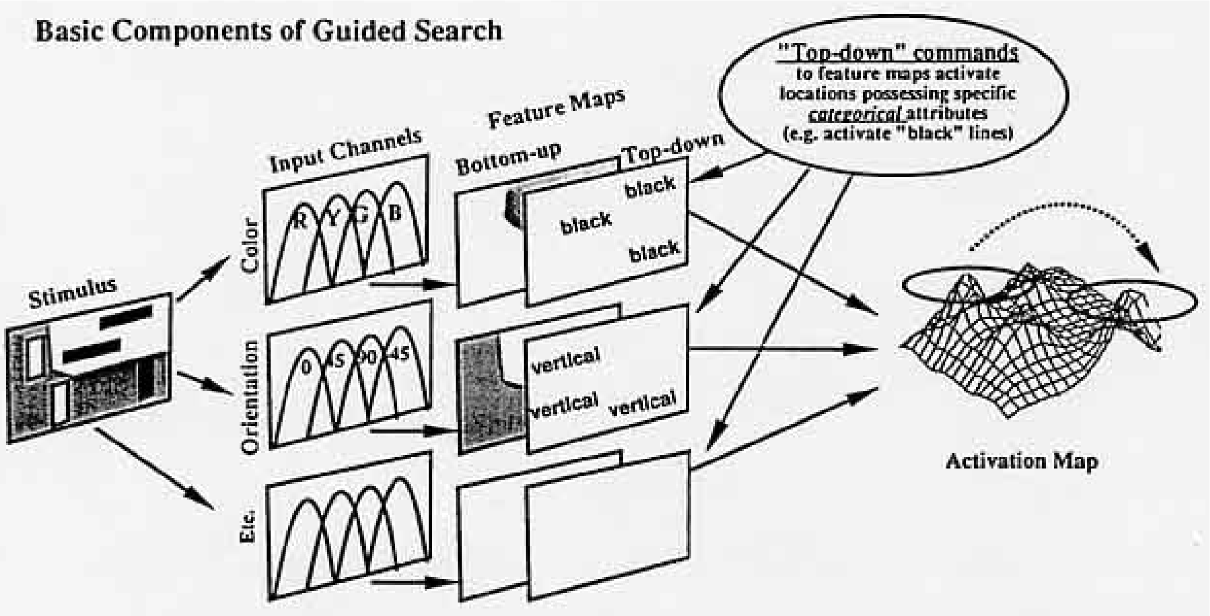

Figure 1.2. A Guided Search model introduced by Wolfe (1994) in which a top-down command might be sent to feature maps in order to modulate weighting with respect to task-relevance. Figure taken from Wolfe (1994).

Intentional weighting with respect to action-relevance

As stated above, a weighting mechanism might take place not only with respect to task relevance but also with respect to other factors. We are not passive viewers of the surrounding world. Instead, we are constantly interacting with it and producing actions of different sorts. It is therefore obvious that planning an action requires specification of action parameters. If we are intending to make a phone call, we need to pick up the receiver and dial the number. In order to pick the receiver up, we need to detect the location of the telephone, its distance from our location, we need to program the type of grip that we will use in order to grab the receiver and, finally, estimate the grip aperture. All these specific sub-actions require complicated computations concerning movement parameters. Additionally, these parameters put limits on perceptual selection. If one is to grasp a phone receiver, one needs to select, from the visually available input, such information that will allow for efficient grasping. For example, size and orientation of the receiver might matter for grasping the receiver, adjusting grip aperture and finally picking it up. At the same time, such characteristics like color should not matter and thus might be ignored. Therefore, it makes sense to assume that the perceptual system weighs the action-relevant information higher allowing for efficient action control. This implies that action and perception systems are strongly interconnected. Such an idea has already been brought up and investigated by many authors. For instance, Allport's (1987) selection-for-action approach postulates that attentional selection takes place only because of limitations at the effector system; the Premotor Theory (Rizzolatti et al.,1994) postulates that attentional selection is mediated by pragmatic maps shared by perceptual and motor systems; and Deubel and colleagues have assumed a strong coupling of selection-for-perception and selection-for-action (e.g. Deubel & Schneider, 1996; Deubel, Schneider, & Paprotta, 1996) . Other authors postulate a common code which allows for binding perceptual features with characteristics of prepared actions (Hommel et al., 2001b). According to the Theory of Event Coding (Hommel et al., 2001b), the common code for perception and action takes the form of *event files* (see Figure 1.3). Action plans, similarly to perceptual events, are coded in a feature-format. Features are integrated via a binding process. Theory of Event Coding postulates that features are bound not only within-domain (particular features of perceptual events) but also across domains, i.e., binding of action-related features with perceptual features. Event files are temporary bindings between particular features across perception and action domains. This implies that whenever one member of an event file is activated, it will automatically prime the other member. In this way, features related to a particular action type have an impact on processing of perceptual features. More specifically, preparing for a particular type of action should lead to a higher weighting of information from action-relevant dimensions—a process that Hommel, et al. (2001b) have called "intentional weighting".

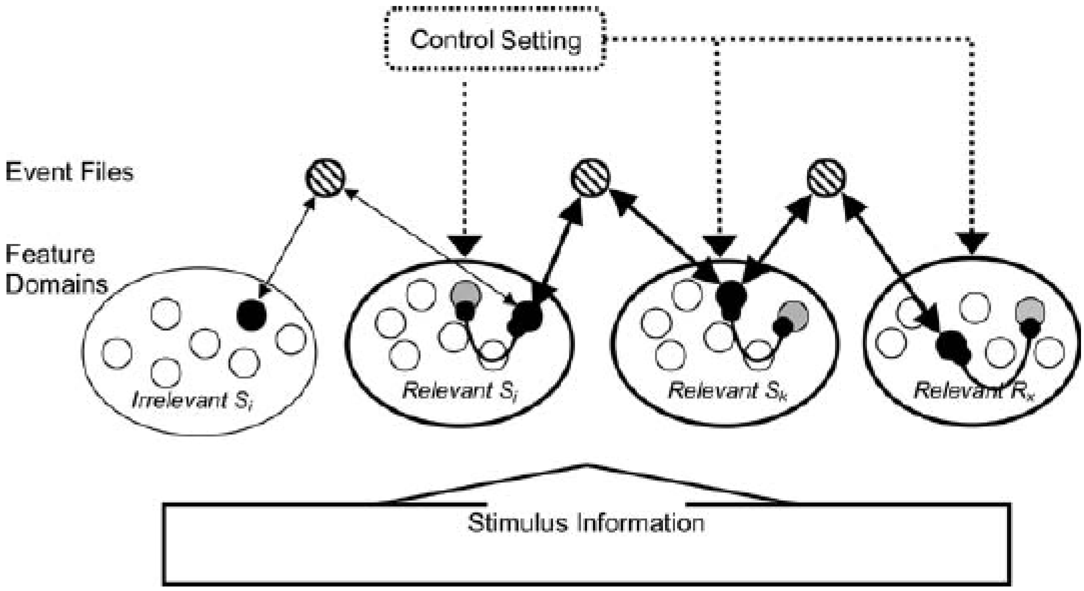

Figure 1.3. A schematic model of processing postulated by the Theory of Event Coding. As illustrated, stimuli and prepared responses can be activated in the Feature Domains (black circles). The codes within the Feature Domains compete for selection (which is reflected by inhibitory connections between particular codes within the Feature Domains). Once selected, the selected features form binary conjunctions (striped circles). Once a feature is bound with other features in an event file, it will prime that feature when activated. Importantly, control settings „weigh“ feature domains related to stimulus (represented as S_j and S_k) as well as response (R_x). This suggests that the features of responses might as well be weighted in a top-down manner. However, once weighted and winning competition for selection, they, in turn, might prime the features related to a stimulus through a common event file (striped circle). In this way, the movement-relevance might modulate perceptual processing. Figure taken from Hommel (2007).

Bottom-up weighting observed as inter-trial repetition effects

Another source of weighting of the perceptual information might be related to the system’s actual state and configuration of weights. If an employee working at a production line is checking whether pieces of Lego are correctly sorted into bags according to a category (say, e.g., small, black pieces in one bag and long, yellow pieces in another bag), they will look for an item that might differ from the others with respect to one feature (say, color). Thus, if they find a yellow piece in a bag of black pieces, they should detect it as erroneous categorization. If a series of bags with a color odd-one out piece will pass one after another, the employee's perceptual system is likely to automatically weight the color dimension higher (due to priming by repetition). Thus, they will be fast with detection of erroneously categorized color pieces. Therefore, if, subsequently, a bag with small black pieces containing one black, long piece will be passing by, the employee's detection of the erroneously categorized long piece will, most probably, take longer and have a higher chance of being missed than if a bag with black pieces and one yellow piece was presented again.

This phenomenon was investigated in experimental setups with a visual search paradigm by, e.g., Müller and colleagues (Müller et al., 1995; Found & Müller, 1996). To account for such dimension-specific priming effects, Müller and colleagues proposed a Dimension Weighting Account (Müller et al., 1995; Found & Müller, 1996), see Figure 1.4. According to the Dimensional Weighting Account, the visual field is represented in separate, dimension-specific 'Maps', such as color or orientation. Saliency signals are transmitted from these Maps to a Master Map of Saliency, which computes the weighted sum of dimension-specific signals.

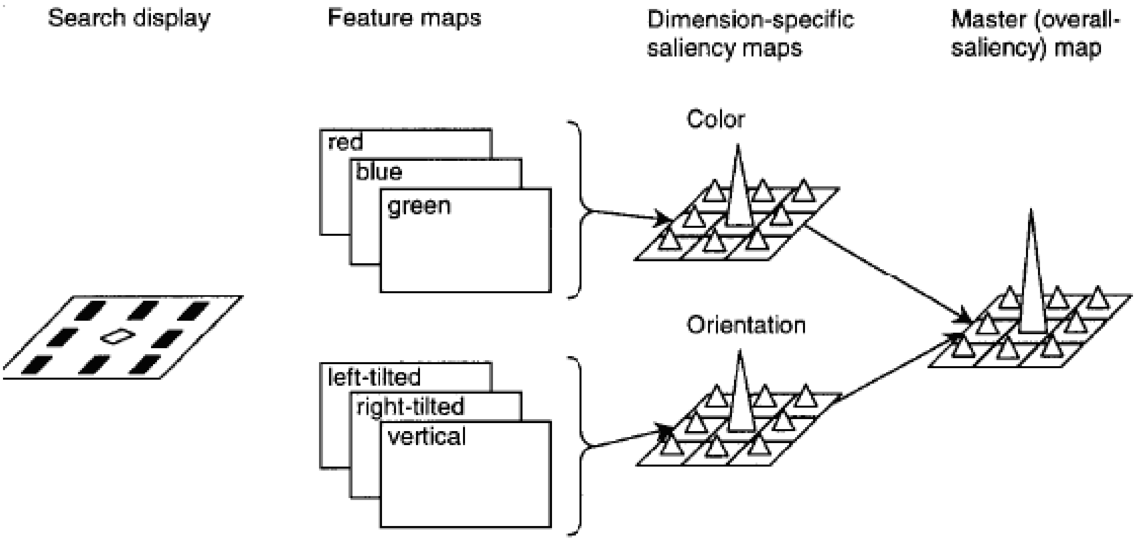

Figure 1.4. A schematic model of the architecture of the Dimensional Weighting Account. The saliency maps are computed separately for each dimension. At the level of Master Map of Saliency, a weighted sum of dimension-specific saliency signals is computed in a location-specific manner. The figure is taken from Krummenacher, Müller, & Heller (2002) and originally illustrated the redundancy gain phenomenon.

Weighting of the saliency signals is affected by task relevance and also other factors. Müller and colleagues (Found & Müller, 1996; Müller et al., 1995) found that responses to detection of a pop-out target were faster when the dimension of the target was repeated across trials compared to when it changed. The authors concluded that the visual system might implicitly set a weight on a dimension that contains a saliency signal in a particular trial. If, in the next trial, a different dimension map contains a saliency signal, a dimension-switch cost occurs because a weight set for that "new" dimension has been lower compared to the weight set for the dimension that contained a saliency signal in the previous trial. Therefore, weights need to be redistributed which results in a cost in reaction times. Results of Found and Müller (1996) showed that weights are assigned to whole dimensions, such as color or orientation rather than to particular feature values like 'red', 'green', or 'right-tilted'.

Interplay between mechanisms of selection

As described above, the weighting mechanism might allow for modulation of selection of visual input with respect to such factors like task-relevance, action-relevance or expectancy. At the same time, the bottom-up component of attention allocation is also active. Such a bottom-up mechanism of attention allocation allows for fast selection of stimuli that highly contrast with the surrounding.

Bottom-up driven selection of salient stimuli

Our perceptual system computes saliency signals for the incoming information that is transferred through separate feature channels like "orientation" or "color". Such saliency signals are nothing else but just local contrast information (see, e.g., Wolfe, 1994). In this way, a red item among green items will pop-out from the surrounding (its saliency values will be high) and as such will be detected with little effort (Itti & Koch, 2000; Treisman & Gelade, 1980; Theeuwes, 1992; Wolfe, 1994; Wolfe, 1998). In an everyday situation, like the one described as a thought experiment above, we are confronted with many events that are of a high saliency value and our system needs to select only some of them while rejecting others. As described above, the visual system might weight the information with respect to relevance and in this way allow for focusing of attention on the relevant input. What happens if the irrelevant items are very salient and compete for attentional resources with the relevant signal? Is the system's weighting mechanism powerful enough to override the salient but irrelevant distraction? Or, will the saliency signal capture our attention automatically regardless its irrelevance?

Some authors postulate (Theeuwes, 1992, 1994, 1995a; Theeuwes, Atchley, & Kramer, 2000) that the salient irrelevant item will capture attention automatically although it is irrelevant to current situation or task. In his studies, Theeuwes found that reaction times to the displays containing an irrelevant color singleton (see Figure 1.5a) were longer relative to responses to displays with only the relevant singleton (see Figure 1.5b).

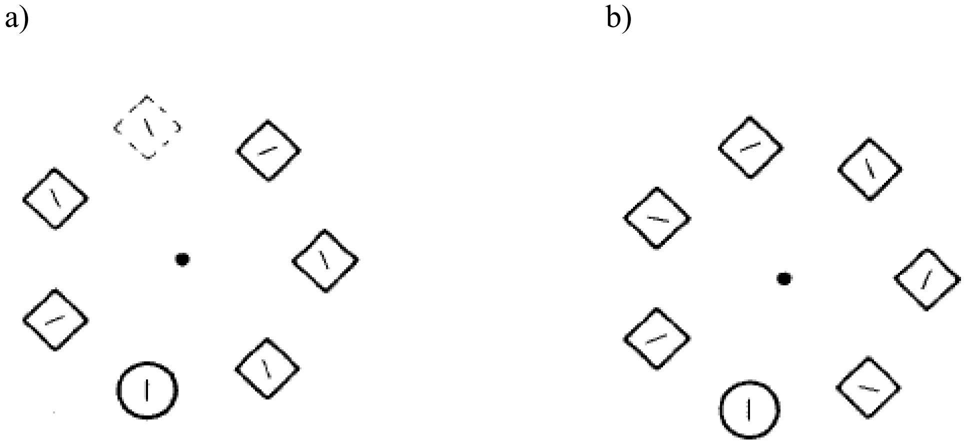

Figure 1.5. Stimuli used by Theeuwes (1992) in order to investigate the attentional capture effects to irrelevant singleton. Participants' task was to detect one of the features (e.g., circle) and ignore the other feature (e.g., different color: depicted here as dashed line) and respond to the orientation of the line presented within the feature-defined target (a so-called compound task). Figure taken from Theeuwes (1992).

Bottom-up driven selection vs. top-down guidance of attention through weighting

According to some authors (Theeuwes, 1992, 1994, 1995a; Theeuwes et al., 2000), interference effects from salient irrelevant items cannot be overridden by top-down activation at the early stage of processing (e.g., Theeuwes et al., 2000). Goal-driven control comes into play but only subsequent to automatic bottom-up capture (e.g., Theeuwes et al., 2000, van Zoest & Donk, 2006; van Zoest, Donk, & Theeuwes, 2004).

On the other hand, other authors argue that stimulus-driven attention capture is contingent on task-relevant attentional settings (e.g. Folk & Remington, 1998, 2006; Folk, Remington, & Johnston, 1992). Proponents of such perspective argue that if our perceptual system is attentionally set for a particular feature, the irrelevant salient item might capture our attention only if it shares characteristics with the target's features. In a cueing paradigm where invalid cues were used (see Figure 1.6), Folk & Remington (1998; 2006) found that attention was allocated to the task-irrelevant cue but only when it shared features of the target defined by instructions.

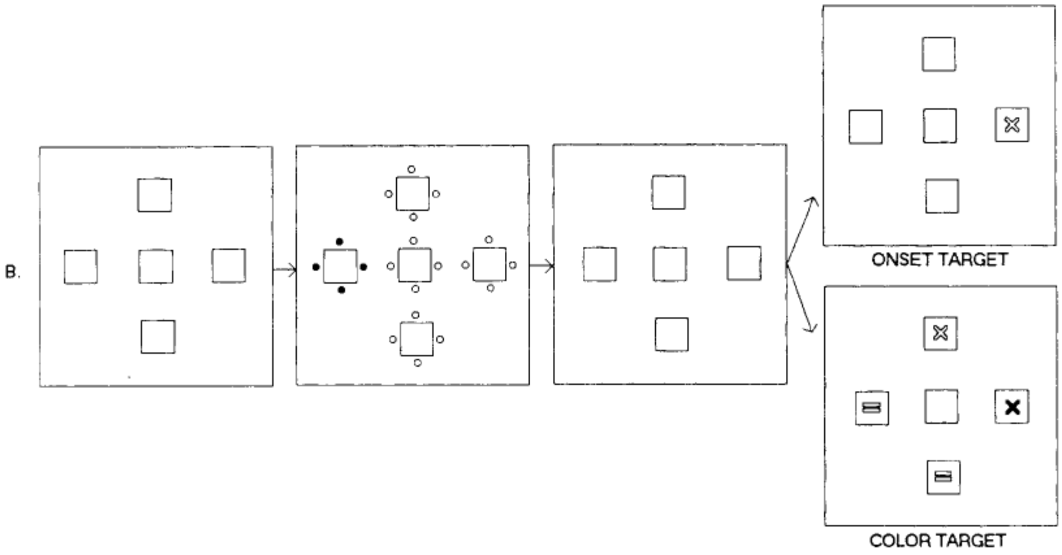

Figure 1.6. A trial sequence used by Folk &Remington (1992). In their study, the participants were asked to respond to a letter target defined by a particular feature (e.g., red). Prior to the display, an irrelevant cue was presented that could be congruent with the target defining feature or not. Figure taken form Folk & Remington (1992).

Time course of mechanisms of selection

Some authors stress the importance of the temporal factor in the issue of interplay between the top-down and bottom-up mechanisms of selection. It seems that these mechanisms might exhibit different time courses and different relative potency depending on a particular temporal window of the processing stream.

For example, Kim & Cave (1999) highlight the aspect of temporal development of top-down control. They claim that at first, attention might be allocated to a salient but irrelevant item in a bottom-up manner. Top-down control might efficiently guide attention to the relevant item only after a certain time. This is similar to the postulates of , e.g., Theeuwes et al., (2000); van Zoest & Donk (2006); van Zoest, et al. (2004). However, Kim & Cave (1999) disagree with Theeuwes and colleagues by stressing that even at the early stages of processing, when the bottom-up mechanism is more prevailing, the top-down modulation still can take place to some extent. Hence, they argue against the strong claim that attentional capture to salient items is impenetrable to top-down modulation. On the other hand, they also argue against the "*contingent capture*" stance of Folk & Remington (1998, 2006). Their argumentation is based on effects of attentional capture to a salient singleton that did not share characteristics of the target (Kim & Cave, 1999).

In a paradigm in which a probe was presented subsequent to a search display (see Figure 1.7), the authors found that attention was allocated to the irrelevant singleton in a bottom-up manner immediately after display presentation. With time, however, the attentional capture phenomenon decayed whereas effects the top-down control of focal attention developed. Interestingly, even when the bottom-up attentional capture effects were observed, they were modulated by top-down control to some extent (for a more detailed discussion see Chapter 2).

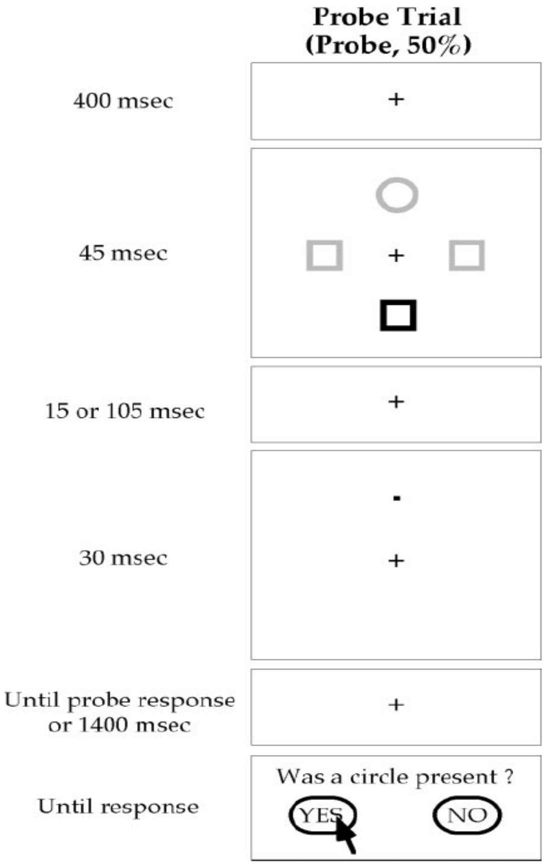

Figure 1.7. A trial sequence introduced in Kim & Cave (1999). In their study, participants were asked to detect a target defined by one dimension (e.g., shape) and ignore the other dimension (i.e., color). Subsequent to display presentation, they were presented with a probe which they were also to detect. Two variable SOAs were introduced to investigate the temporal dynamics of the interplay between the bottom-up and the top-down mechanisms. Figure taken from Kim & Cave (1999).

Chapter 2: On the action-related weighting of perceptual dimensions

Abstract

Three experiments investigated the impact of planning and preparing a manual grasping or pointing movement on feature detection in a visual search task. Action planning may prime dimensions that provide information for the open parameters of that action. Indeed, preparing for grasping facilitated the detection of size targets while preparing for pointing facilitated the detection of luminance targets. The present results show, in line with the Theory of Event Coding, that action planning is accompanied by the "intentional weighting" of action-relevant perceptual dimensions.

Interestingly, the action-related bias was observed only when perceptual dimensions were also weighted with respect to task relevance, that is, when participants searched for a target defined in advance. This implies that action-related weighting is not independent from weighting according to task-relevance.

To account for these findings, an integrative model of visual search that incorporates input from action-planning processes has been suggested at the end of this chapter.

Theoretical background

Human perceptual system needs to select information for further processing. Which pieces of information will be selected depends on many factors. Stimuli that are salient will, most probably, capture attention. At the same time, the perceptual system is tuned to currently relevant information. Various theories and models have been postulated to describe and to account for mechanisms of selection and large amounts of empirical data have been collected to test them (e.g., Bundesen, 1990; Desimone & Duncan, 1995; Eriksen & Yeh, 1985; Müller, Heller & Ziegler, 1995; Posner, 1980; Wolfe, 1994; and many others). Many authors have also stressed that the action context in which perceptual events are processed might also influence perceptual processing (e.g., Craighero, Fadiga, Rizzolatti, & Umiltà, 1999; Deubel & Schneider, 1996; Fagioli, Hommel & Schubotz, 2007; Hommel, Müsseler, Aschersleben, & Prinz, 2001b; Humphreys & Riddoch, 2001; Rizzolatti, Riggio & Sheliga, 1994 and many others). As argued later, preparing for a particular type of action prepares an agent to process particular types of information. To be more precise, preparing to act should weight higher those stimulus dimensions that are relevant for the control of the respective action (Fagioli, et al., 2007). The following question will be addressed by Experiment 2.1-2.3: how action-related weighting interacts with other ways of biasing the visual input, i.e. bias related to task-relevance as well as bias that might occur implicitly through, e.g., priming by repetition of the same type of stimulus.

Weighting mechanisms in visual processing

Many authors agree that task requirements and behavioral relevance influence processing of visual features (e.g., Bacon & Egeth, 1994; Egeth, Virzi & Garbart, 1984; Wolfe, 2001; Wolfe, Horowitz, Kenner, Hyle & Vasan, 2004). To account for this impact, several theories have proposed a biasing or a weighting mechanism (e.g., Bundesen, 1990; Found & Müller, 1996; Müller et al., 1995; Müller, Reimann, & Krummenacher, 2003;

Wolfe, 1994). The cognitive system is assumed to assign weights to information that is particularly relevant so that stimuli that vary on highly-weighted dimensions are prioritized and have a higher chance of winning the competition for selection. Evidence for a weighting mechanisms has been provided by behavioral studies (e.g., Egeth et al., 1984; Wolfe, 2001, Wolfe, Butcher, Lee, & Hyle, 2003; Wolfe et al., 2004) and neurophysiological observations (e.g., Chelazzi, Duncan, Miller & Desimone, 1998; Luck, Chelazzi, Hillyard & Desimone, 1997; Moran & Desimone, 1985; Reynolds, Chelazzi & Desimone, 1999). In some of the above-mentioned studies, weighting was induced explicitly, via task instruction (e.g., Bacon & Egeth, 1994; Wolfe et al., 2004) or cueing (e.g., Luck et al., 1997; Moran & Desimone, 1985; Reynolds et al., 1999). However, a weighting mechanism might also be induced implicitly, through, for example, priming of dimensions via repetition across subsequent trials (e.g., Found & Müller, 1996; Müller et al, 1995). According to the Dimensional Weighting Account of Müller et al. (1995), the visual field is represented in separate, dimension-specific 'maps', such as color or orientation. Saliency signals are transmitted from these maps to a master map of saliency, which computes the weighted sum of dimension-specific signals. Weighting of the saliency signals might be affected by task relevance. Results of e.g., Found & Müller (1996), Müller et al. (1995) showed that it also might be affected by implicit priming. In series of experiments where participants searched for a pop-out item, the authors found a benefit in performance for trials preceded by same-dimension trials relative to trials preceded by a different dimension. The authors concluded that the system weights relevant dimensions and that a switch from one dimension to another (as in the case of dimension change) results in a performance drop.

Interactions between perception and action

Part of the function of perceptual processes is to identify contextual trigger conditions, that is, conditions under which particular actions are to be carried out. Psychological experiments often focus on this trigger function of perception by using stimuli that are only arbitrarily mapped to responses, such as when left and right key presses are signaled by, for example, green and red dots on a computer monitor. However, everyday actions are often rather different (cf., Kelso & Kay, 1987). Controlling the grasping of a cup of coffee requires more than the sight of a coffee cup: processing the location of the cup is necessary to steer the hand towards it (Jeannerod's, 1984, transport component) and processing its shape is necessary to program the hand for the eventual grasp (the grasping component proper). In other words, perception is often needed to detect and process information that is suited to control relevant parameters of action programs.

A number of authors have considered the possibility that visual selection and action are interdependent. For instance, Allport's (1987) selection-for-action approach claims that attentional selection takes place only because of limitations at the effector system; the Premotor Theory (Rizzolatti, Riggio & Sheliga, 1994) postulates that attentional selection is mediated by pragmatic maps shared by perceptual and motor systems; and Deubel & Schneider have assumed a strong coupling of selection-for-perception and selection-for-action (e.g. Deubel & Schneider, 1996; Deubel, Schneider, & Paprotta, 1996).

In the following sections, it will be argued that action planning constitutes a bidirectional link between perceptual and action systems. Since a strong link between perception and action exists, it makes sense to assume that the link exhibits bidirectional effects as postulated by some authors (e.g., Hommel et al., 2001b in the Theory of Event Coding). It is obvious that through perception we control our action planning. However, in order to control actions successfully, we need to select action-relevant information from the abundance of input. Hence, not only perception influences action but also action planning should influence perception. This implies that setting up a particular action program should also bias perceptual systems to focus on those perceptual dimensions that are likely to provide control-relevant information. Therefore, weighting of perceptual dimensions might have yet another source, i.e., action control. Such an action-related weighting process was called "intentional weighting" by Hommel et al. (2001b).

Intentional weighting – a link from action to perception

Craighero et al. (1999) found evidence for what might be interpreted as such a weighting mechanism. In a series of studies, the authors demonstrated that latencies of a grasping movement towards a particular object were dependent on whether the orientation of a visually presented go-signal was congruent with the to-be grasped object. Their results showed that the congruent go-signals decreased latencies of the movement towards a left- or right- oriented bar. Also in cases when the grasping movement was supposed to be prepared but subsequently withheld and substituted by a response with a foot pedal, response times were dependent on the congruency factor. Therefore, the authors concluded that preparing for a movement (grasping, in the case of their studies) influenced visual detection (of the go-signal) dependent on whether the visually presented stimulus shared characteristics of the to-be grasped object or was incongruent with it.

Furthermore, Humphreys & Riddoch (2001) showed, in a neuropsychological study, that our perceptual system is capable of guiding visual selection by action-defined search templates. The authors observed a unilateral neglect patient who was impaired at finding objects defined by perceptual features. His performance on a visual search task was improved when the target was defined by its possible action-related function. That is, in a visual search test, the patient's task was to detect a target which was defined by either its name, its color or by an associated action (e.g., something to drink from). Results showed that the patient was better in the condition in which he was to search for the target defined by associated action compared to when the target was defined by color or name. In this way, the authors showed that object affordances (action-related, functional characteristics of an object) can influence visual selection. They argued in favor of a pragmatic route linking action with perception.

Such a route would allow for an efficient action-related template matching in a situation when using perceptual templates is impaired.

Another interesting line of evidence for action-related weighting of perceptual processing was obtained by Bekkering & Neggers (2002) who demonstrated movement-related influences on search for a target item in a visual search paradigm. The task was to detect a target defined by a conjunction of orientation and color features. Subsequent to detection, observers were asked to either grasp the target or point to it. The results showed that a smaller amount of orientation errors was committed when participants prepared for grasping compared to pointing. Errors were measured as the first landing point of the first saccade on an irrelevant item with the correct color but incorrect orientation. The authors argued that activating representation of a particular movement enhances the processing of task-relevant features.

Intentional weighting of perceptual dimensions

While the observations of Bekkering & Neggers (2002) support the idea that the selection of perceptual targets interacts with the selection of action targets, they do not require the assumption that preparing for a particular *type* of action biases a whole *dimension*. However, more recent evidence suggests that this is what actually happens. Fagioli, Hommel, & Schubotz (2007) presented participants with sequences of stimuli. In these sequences, one dimension varied in a predictable fashion (e.g., by alternating size: large-small-large-small…; or systematically shifting location from bottom-left to top-right), and participants were to detect oddballs, i.e., stimuli deviating from the respective “rule”. Before each trial, a movement cue signaled the preparation of grasping or pointing action to be carried out after the presentation of the visual sequence. Results showed that preparing for pointing facilitated the detection of location oddballs while preparing for grasping facilitated the detection of size oddballs. Results of Fagioli et al. (2007) support the idea of intentional weighting in the sense of Hommel et al.’s (2001b) Theory of Event Coding (TEC).

Although Fagioli et al. (2007) found evidence for action-related weighting at early stages of processing, neither these authors nor any others have investigated how such a mechanism is related to other types of bias such as explicit task-relevance weighting or weighting observed as inter-trial repetition effects (examined by, e.g., Found & Müller, 1996; Maljkovic & Nakayama, 1994; Müller et al., 1995). If perceptual dimensions might be weighted with respect to action-relevance, task relevance, or inter-trial repetition, the question arises whether the action-related weighting is independent of other types of bias or if they interact in some way. Present series of experiments aimed at investigating the influence of movement intentions on processing perceptual dimensions in situations when different types of weighting were induced, i.e., either the explicit task-relevant weighting or only the bottom-up type of weighting through inter-trial repetition.

Rationale of the experiments

The present study was designed to investigate the effects of action-related weighting of perceptual dimensions in a visual search task, i.e., in a task that is known to tap into relatively early aspects of visual processing. Experiments 2.1.-2.3 aimed at examining whether such action-related weighting mechanism would be observed at the early stages of processing, i.e., at level of simple detection and whether it would depend on other types of bias, i.e., an explicit task-relevance bias and/or weighting through repetition.

Experiment 2.1 was designed to test whether the action-related effects would be observed in a classical attentional task, namely a visual search task for pop-out item. In particular, the goal of Experiment 2.1 was to examine whether targets with action-relevant characteristics would be easier to select than targets with action-irrelevant characteristics. Even though the available findings are encouraging with respect to the possible impact of action control on visual attention, they used rather atypical tasks and designs, which raises the question whether evidence for such an impact can also be demonstrated in more classical attentional tasks.

Unlike Bekkering and Neggers (2002) and other previous studies, Experiment 2.1 aimed at investigating weighting mechanisms that operate at the level of simple feature detection and not on objects defined by conjunctions of features. This linked Experiment 2.1 to the study by Fagioli et al. (2007) but, unlike these authors, Experiment 2.1 would examine the process of selection in space (as required in a visual search task) rather than selection in time (as required in an oddball paradigm with a sequence of stimuli).

In particular, participants were asked to prepare for a pointing or grasping movement while they had to detect, from a set of distracting items, a target defined as a circle of either lighter luminance or smaller size. Two movement types and two dimensions that could be combined to two *congruent* and two *incongruent* action-dimension pairs were selected in order to examine the impact of action preparation on selection of particular perceptual dimensions. It was assumed that size should be relevant for grasping movement (see e.g., Ellis & Tucker, 2001). When preparing for a grasping movement, one needs to program such parameters as, e.g., grip aperture. In order to do so, one needs to select relevant information such as size. The brightness of an object should not matter in preparing a specification for a grasping movement. Therefore, the perceptual size dimension and the grasping movement should constitute a *congruent* pair. Accordingly, the first hypothesis stated that intending to grasp should be beneficial for the detection of size-defined visual targets. As for the pointing movement, localization of a to-be pointed object is important. Pointing does not require specification of, e.g., grip aperture so programming a pointing movement probably does not involve selection of such characteristics like size. Size is presumably not relevant as long as the object is not reached, but only pointed to from a distance. Therefore, for pointing, fast localization should be relevant. In line with results showing that luminance targets allow for efficient localization of an object with a pointing-movement response (e.g., Anderson & Yamagishi, 2000;

Gegenfurtner, 2004; Graves, 1996), luminance should constitute relevant dimension for a pointing movement. Also, due to the fact that luminance contrasts are, most probably, processed in the mango-cellular system (as discussed in Anderson & Yamagishi, 2000) and might therefore be more closely linked to the dorsal stream responsible for localization (Ungerleider & Mishkin, 1982), luminance dimension seemed to be appropriate for pointing. Hence, a second *congruent* pair was created by combining the perceptual luminance dimension and pointing movement. Accordingly, the second hypothesis stated that intending to perform a pointing movement should be beneficial for detection of luminance-defined targets.

Experiment 2.2 and Experiment 2.3 were designed to test whether the action-related influences on perceptual processing would depend on other types of bias, namely the explicit task-relevance bias and the inter-trial repetition effects. In order to manipulate the explicit task-related bias, Experiment 2.2 and Experiment 2.3 were designed according to the assumption that there is two possible ways how participants might perform a task when they search for a target differing from distracters with respect to only one feature. Depending on an experimental design and instructions, participants might either search for a predefined target characteristics or base their selection on any saliency signals appearing in the visual field (for discussion see, e.g., Bacon & Egeth, 1994).

In the first case, prior target specification might allow an observer to generate a target template that may be used to select items matching the template while ignoring non-matching items (Duncan & Humphreys, 1989). When selection is based on a specific target dimension defined in advance, this dimension will be weighted according to its relevance for target detection in the visual search task.

In the second case, when participants are not informed about the dimension of a target and are instructed to select any item that pops out from the surrounding distracters, they might perform the task based rather on singleton detection (Bacon & Egeth, 1994). Such a strategy might be based on a bottom-up driven mechanism which allows for efficient detection of saliency signals. Performing detection task based on this strategy might, therefore, not make use of weighting of dimensions with respect to task-relevance or might weight all dimensions to equal amount.

Explicit weighting with respect to task relevance may thus be prominent when search is based on specific target characteristics but nearly absent when search is based on saliency detection (in singleton detection).

Weighting through repetition might be present also in case of search based on bottom-up driven singleton detection mode. However, it might be observed only in a design in which performance in trials that follow same-dimension trials (repeated-dimension condition) are compared to performance on trials that follow trials with a singleton of a different dimension (different-dimension condition).

In Experiment 2.1, target dimension was blocked and defined prior to each block. Therefore, participants were informed that if a target will be present, it will be of a particular dimension. Hence, they might have generated a target template for a particular dimension allowing for weighting that dimension higher. Obviously, they could additionally select the target based on the bottom-up “information” about a presence of a singleton that would pop-out from the surrounding distracters. Therefore, in Experiment 2.1, both the “singleton-detection” mode as well as task-relevance weighting of a particular dimension was possible. Inter-trial repetition effects could not have been measured as the target dimensions were blocked. This did not allow for a comparison of repeated-dimension trials with a condition in which dimensions would differ across trials.

In Experiment 2.2, the target dimensions were intermixed, i.e., both size and luminance target displays could be presented within a block of trials. Moreover, participants were instructed to detect any singleton that would pop out from the distracter elements. Therefore, Experiment 2.2 encouraged the “singleton-detection” strategy that should be primarily based on detecting bottom-up saliency signals (any salient singleton) and hence discouraged the explicit task-relevance weighting. At the same time, weighting through inter-trial repetition should be observable, i.e., comparing trials with repeated dimensions to trials with consecutively different dimensions possible. According to the results of Müller and colleagues (e.g., Found & Müller, 1996; Müller et al., 1995), if a singleton of a particular dimension is presented on a particular trial, it primes detection of the same (repeated) dimension on subsequent trial. Experiment 2.2 was designed to test whether action-related weighting mechanism would be observed in case of discouraged task-relevance weighting (whether it would, therefore, be independent of the explicit task-relevance weighting mechanism) and whether it would be related to weighting through inter-trial dimension repetition.

In Experiment 2.3, two types of singletons were also intermixed, i.e., both size and luminance target displays could be presented within a block of trials. However, in this Experiment, participants were asked to detect one of the types (say, size) and reject the other as irrelevant. The relevance assignment was blocked and counterbalanced. In this way, Experiment 2.3 discouraged the singleton detection mode and was designed to induce the task-related weighting of a particular dimension. At the same time, also the inter-trial repetition effects should be observable. The aim of Experiment 2.3 was to examine how action-related weighting, task-relevance explicit weighting and weighting induced by inter-trial repetition would interact.

General methods

Stimuli and apparatus

Stimuli were presented on a 17-inch computer screen with a 60 Hz refresh rate (Iiyama MA 201D, Vision Master 511) placed at a distance of 100 cm from an observer. The experiment was run on a Siemens Celsius 420 computer with a Celeron 466 MHz processor.

The search display contained always 28 items (grey circles of 1.7° of visual angle; R: 178, G:178, B:178 in the RGB scale) positioned on three imaginary circles with a diameter of 6.8°, 4.8°, and 2.8°. The target could appear on one of four positions on the middle circle of

4.8° diameter at the upper left/right or lower left/right from the middle point. The target was defined either by luminance (lighter grey, R: 221, G: 221, B: 221 in the RGB scale) or by size (smaller circle, 1.1° cm of visual angle), see Figure 2.1.

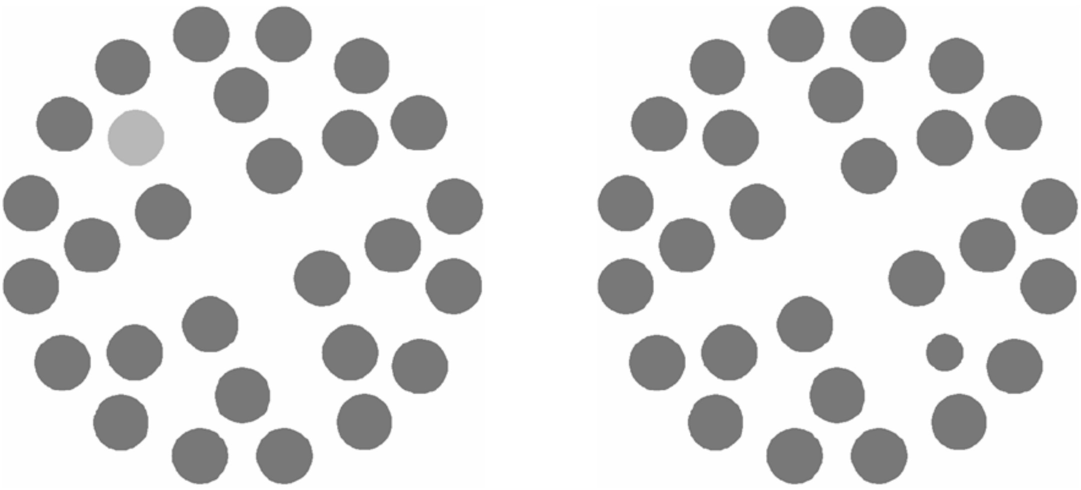

Figure 2.1. Example of search displays. Two displays each containing a singleton: a luminance singleton (left) and size singleton (right). Targets could appear in four possible positions on the middle imaginary circle.

Movement Execution Device[1] (MED, Figure 2.2) was positioned below the computer screen, at a distance of 80 cm from the participants' seat. Midpoint of the device was situated at 40 cm below and 20 cm distance forward of the midpoint of the computer screen. The MED was designed for the purpose of this study to allow participants to perform grasping and pointing movements on the same objects. It consisted of a 43 cm x 54 cm x 13 cm box containing eight holes positioned on an imaginary circle of 22.2° of visual angle. Round plastic items that could vary in luminance and size each covering a LED could be attached and detached from the box. For the purpose of these experiments, the following combination of the circular items was used: four grey (R: 178, G:178, B:178 in the RGB scale), medium-sized (3.7° of visual angle) items; two grey items that differed in size being smaller (2°) and larger (5.4°) than the standard elements; and finally two items that differed in luminance

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[1] MED was designed by Agnieszka Wykowska and Anna Schubö. It was constructed by Aleksander Dziadecki, University of Science and Technology, Kraków, Poland.

being darker (R: 148, G: 148, B: 148 in the RGB scale) and lighter (R: 221, G: 221, B: 221 in the RGB scale) than the standard elements.

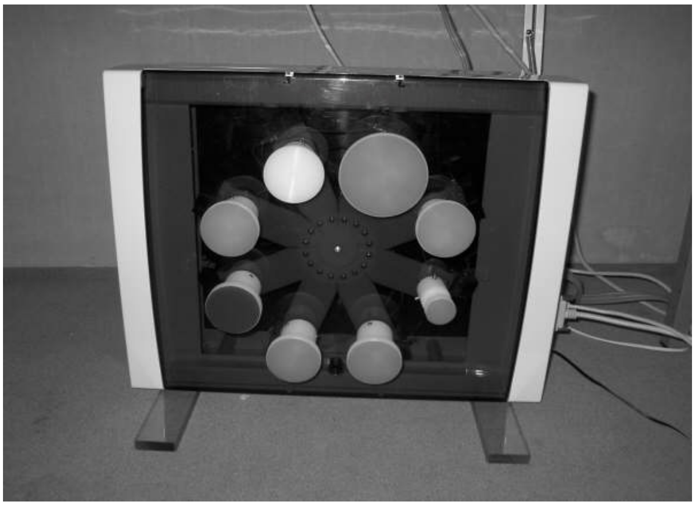

Figure 2.2. Movement Execution Device (MED) on which observers performed the required movement type (grasping or pointing) upon completion of the detection task. Grasping consisted in grasping and pulling one of the plastic circles sticking out of the box (the one that lit up) and pointing required a pointing movement towards the lit circle without touching it.

Participants were seated in a dimly lit, electrically shielded and sound attenuated chamber with response keys embedded in a response pad (ERTS ExKey) positioned below their dominant hand. Grasping/pointing action was performed with their other hand on the MED. The device was connected to the experimental computer via an LPT port and was controlled by the computer receiving signals at which moment which particular LED (out of the 8 attached LEDs) should light up and for how long it should remain lit. The computer screen was positioned at 1 m distance from the participants' eyes.

Procedure

All participants practiced the movement execution on MED before the experimental session (minimum one day and maximum two days in advance). The aim of the training was to practice the movement execution so that the whole experimental task would be easier to perform. In the training session, participants performed 4 blocks of only one pointing or grasping and 2 blocks of pointing and grasping randomly intermixed (64 trials per each block). Participants were trained to perform the movement with both hands. For the first four blocks of the practice session, participants were verbally instructed (at the beginning of a block) regarding the type of movement to be trained. For the two last blocks, where grasping and pointing movements were randomly intermixed, participants were cued on a trial-by-trial basis with respect to what type of movement is to be performed. Cues consisted in a picture of a particular movement type (see Figure 2.3.).

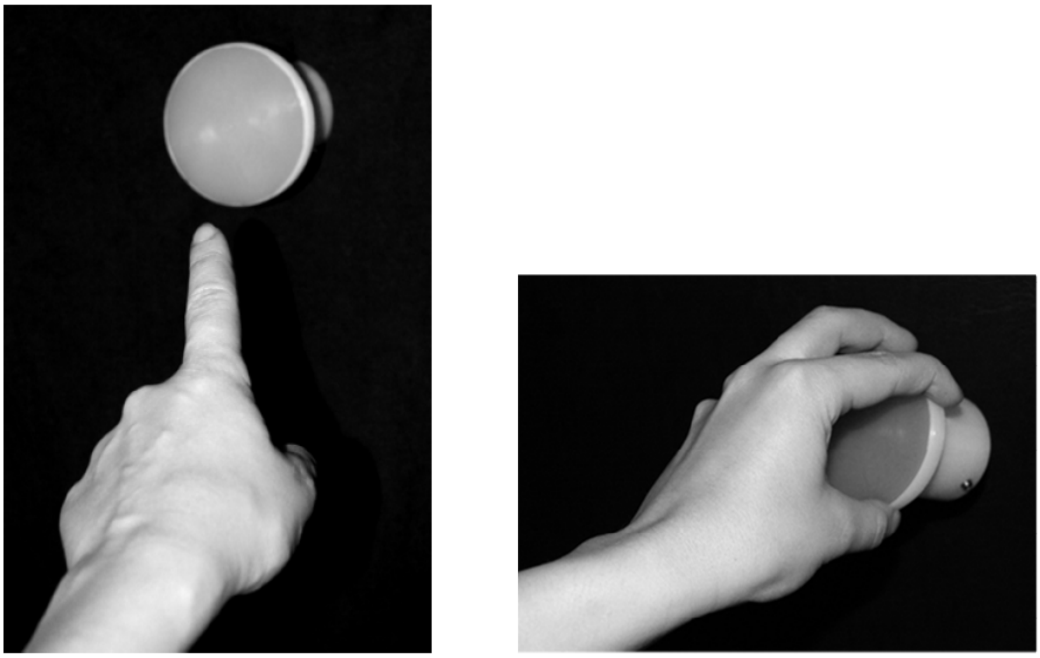

Figure 2.3. Movement cues. A *pointing movement cue* (left) or a *grasping movement cue* (right) was presented prior to the search display. The cues informed about the movement type that had to be prepared but not executed until the completion of the detection task.

Before the practice session, all participants' visual acuity was tested with a Rodenstock R12 vision tester, stimuli nr.112. The experiment was conducted with the understanding and consent of each participant.

Experiment 2.1

The aim of Experiment 2.1 was to investigate effects of action planning on visual selection. Preparing to grasp should bias and enhance processing of the size dimension. As argued before, when preparing to grasp, one needs to program such parameters as, e.g., grip aperture and thus, size provides relevant information for such specification. In case of grasping, brightness of an object should not be relevant to that extent as size. In contrast, for the pointing movement, fast localization of a to-be pointed object should be important. Since luminance enables efficient localization, preparing to point should facilitate detection of the luminance dimension (see discussion above). Pointing does not require specification of, e.g., grip aperture so programming a pointing movement probably does not involve selection of such characteristics like size.

Therefore, the particular hypotheses postulated that reaction times to size detection should be faster when preparing for a grasping movement relative to pointing movement whereas reaction times to luminance detection should be faster when preparing for a pointing movement relative to grasping.

Moreover, since the target-defining dimensions were blocked, it was assumed that the target might be selected in a bottom-up manner (based on its saliency signals) but, additionally, dimensions might be weighted with respect to task relevance. Since participants were asked to select a target of a particular dimension (e.g., size targets) and they were informed that only two types of displays, i.e., target displays (size in the example case) or blank displays, would be presented, they could weigh the target dimension higher with respect to task relevance for the whole block of trials. Therefore, in the case of Experiment 2.1, a twofold bias towards perceptual dimensions was assumed, i.e., a bias with respect to task-relevance on the one hand and a bias resulting from action-relevance on the other. Inter-trial repetition effects could not be observed due to the fact that it was impossible to compare dimension-repetition trials with different-dimension trials in case of such a blocked design.

Method

Participants

Twelve paid volunteers (6 female; age range: 18-30 years) took part. One participant was left-handed, all had normal or corrected to normal vision. Participants were not informed about the exact the aims of this particular experiment.

Procedure

The experimental session consisted of 4 blocks à 128 trials. At the beginning of the experimental session, participants performed a practice block in which they practiced the detection task (one block for luminance and one for size) together with the movement preparation and subsequent execution.

In the experimental blocks, the two target types (size and luminance) remained constant for half of the blocks, with their order balanced across participants. The movement task was intermixed within blocks and participants were presented with a picture cue concerning the movement type they were to execute.

Each trial began with a fixation cross presented for 500 ms. which was followed by a movement cue presented for 1500 ms. Participants were instructed to prepare for the cued movement but execute it only after a signal from the MED would appear. Subsequent to cue presentation, a search display appeared for 100 ms. Then, a blank screen followed and remained on the computer screen for 2500 ms while the participants were to perform the detection task. Participants were asked to press one of the keys for target present trials and the other one for target absent. Key assignment (left or right key response for target presence) was counterbalanced across participants. The blank screen was followed by a signal from the MED, i.e., one of the LEDs was lighting up for 300 ms. Observers were instructed to execute the prepared movement only at this point, i.e., they were to either point or grasp the item that lit up. After 1500 ms, subsequent to LED light offset, a new trial began. The trial sequence is depicted in Figure 2.4., left panel.

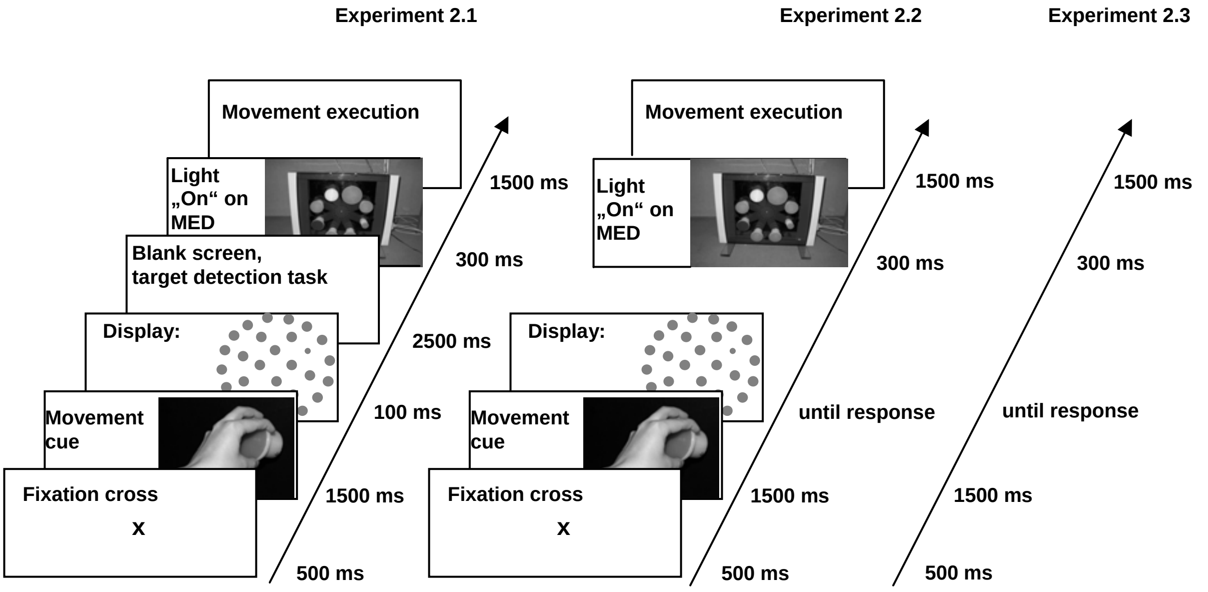

Figure 2.4. Trial sequences in Experiment 2.1 (left), Experiment 2.2 (middle) and Experiment 2.3 (right). A trial started with a fixation cross (500 ms) followed by a movement cue (1500 ms). With the presentation of the movement cue, participants were instructed to prepare the cued movement but not execute it prior to completion of the detection task. Subsequent to presentation of the movement cue, the search display was presented. It remained on the screen for 100 ms (Experiment 2.1) or until response (Experiment 2.2 and 2.3). Subsequent to response in the detection task, one of the lights on MED lit up and observers were asked to execute the movement type they have been preparing. With the execution of the movement, a trial ended.

Correctness of movement execution was registered by the experimenter seated in the same chamber as the participants.

For the detection task, both speed and accuracy were stressed whereas for movement execution, participants were asked only to be as accurate as possible. Observers were instructed in detail about their task before the experiment started.

Data analysis

Prior to analysis, mean response times (RT) and standard deviations (SD) were computed for each participant and each experimental block. Incorrect movement trials, trials with no responses, as well as outliers in the search task (+/- 3 SD from the overall mean of RT for each participant and each block separately) were excluded from further analyses. From the remaining data, individual mean reaction times and errors in the detection task were submitted to analysis of variance (ANOVA) with: *task-relevant dimension* (luminance vs. size), *movement type* (point vs. grasp), *trial type* (target absent vs. target present trials) as within-subject factors. Wherever appropriate, specific sub-group differences were tested with paired-sample t-tests.

Results

Reaction times

The 2×2×2 ANOVA showed a main effect of task-relevant dimension, $F(1, 11) = 19.74$, $p < .005$, $\eta_p^2 = .642$, indicating slower reaction times for size detection (*M* = 573 ms, *SEM* = 28) compared to luminance detection (*M* = 502 ms, *SEM* = 18). There was also a main effect of trial type, $F(1, 11) = 10.11$, $p < .01$, $\eta_p^2 = .479$, showing longer reaction times for target absent trials (*M* = 558 ms, *SEM* = 25) compared to target present trials (*M* = 517 ms, *SEM* = 21).

The analysis showed also a significant interaction between task-relevant dimension and movement type, $F(1, 11) = 5.99$, $p < .05$, $\eta_p^2 = .353$, (cf. Figure 2.5) and, additionally, an interaction between trial type and task-relevant dimension factors, $F\ (1, 11) = 25.6$, $p < .001$), $\eta_p^2 = .700$.

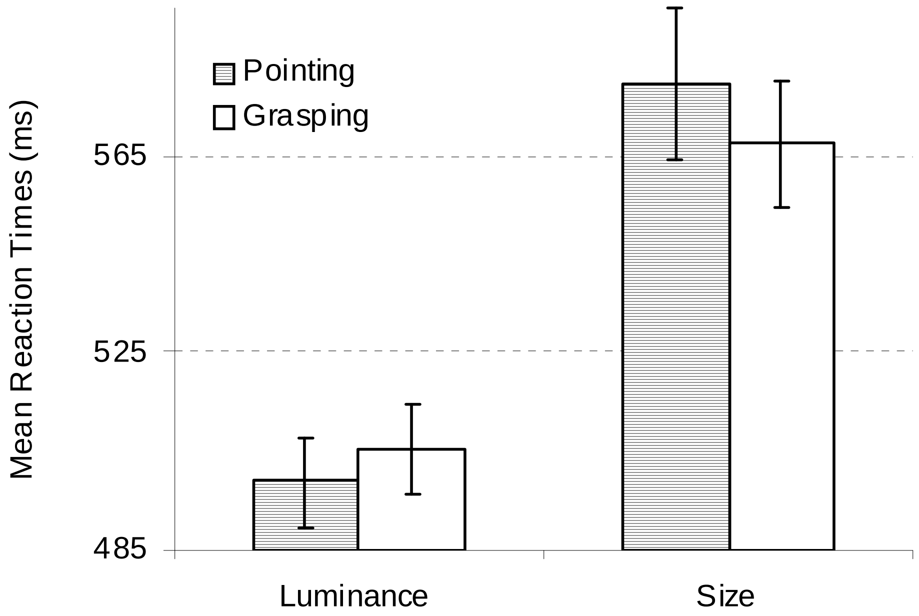

Figure 2.5. Effects of task-relevant dimension and movement type in Experiment 2.1. Mean reaction times (RTs) to *luminance* as task-relevant dimension (left panel) and *size* as task-relevant dimension (right panel) while participants prepared a *pointing* movement (filled bars) or a *grasping* movement (empty bars). Error bars represent standard errors of the mean.

In order to compare mean reaction times in grasping and pointing conditions in luminance and size detection separately, additional one-tailed t-tests were conducted. T-tests showed that when luminance was the task-relevant dimension, the difference between reaction times in grasping compared to pointing condition was significant, $t(11) = 2.2$, $p < .05$ showing faster reactions to luminance targets when preparing for pointing compared to grasping (cf. Figure 2.5, left panel). When size was the task-relevant dimension, the t-tests showed also a significant difference between the grasping and the pointing condition $t(11) = 1.8$, $p < .05$. In this condition, reactions in size detection were faster in grasping condition compared to pointing (cf. Figure 2.5, right panel). Summarized results of the interacting movement type and task-relevant dimension factors are given in Table 2.1.

Task-relevant dimension	Mean RTs		SE	
	Pointing	Grasping	Pointing	Grasping
Luminance	498 ms	505 ms	18	18
Size	580 ms	567 ms	31	26

Table 2.1. Mean reaction times (RTs) and standard errors of the mean (SE) to task-relevant dimensions as a function of movement type (pointing vs. grasping) in Experiment 2.1.

Furthermore, separate t-tests were conducted to compare reaction times to target present and target absent trials for each task-relevant dimension (luminance vs. size) separately. When size was the task-relevant dimension, reaction times were significantly longer for target absent trials (vs. target present), $t(11) = 4.6$, $p < .005$, while this difference did not reach significance for luminance, $p > .26$.

Error rates

Overall mean error rates were below 5%. The 2×2×2 ANOVA showed a main effect of task-relevant dimension, $F(1, 11) = 6.94$, $p < .05$, $\eta_p^2 = .387$, showing larger error rates for size ($M = 6.2$ %, $SEM = 1.5$) compared to luminance detection task ($M = 2.9\%$, $SEM = 0.5$). No other effects reached the level of significance.

Discussion

This experiment investigated whether the intention to act biases attentional selection in a visual search task. In line with the TEC's intentional weighting principle (Hommel et al., 2001b), intention to perform a particular action should increase weights of action-relevant perceptual dimensions. In particular, it was expected that searching for size targets would be easier while intending to perform a grasping movement compared to a pointing movement, while searching for luminance targets would be easier while intending to carry out a pointing movement. The obtained results were as expected. The significant interaction between movement type (grasping vs. pointing) and task-relevant dimension (size vs. luminance) in the RT data clearly showed an influence of movement preparation on visual search. When the perceptual dimension was relevant for the intended movement, it was detected faster compared to when it was incongruent with the intended movement type.

In addition to these results, RTs were slower when size was the task-relevant dimension. This effect might reflect a search asymmetry as has been found for other dimensions (e.g., Treisman & Gormican, 1988).

The second effect, namely, that of trial type showing longer RTs to target-absent trials vs. target-present trials, is also a common phenomenon in visual search experiments (Chun & Wolfe, 1996).

Finally, an interaction between trial type and task-relevant dimension was observed, showing that the difference between target absent and target present trials was especially pronounced when people searched for size but insignificant when they searched for luminance. This result might also be due to the search asymmetry effect and is in line with earlier results (e.g., Treisman & Gormican, 1988).

Experiment 2.2

The second experiment was designed to investigate whether action-induced biases would also be observed under conditions that discourage employing an explicit task-relevance bias. A “singleton-detection” strategy that takes advantage of saliency signals in target detection (see Bacon & Egeth, 1994) was assumed to be encouraged. In Experiment 2.1, this strategy was possible but not particularly obvious or suggested by the instructions. Due to the fact that participants were informed about the task-relevant dimension in advance and as that the task-relevant dimension was blocked, it is likely that the task-relevant dimension was weighted for the whole block of trials, that is, selection was based on the prior knowledge of the target dimension rather than on the detection of saliency signals.

Experiment 2.2 aimed at making a singleton detection strategy particularly plausible. Therefore the target-defining dimensions were randomly mixed and participants were asked to respond to *any* singleton independent of its dimension. That is, size singletons and luminance singletons as well as target-absent trials could appear within the same block and any type of singleton required a target-present response.

Therefore, since both dimensions were equally task-relevant, a search strategy based on bottom-up saliency signals was more likely - as instructions required detection of *any* singleton present in the display. Hence, explicit task-relevance weighting mechanism was assumed to be discouraged. At the same time, an inter-trial repetition effects should be observable: in the case of the present experiment, trials with repeated type of singleton (repeated-dimension trials) could be compared to trials following a different type of singleton (different-dimension trials).

The experimental question was whether intentional weighting would occur in the absence of explicit task-relevance weighting. If action-related weighting relies on the activation of a task-relevance bias, one could assume that, as no explicit weighting was induced by the search task in the present experiment, also no action-specific weighting should be observed. Hence, the congruency between the type of the intended movement and the target-defining dimension should not matter and no reliable interactions between intended movement and target dimensions should be expected.

On the contrary, if action-related weighting is independent of explicit task-relevant weighting, the action-related influences on processing of perceptual dimensions should be observed also in the situation when task-relevant weighting is discouraged. In such a case, the question arises whether action-related bias would be dependent on bottom-up weighting through inter-trial repetition. If so, action-related effects should be observed when weighting through repetition takes place. That is, these effects should occur when singleton dimension is repeated.

Method

Participants

Eleven paid volunteers (4 female; age range: 20 to 35 years) took part. Two participants were left-handed, all had normal or corrected to normal vision. All participants were already experienced with other visual search experiments but they were not informed about the exact aims of this particular study. None of these volunteers participated in Experiment 2.1.

Materials, Procedure and Data Analysis

Stimuli and apparatus were as described in the *General Methods* section. Experiment 2.2 differed from Experiment 2.1 only with respect to the trial sequence (see Figure 2.4, middle panel). In contrast to Experiment 2.1, both *task-relevant dimension* and *movement type* varied randomly across trials. Participants were to respond to any pop-out target in the search array and to simply decide whether a target had been presented or not. The detection display was presented until response[2]. Participants performed one practice block followed by two experimental blocks, 256 trial each. The data was analyzed using a 2 × 3 ANOVA design with *movement type* (point vs. grasp) and *display type* (blank vs. luminance vs. size) as within-subject factors. Due to the intermixed design, there was no proper factor of *task-relevant dimension* in Experiment 2.2 as singletons of both dimensions were to be selected as targets. The *display type* factor (luminance vs. size vs. blank) therefore combined two factors of

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[2] Presentation time of the display was increased (relative to Experiment 2.1) because a pilot study with the same parameters as in Experiment 2.1 yielded an error rate of over 30 percent. Such an effect might be due to the fact that participants were to perform two tasks, namely detect a target by responding with their dominant hand while preparing to perform a particular movement type with their other hand. In such a situation, when the target is not blocked and unpredictable on each trial (Experiment 2.2), it might be more difficult to detect it compared to when the target is blocked and, therefore, participants know in advance that if there will be a target, it will be of a particular dimension (Experiment 2.1). That does not imply that a singleton search (Experiment 2.2) is more difficult than search for a particular feature dimension (Experiment 2.1). In Experiment 2.1., the target could have been detected both based on its saliency signals (singleton search) and based on search for a particular, pre-defined dimension.

Experiment 2.1, namely: *task-relevant dimension* (both size and luminance were relevant) and *trial type* (singleton present vs. blank). In order to test the movement-related effects with respect to inter-trial repetition effects, a subsequent analysis was conducted for target trials only with *display type* (luminance vs. size), *movement type* (point vs. grasp) and *dimension repetition* (same dimension vs. different dimension) as within-subject factors.

Results

Reaction times

The 2×3 ANOVA indicated a main effect of display type, *F*(2, 20) = 15.04, $p < .005$, $\eta_p^2 = .601$, showing the slowest responses in blank trials (*M* = 591 ms, *SEM* = 19), intermediate responses in size trials (*M* = 558 ms, *SEM* = 22), and fastest responses in luminance trials (*M* = 535 ms, *SEM* = 22 . No other main or interaction effect reached significance: movement type × display type, *F*(2, 20) < 1, $p = .61$, $\eta_p^2 = .048$.

Subsequent analysis conducted for target trials only with the factors display type (luminance vs. size), movement type (point vs. grasp) and dimension repetition (repeated dimension vs. different dimension) indicated a main effect of display type, F(1, 10) = 13.9, p < .005, $\eta_p^2 = .583$, and a main effect of singleton repetition, F(1, 10) = 8.2, p < .05, $\eta_p^2 = .451$, showing faster reaction times in the repeated dimension condition (M = 529 ms, SEM = 24) compared to the different dimension condition (M = 554 ms, SEM = 21). Again the interaction between display type and movement type did not reach the level of significance, F(2, 20) = 1.7, p = .21, $\eta_p^2 = .147$. A further analysis conducted only for the repeated singleton condition with the factors display type (luminance vs. size) and movement type (point vs. grasp) also did not reveal a significant interaction between target type and movement type, F(1, 10) = 1, p = .33, $\eta_p^2 = .094$.

Further analyses were conducted for five reaction time bins (each containing one-fifth of total number of trials). Each participant's correct reaction times (raw data) were rank ordered according to response speed. The ranked reaction times were then divided into five equal bins and, subsequently, divided into the experimental conditions (similarly to a procedure applied by, e.g., Craighero et al., 1999; De Jong, Liang, & Lauber, 1994; Ellis & Tucker, 2001). These analyses were conducted in order to test if there are any action-related influences on target detection depending response speed. The 3×2×5 ANOVA with the factors display type (luminance vs. size vs. blank), movement type (point vs. grasp) and bin (shortest through longest reaction times) showed only a main effect of bin, $F(4, 36) = 320$, $p < .001$, $\eta_p^2 = .973$, which was produced by data subdivision. No significant interaction between bin and other factors was obtained. Additionally, no effects of movement type for any of the bins separately were observed.

Error rates

Overall error rates were below 3 percent. In the 2×3 ANOVA with the factors *movement type* (point vs. grasp) and *display type* (blank vs. luminance vs. size), no effects reached the level of significance. Also the 2×2×2 ANOVA for target trials only with the factors *display type* (luminance vs. size), *movement type* (point vs. grasp) and *dimension repetition* (repeated dimension vs. different dimension), revealed no significant effects or interactions.

Discussion

In Experiment 2.2, the target dimension was unpredictable in each trial and participants were instructed to search for any item that differed from others in either luminance or size. According to Bacon and Egeth (1994) as well as Wolfe, Butcher, Lee, and Hyle (2003), the best strategy in such a search task is the singleton-detection mode, i.e., a strategy that is based on detection of local bottom-up saliency signals. Present findings indicate that the action-related bias observed in Experiment 2.1 did not take place in Experiment 2.2 suggesting that weighting with respect to action-relevance is not independent of weighting with respect to task-relevance. The lack of movement-related influences on target detection for any of the five reaction time bins provided further evidence that intentional weighting did indeed not occur when task-relevance bias was discouraged. If action-related bias would depend on other factors, such as, e.g., depth of processing, it would have been observed in longer reaction times but not necessarily in shorter responses (as in, e.g., Craighero et al., 1999). Experiment 2.2 showed that action-related bias is dependent rather on the task-relevance weighting and not on depth of processing of the stimuli.

Although this experiment was designed to discourage explicit weighting with respect to task relevance, the bottom-up type of weighting should be observed as inter-trial repetition effects. The results showed that it was indeed the case: Reaction times to repeated-dimension trials were significantly faster compared to different-dimension trials (for similar results, see, e.g., Found & Müller, 1996; Maljkovic & Nakayama, 1994; Müller et al., 1995).

Interestingly, no interaction between the dimension repetition and movement type factors was observed. Furthermore, when only the repeated-dimension trials were analyzed, also no movement-related influences on processing of perceptual dimensions were observed. This suggests that the weighting due to dimension repetition does not necessarily induce the action-related weighting mechanism.

Summarizing, results of Experiment 2.2 showed an indication that action-related weighting mechanism might not be independent of explicit task-related bias but might not rely on the bottom-up dimensional weighting mechanism related to inter-trial repetition.

Experiment 2.3

Experiment 2.2 was successful in suggesting that adopting a bottom-up driven search strategy eliminates the impact of action preparation on visual selection. Experiment 2.3 aimed at further investigating the interplay between the mechanisms of action-related bias, explicit task-relevant weighting and weighting due to inter-trial repetition. The task characteristics were changed in such a way that bottom-up saliency signals would no longer provide a reliable basis for response selection, which made a selection strategy that relied on prior knowledge of a relevant target dimension necessary. That is, the goal of Experiment 2.3 was to encourage an explicit weighting mechanism of a particular, task-relevant dimension while maintaining other characteristics of the task used in Experiment 2.2 as far as possible. This implies that Experiment 2.3 was designed to induce an explicit task-relevance bias at the same time allowing for observing inter-trial repetition effects. Again, two types of singletons (luminance and size) were presented within the same block. However, this time, participants were instructed to detect targets on a particular dimension while being explicitly asked to ignore the irrelevant singletons on the other dimension. Like in Experiment 2.2, the displays containing size or luminance singletons were randomly intermixed across trials but the task of detecting size or luminance was kept constant within a block. In Experiment 2.2, there was no proper factor of *task-relevant dimension* as singletons of both types of singleton were to be selected as relevant targets. In Experiment 2.3, however, although singletons of both dimensions were presented within the same block, the *task-relevant dimension* factor (size vs. luminance) denoted which of the singletons should be selected as a target (and which should be rejected as an irrelevant singleton). This entailed that observers could not detect a target item based solely on the saliency signal but had to search for the specific, task-relevant target dimension. It was assumed that encouraging explicit weighting of a task-relevant dimension should also affect and increase the impact of action-related effects as observed in Experiment 2.1. At the same time, according to the results of Experiment 2.2, the action-related intentional weighting should not interact with the inter-trial repetition effects.

Method

Participants

Seventeen paid volunteers (9 male) aged from 20 to 36 (mean age: 26.3) took part. One participant was left-handed, all had normal or corrected to normal vision. All participants were experienced with other visual search experiments but they were naïve with respect to the purpose of this particular experiment. None of the participants took part in Experiment 2.1 or Experiment 2.2. One participant had to be excluded from analysis due to extremely long reaction times (*M* = 948 ms) and a large overall standard deviation (*SD* = 364).

Procedure

Procedure and trial sequence remained the same as in Experiment 2.2 (cf. Figure 2.4, right panel) except for instructions in the experimental session. As in Experiment 2.2, singletons of two types (i.e., size and luminance) varied randomly across trials. In one of the sessions, the target was defined as a smaller-size item and participants were asked to respond with the target-related key when a size target would appear, and with the alternative key otherwise (i.e., for irrelevant luminance singletons and blank trials). In the other session, the target was defined by lighter grey.

Participants performed 8 blocks of 64 trials each in two sessions. There was one practice block at the beginning of the first session and another practice block at the beginning of the second session. The order of target-defining dimensions (luminance vs. size) was counterbalanced across participants. The data were analyzed using a 2 × 2 × 3 ANOVA design with *task-relevant dimension* (luminance vs. size), *movement type* (point vs. grasp) and *trial type* (target vs. irrelevant singleton vs. blank) as within-subject factors. In order to test the movement-related effects with respect to inter-trial repetition effects, a subsequent analysis was conducted only for singleton-present trials with *task-relevant dimension* (luminance vs. size), *movement type* (point vs. grasp), *trial type* (target vs. irrelevant singleton) and *dimension repetition* (repeated dimension vs. different dimension) as within-subject factors.

The rest of the procedure of data analysis remained the same as in Experiment 2.1 and 2.2.

Results

Reaction Times

The 2×2×3 ANOVA showed a main effect of task-relevant dimension, $F(1, 15) = 15.99$, $p < .01$, $\eta_p^2 = .516$, indicating slower RTs for size ($M = 601$ ms, $SEM = 22$) than for luminance ($M = 546$ ms, $SEM = 20$). The main effect of trial type, $F(2, 30) = 5.41$, $p < .05$, $\eta_p^2 = .265$, was due to slower responses to target absent trials ($M = 583$ ms, $SEM = 20$) and irrelevant singleton trials ($M = 581$ ms, $SEM = 21$) compared to target present trials ($M = 556$ ms, $SEM = 21$).

The three-way interaction of task-relevant dimension, movement type, and trial type was reliable, $F(2, 30) = 5.31$, $p < .05$, $\eta_p^2 = .262$ (see Figure 2.6). Because both luminance and size singletons could play the role of either targets or irrelevant singletons (luminance singletons in the conditions where size was task-relevant and size singletons in the condition where luminance was task-relevant), subsequent separate analyses with the factors: *task-relevant dimension* (luminance vs. size) and *movement type* (point vs. grasp) were conducted for target trials and irrelevant singleton trials.

In the case of target trials (see Figure 2.6a), the task-relevant dimension interacted with movement type, $F(1, 15) = 4.5$, $p = .05$, $\eta_p^2 = .233$ showing that in the luminance task condition, participants reacted faster when they were preparing for a pointing movement ($M = 540$ ms, $SEM = 23$) relative to the grasping movement ($M = 552$ ms, $SEM = 23$, see Figure 2.6a, left panel) whereas in the size task condition, participants were slightly faster when preparing for grasping ($M = 564$ ms, $SEM = 21$) compared to pointing ($M = 569$ ms, $SEM = 21$, see Figure 2.6a, right panel). Further one-tailed t-tests showed that the difference was significant in the luminance condition, $t(15) = 2.1$, $p < .05$, but did not reach the level of significance for the size condition, $t(15) = 1.08$, $p = .147$.

In the case of irrelevant singleton trials (see Figure 2.6b), the interaction between task-relevant dimension and movement type was marginally significant, $F(1, 15) = 4.1$, $p = .058$,

$\eta_p^2 = .219$ showing that in the luminance task condition, participants reacted faster when they were preparing for a grasping movement (M = 542 ms, SEM = 19) relative to the pointing movement (M = 556 ms, SEM = 20, see Figure 2.6b, left panel) whereas in the size task condition, there was no difference in reaction times with respect to the type of movement prepared (pointing movement: M = 612 ms, SEM = 25; M = 613 ms, SEM = 23, see Figure 2.6b, right panel). Further one-tailed t-tests showed that the difference was significant in the luminance condition, $t(15) = 2.1$, $p < .05$, but not in the size condition.

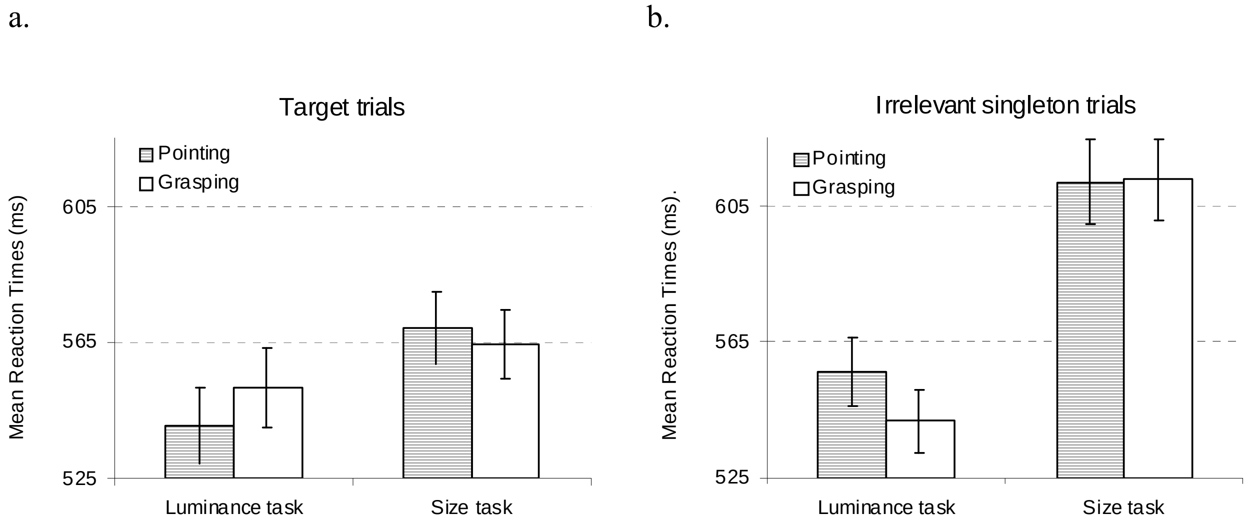

Figure 2.6. Effects of task-relevant dimension, movement type, and trial type in Experiment 2.3: target trials (2.6a) and irrelevant singleton trials (2.6b). Mean reaction times (RTs) to *luminance* as task-relevant dimension (2.6a, 2.6b, left panels) and *size* as task-relevant dimension (2.6a, 2.6b, right panels) as a function of movement type: pointing (filled bars) vs. grasping (empty bars). Error bars represent standard errors of the mean.

Note: In Figure 2.6a, the panel representing size as task-relevant dimension depict trials containing irrelevant luminance singletons and the bars representing luminance as task-relevant dimension depict trials containing irrelevant size singletons.

The analysis conducted for blank trials showed only a significant effect of task-relevant dimension, $F(1, 15) = 28$, $p < .001$, $\eta_p^2 = .655$ revealing faster reaction times in the luminance condition (M = 541 ms, SEM = 19) relative to the size condition (M = 624 ms, *SEM* = 24). No other effects reached the level of significance. For a summary of the task-relevant dimension × trial type × movement type effects, see Table 2.2.

Task-relevant dimension	Mean RTs		SE	
	Pointing	Grasping	Pointing	Grasping
	Target Trials			
Luminance Task	541 ms	552 ms	23	23
Size Task	569 ms	564 ms	21	21
	Irrelevant singleton trials			
Luminance (size singletons)	556 ms	542 ms	20	19
Size (luminance singletons) [a]	612 ms	613 ms	25	24
	Blank trials			
Luminance Task	544 ms	539 ms	19	20
Size Task	619 ms	630 ms	26	23

Note. Reaction time data is given in milliseconds.

[a] Irrelevant singleton trials denote those trials in which size singletons were presented in the condition in which luminance was the task-relevant dimension and trials with luminance singletons when size was the task-relevant dimension.

Table 2.2. Mean reaction times (RTs) and standard errors of the mean (SE) to task-relevant dimensions as a function of movement type (pointing vs. grasping) for target trials (two upper rows) and irrelevant singleton trials (two lower rows) in Experiment 2.3.

Additionally to the effects of interest, an interaction between task-relevant dimension and trial type was significant, $F(2, 30) = 22.53$, $p < .001$, $\eta_p^2 = .600$, (see Figure 2.7). To get a grip on this effect, data from the two tasks was analyzed separately. *For size dimension,* the trial-type effect was significant, $F\ (2, 30) = 15.8$, $p < .001$, $\eta_p^2 = .511$, (see Figure 2.7, right panel). A planned comparison showed that target trials were responded to faster than irrelevant singleton trials, $F(1, 15) = 14.1$, $p < .005$, $\eta_p^2 = .487$, (see Figure 2.7, right panel, empty bar) while there was no difference between irrelevant singleton trials and blank trials (see Figure 2.7, right panel, striped and checked bar respectively). For the luminance dimension, the trial-type effect did not reach the level of significance, $F(2, 30) = .285$, $p = .662$, $\eta_p^2 = .019$, (see Figure 2.7, left panel). Planned comparisons showed also no significant differences.

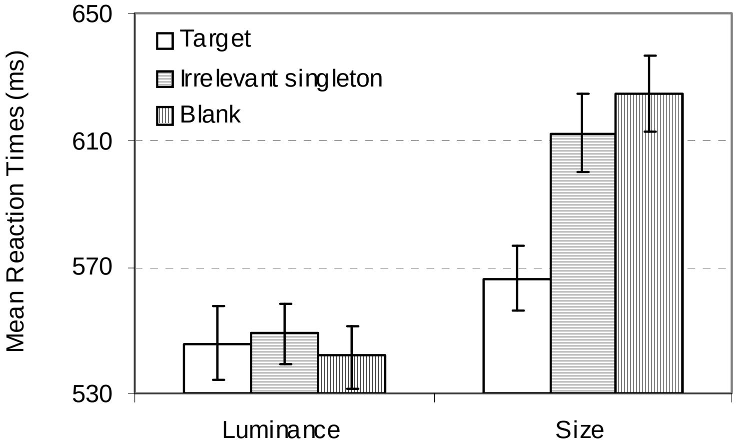

Figure 2.7. Effects of task-relevant dimension and trial type in Experiment 2.3. Mean reaction times (RTs) to *luminance* as task-relevant dimension (left panel) and *size* as task-relevant dimension (right panel) as a function of trial type (target trials (empty bars) vs. irrelevant singleton trials (filled bars) vs. blank trials (checked bars)). Note: The filled bar in the left panel represents trials containing irrelevant size singletons (luminance task) and the filled bar in the right panel represents trials containing irrelevant luminance singletons (size task).

Further analysis on target-present trials only, conducted in order to reveal movement-related effects with respect to inter-trial repetition effects, showed no interaction between dimension repetition and movement type, $F(2, 30) = .9$, $p = .34$, $\eta_p^2 = .057$ and no interaction between dimension repetition, movement type and task-relevant dimension, $F(2, 30) = .07$, $p = .78$, $\eta_p^2 = .005$.

Error rates

Overall error rates were below 1 percent, which did not allow for a meaningful analysis.

Analysis across Experiments 2.1-2.3

A final analysis compared the data across all three experiments for target-present trials. An ANOVA with the within-subjects factors of *target type* (luminance vs. size) and *movement type* (point vs. grasp) as well as a between-subject factor of *experiment* (Experiment 2.1 vs. Experiment 2.2 vs. Experiment 2.3) revealed a main effect of target type, $F(1, 36) = 15$, $p < .001$, $\eta_p^2 = .298$ indicating longer reaction times for size targets ($M = 555$ ms, $SEM = 13$) relative to luminance targets ($M = 525$ ms, $SEM = 13$) in all three experiments. The analysis revealed also a marginally significant three-way interaction of experiment, movement type, and target type, $F(2, 36) = 2.95$, $p = .06$, $\eta_p^2 = .141$. Planned comparisons indicated that the interaction of movement type and target type, $F(1, 26) = 8.64$, $p = .01$, $\eta_p^2 = .250$, showed the same pattern for Experiment 2.1 and 2.3, $p > .97$, but differed when Experiment 2.1 and 2.3 were averaged and compared to Experiment 2.2, $F(1, 36) = 5.87$, $p < .05$ (see Figure 2.8). This finding suggests that action planning influenced visual search in a similar way in Experiment 2.1 and 2.3 but did not show modulatory effects in Experiment 2.2.

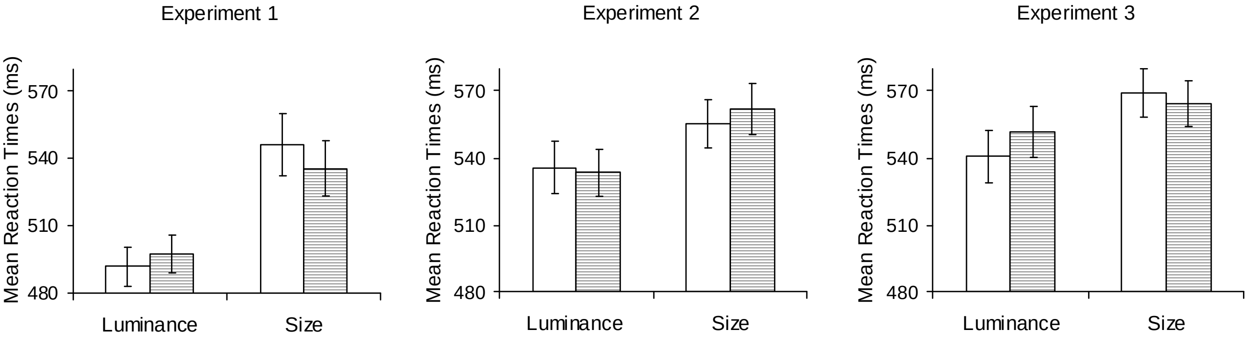

Figure 2.8. Effects of movement type and target type across the three experiments for target-present trials only. Mean reaction times (RTs) to size targets and luminance targets as a function of movement type (point: empty bars vs. grasp: filled bars) in Experiment 2.1 (left panel), Experiment 2.2 (middle panel) and Experiment 2.3 (right panel). Error bars represent standard errors of the mean.

Discussion

Experiment 2.3 tested whether replicating Experiment 2.2 under conditions that are likely to encourage an explicit weighting mechanism of a task-relevant dimension would make action-related effects reappear. That is, whether action-related weighting would occur again when task-related weighting was supposedly induced. Indeed, detecting luminance targets was easier when preparing for a pointing movement compared to a grasping movement, whereas detecting size targets tended to be easier when preparing to grasp. Even irrelevant singletons could be rejected faster when a congruent action was prepared suggesting that preparing a particular movement type automatically increases the weights on congruent perceptual dimensions. This, in turn, results in easier rejection of the movement-congruent dimension as task-irrelevant (similar effects, denoted as "partial repetition costs", were discussed in, e.g., Hommel (2004) as an evidence of event-files). That is, Experiment 2.3 clearly confirmed the assumption that selection in visual search may be biased by movement intentions.

The result showing that differences between pointing and grasping conditions were significant in the luminance task condition, i.e., for luminance targets but not for size targets (Figure 2.6a) and for irrelevant size items but not irrelevant luminance items (Figure 2.6b) might be either due to the fact that the size task condition was in general more difficult (RTs to all display types were longer in this condition, c.f. right panel of Figure 2.7) or due to different pathways in which size and luminance are processed (e.g., the dorsal vs. ventral pathway; Milner & Goodale, 1995; Ungerleider & Mishkin, 1982).

Interestingly, the action-related weighting did not interact with weighting due to dimension repetition as the respective interaction of dimension repetition (repeated-dimension vs. same dimension), movement type (point vs. grasp) and task-relevant dimension (luminance vs. size) was not observed.

In addition to the effects of interest, a main effect of trial type was obtained showing that blank trials and irrelevant singleton trials slowed down responding as compared to target present trials. As argued above, the difference between blank and target present trials, which showed the same pattern as in Experiments 2.1 and 2.2, is an effect often observed in visual search research. The difference between irrelevant singleton trials and target present trials might be due to that irrelevant items induce a strong saliency signal which has to be overridden by the task-relevance control classifying the saliency signal as irrelevant. In other words, the bottom-up signal calls for a positive response, which top-down control has to inhibit. However, the significant interaction of trial type and task-relevant dimension showed that the difference between target present and blank trials was mainly stemming from the condition in which size was the task-relevant dimension (see Figure 2.7, right panel) but not when luminance was task-relevant (Figure 2.7, left panel). Such an interaction, as discussed above, might reflect another effect of feature asymmetry. As the difference between target trials and irrelevant singleton trials was basically only observed for luminance items (in size task) and as in all three experiments RTs were generally shorter when luminance was the task-relevant dimension, luminance singletons might have been more salient and thus more difficult to reject.

To summarize, results of Experiment 2.3 show that the same setup that eliminated action-induced biases in Experiment 2.2 can produce such biases if only explicit weighting of a task-relevant dimension is encouraged. At the same time, Experiment 2.3 showed, in line with results of Experiment 2.2, that the action-related weighting is independent from weighting due to inter-trial dimension repetition.

General discussion

Three experiments were designed to test whether planning a movement biases visual search towards a dimension that delivers important information for controlling that movement. The goal of the present study was to investigate how such bias is dependent on other types of weighting mechanisms. Clear evidence for a movement-related bias was obtained in Experiments 2.1 and 2.3, where a particular dimension was also explicitly weighted with respect to task-relevance. Experiment 2.2, in which bottom-up saliency signals were sufficient to allow for target selection, did not yield action-related effects.

The implication of the present findings is that even tasks that are commonly taken to tap rather early interactions of perception and attention, such as simple visual search, are sensitive to action control processes. In the present study, planning a grasping or a pointing movement facilitated the detection of targets and rejection of irrelevant singletons (as in Experiment 2.3) on action-congruent dimensions even under conditions where movement and visual search were logically independent and entirely unrelated. Considering that action-induced biases are no less likely to occur under conditions where action-planning and search processes belong to the same task, as in standard visual search tasks, it seems possible that much of our present knowledge about attentional operations in visual search is specific to the actions used to indicate them - commonly button pressing.

It seems clear that preparing for a particular type of action primes processing of action-related information. This supports the idea that action planning primes dimensions that are likely to provide information that is useful for the control of the planned action. Well-practiced actions are commonly driven by two types of information: feed-forward information about the invariant characteristics of the action, which can be retrieved from long-term memory and used to prepare the action off-line, and on-line information that specifies open parameters and adapts the action to the current environment (Glover, 2004; Hommel, Müsseler, Aschersleben & Prinz, 2001a; Schmidt, 1975). Considering the present findings, together with those of Fagioli et al. (2007), it makes sense to believe that off-line action preparation has not only the function of specifying and implementing invariant action properties but also to prepare the perceptual system to deliver information that is suited to specify the still open parameters. With regard to grasping, these parameters are likely to comprise of object size (as suggested by the present study as well as by Fagioli et al., 2007), and with regard to pointing, they are likely to comprise of luminance (as suggested by the present study) and location (as suggested by Fagioli et al., 2007).

The present findings suggest a much more general effect of action planning on selection compared to previous demonstrations which showed that actions aiming at particular objects prime particular features of that object (Bekkering & Neggers, 2002; Craighero, 1999; Deubel et al., 1996). Rather than specific feature values, it seems that preparing for an action is priming a whole dimension, thereby enhancing the processing of any feature value falling in that dimension. Hence, dimensions are intentionally weighted (Hommel et al., 2001b), to the degree that they are considered action-relevant. The mechanism underlying this weighting process may be the same as the one that has been hypothesized to account for other top-down effects on visual selection. According to the Dimensional Weighting approach of Müller and colleagues (e.g., Müller et al., 1995), a visual scene is encoded in dimension maps from where the signal is transmitted to a master map (cf., Treisman, 1988; Wolfe, 1994). On the master map, dimension-specific saliency signals are weighted and summed in parallel. Importantly, it is assumed that whole dimensions are weighted (e.g., color), but not particular feature values (e.g., red), and that weights modulate the impact of the respective dimensions on further processes. Weights can be explicitly assigned in a top-down manner, e.g., as a consequence of instruction, but they can also be implicitly induced, e.g., through inter-trial repetition (e.g., Found & Müller, 1996; Geyer, Müller, & Krummenacher, 2007; Maljkovic & Nakayama, 1994; Müller et al., 1995) to the degree that the particular weighting adopted improves performance. In case of the present experiments, perceptual dimensions have also been weighted with respect to action relevance.

Interestingly, present experiments provided evidence that action-related bias is not independent from task-relevance bias. Experiments 2.1 and 2.3 encouraged an explicit weighting of particular target dimensions with respect to their task-relevance, whereas

Experiment 2.2 encouraged selection based on bottom-up saliency signals. These manipulations also affected action-induced weighting, as action-related effects were observed in Experiments 2.1 and 2.3 but not in Experiment 2.2. This suggests that action-induced dimension weighting affects selection only when task-relevance bias also comes into play. If selection may be based on bottom-up saliency signals only, the prepared action has no effect. This parallels comparable observations regarding potency of top-down task-relevance weighting reported by Bacon and Egeth (1994), and supports the idea that the mechanism realizing action-induced biases is closely related to the mechanism responsible for task-induced top-down biases towards particular dimensions. On the other hand, results of these experiments allow for a speculation that the action-related bias is independent from weighting of dimensions due to inter-trial dimension repetition (see results of Found & Müller, 1996; Maljkovic & Nakayama, 1994; Müller et al., 1995). Present results revealed the inter-trial repetition effects in Experiment 2.2: Responses to trials with repeated singleton dimension were faster relative to trials which followed a singleton of a different dimension. At the same time, this weighting mechanism did not interact with action-induced bias. Even if only repeated-dimension trials were analyzed, no movement-related influences on processing of the perceptual dimensions were observed. Moreover, also in Experiment 2.3, the action-related bias and the weighting through repetition were independent.

To account for the present findings, a model combining Hommel et al.'s (2001b) intentional weighting mechanism with the Dimensional Weighting Account (Found & Müller, 1996; Krummenacher, Müller & Heller, 2002; Müller et al., 1995; see also Wolfe, 1994, 2003) has been put forward (Figure 2.9). The former visual search models have been extended by postulating a biasing mechanism related to the intentions of an agent. It has been assumed that the agent sets intentional weights, not necessarily consciously, to those perceptual dimensions that he or she considers relevant, or that were learned to be relevant, for those tasks that are to be performed: the search task and the motor task. Weight setting with respect to task-relevance and weight setting with respect to action planning take place in separate modules as weighting results from different (sub-) tasks. However, although weighting by task-relevance and weighting by action planning stem from separate sources, they form a common intentional weight that is capable of modulating signals of the bottom-up processing stream. Interestingly, the influence of the action-related weighting on perceptual dimensions seems not independent from the existence of a task-relevance bias towards these dimensions - as in the present experiments action-effects were only observed when dimensions were also weighted as relevant in the search task. Although the exact nature of the inter-relation between both weighting mechanisms is not clear at the present state, results favor a direct weighting link from task-relevance to perceptual dimensions for the actually performed search task (w_i) and a modulatory influence of the action-planning bias (v_i). Only if a task-relevance bias is present, will the action-related bias also influence perceptual processing and the bottom-up stream of processing will be modulated by the common weight combined of task-relevance and action-relevance biases. At the same time, as the present results showed, the action-related intentional weighting seems not to rely on another type of weighting that might occur also independently of the explicit task-relevance weighting, namely a dimension-weighting mechanism due to inter-trial repetition (e.g., Found & Müller, 1996; Maljkovic & Nakayama, 1994; Müller et al., 1995).

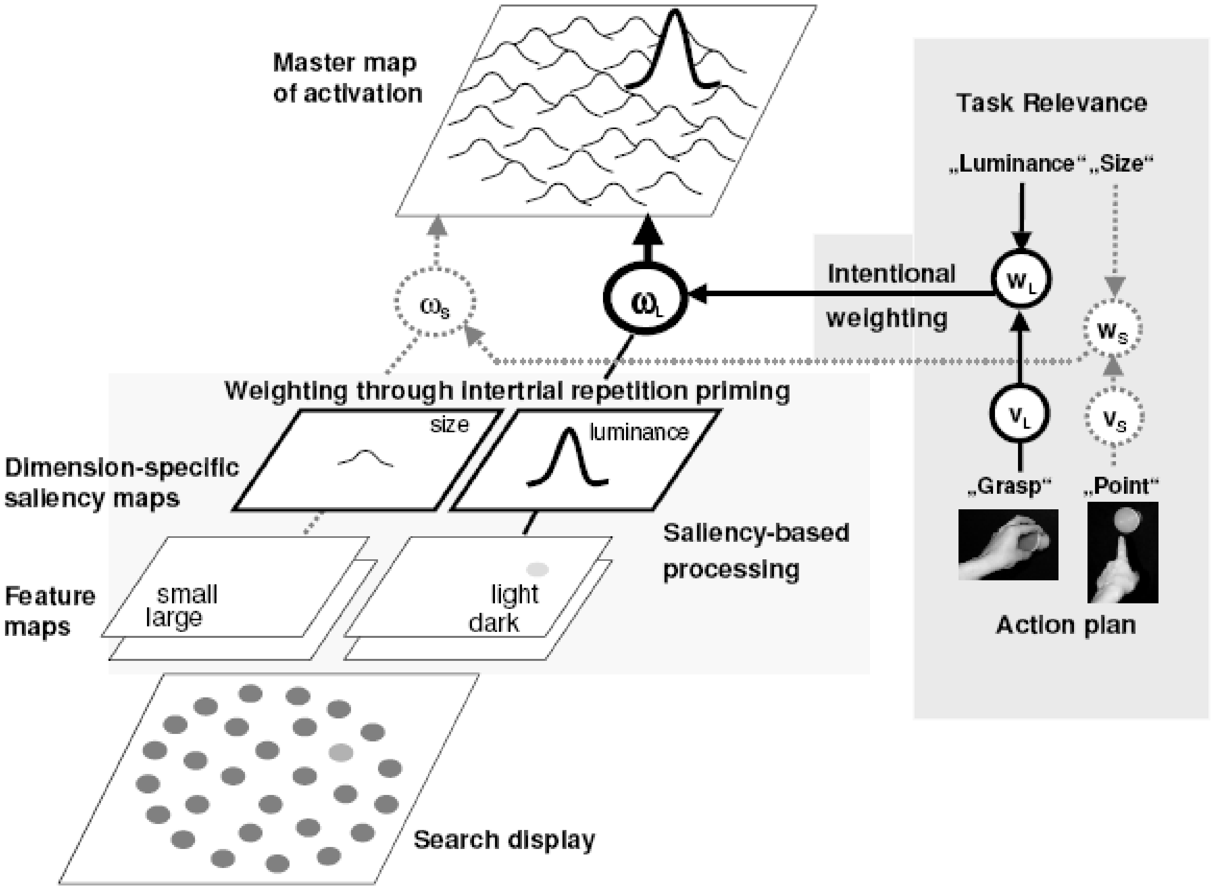

Figure 2.9. Graphical illustration of an action-based model of visual processing postulated to account for the results of the present three experiments. Visual information is processed in dimension-specific modules, salient objects cause increased activation. Before the activation is summoned across all dimensions in a master map, weights (ω_i) can be assigned to those dimensions. The weights may be set intentionally (e.g., when the observer is instructed to search for a specific task-relevant perceptual dimension (right side, upper part), or implicitly, e.g., by the observer's expectations (inter-trial repetition) or prior experience in similar situations (not shown in graph). Present experiments show that intentional weighting incorporates not only weighting due to task-relevance (w_i,right side, upper part) but also weighting due to action planning. Both form an intentional weight (dark-grey area on the right) that modulates bottom up saliency-based processing (light-grey area on the left). Task-relevance weighting and action-induced weighting, however, do not have equivalent potency: when the task-relevance bias is absent, action-related weighting cannot directly modulate weights at the specific dimensions (ω_i). Bottom-up processing is thus modulated by a combined common bias (ω_i) that incorporates intentional weighting (action-related and task-relevance bias), bottom-up type of weighting due to inter-trial repetition as well as other possible forms of weighting mechanisms.

The assumption that weighting by task-relevance and weighting by action planning are based on similar mechanisms suggests the speculation that top-down attentional control might originally have derived from action control. As recent findings from neuroimaging studies show, attending to particular visual dimensions activates the human premotor cortex and other action-related areas even under conditions that do not require immediate action (Schubotz & von Cramon, 2001, 2002). Even more interesting, this activation follows a rather systematic pattern (Schubotz & von Cramon, 2003): attending to shape is accompanied by the activation of a fronto-parietal prehension network and attending to location by the activation of cortical areas involved in manual reaching, while attending to temporal aspects activates a network associated with tapping and uttering speech. These observations may reflect an important integrative role of premotor cortex in the anticipation of perceptual events and the control of actions related to these events (Fagioli et al., 2007; Schubotz, 2007). The premotor cortex may integrate actions and their expected consequences into a kind of habitual pragmatic body map (Schubotz & von Cramon, 2001, 2003) that is part of a broader representational system for the "common-coding" of perceptual events and action plans (Hommel et al., 2001b).

The possibility of anticipating the consequences of an action, and the need to control it in such a way to maximize wanted consequences, may have laid the ground for the (phylogenetic and/or ontogenetic) development of selective attention mechanisms. As suggested by Milner and Goodale (1995), off-line channels of information processing are likely to have developed phylogenetically later than, and to some degree independently from on-line channels. This raises the problem of how off-line channels, that are capable of setting up planned, anticipatory action, can make use of, and exert control on on-line processing. Dimensional weighting would be a very useful means to exert some relatively indirect but still useful control. Even though on-line channels would not be top-down limited with respect to what kind of information they process, the degree to which this information is fed into action control is determined by the weights currently assigned to the respective dimension. Once this highly adaptive mechanism has been acquired, it can be used for purposes other than action control, and it may be these purposes that are tapped by most studies on human attention.

In any case, the present study provides strong evidence that even presumably “early” operations of visual attention are more dependent on the type of action accompanying it than hitherto believed. As actions commonly do not play a major role in attentional theorizing and the interpretation of attentional studies, this raises the question of how general and generalizable the available accounts and findings are.

Chapter 3: On the time course of visual selection

Abstract

Two mechanisms are said to be responsible for guiding focal attention in visual selection, namely bottom-up, saliency-driven capture and top-down, goal-oriented control. A paradigm combining a visual search task with post-display probe detection was used to examine these mechanisms. Two different SOAs between the search display and probe onsets allowed for investigating the dynamic interplay between the stimulus-driven and task-related control of selection. Behavioral effects revealed, in line with earlier results (e.g., Kim & Cave, 1999) that top-down control needed time to develop, whereas bottom-up attentional capture effects were observable earlier as transient and decaying with time. ERPs recorded time-locked to probe onset revealed modulations in the P1 component likely reflecting top-down control of focal attention. Analysis of ERPs time-locked to the onset of the search display suggested that target displays might have been differentiated from other types of displays only later in time, i.e., later than the discrimination and rejection of blank displays.

Taken together, the present study provides a strong evidence for top-down control of focal attention. The bottom-up attentional capture, as observed solely in the behavioral data, received only weaker support.

Theoretical background

When we receive input from the environment through our perceptual apparatus, we obtain an abundance of diverse visual information. Our visual system must have developed mechanisms of selection of the important and relevant information in order to function effectively in our world. Two main mechanisms are said to be relevant during the course of selection processes: a so-called bottom-up, stimulus-driven or exogeneous mechanism (e.g., Posner, 1980; Theeuwes, 1992) and a top-down, or goal-directed control mechanism (e.g., Bacon & Egeth, 1994; Bundesen, 1990; Folk & Remington, 1998, 2006; Kim & Cave, 1999; Posner, 1980; Wolfe, 1994; Wolfe, Butcher, Lee, & Hyle, 2003; see also Wolfe, 1998 for an overview). Bottom-up selection is mainly driven by the properties of the stimulus. When a stimulus is salient, i.e., contrasts with the surrounding background, it will result in strong saliency signals evoked and transmitted in our system. On the contrary, when a stimulus is hardly distinguishable from the surrounding, its saliency values will be low and attentional focus will not be attracted efficiently and directly to the stimulus at hand (e.g., Bravo & Nakayama, 1992; Found & Müller, 1996; Treisman & Gelade, 1980; Wolfe, 1994). In this case, goal-oriented or top-down control might allow facilitation of processing of relevant information via assigning weights or, in other words, biasing pertinent input. Such a weighting mechanism enables selection not only on the basis of saliency signals but also with respect to task relevance (e.g., Bundesen, 1990; Folk & Remington, 1998, 2006; Wolfe, 1994).

The temporal interplay between top-down and bottom-up mechanisms

Extensive research has been conducted in order to pinpoint these two mechanisms and the temporal relations between them (e.g., Bacon & Egeth, 1994; Folk & Remington, 1998, Müller, von Mühlenen & Geyer, 2007; van Zoest & Donk, 2006; Theeuwes, 1992, 1994). Some authors claimed (e.g. Itti & Koch, 2000; Theeuwes, 1992, 1994, 1995a) that the saliency signals are so strong that they will capture attention automatically regardless their irrelevance to the task at hand. According to this view, bottom-up attentional capture is not penetrable by top-down modulation and interference effects from salient irrelevant items cannot be overridden by top-down activation at the early stage of processing (e.g., Theeuwes, Atchley, & Kramer, 2000). Goal-driven control comes into play but only subsequent to mandatory bottom-up capture (e.g., Theeuwes et al., 2000). Van Zoest and colleagues (van Zoest & Donk, 2006; van Zoest, Donk, & Theeuwes, 2004) recorded eye movements in their experiments. Eye-movements are considered to be coupled with attentional selection processes (e.g., Deubel & Schneider, 1996). From their results, van Zoest and colleagues argued in favor of a *timing account* of visual selection. According to this account, stimulus-driven control of eye-movements is potent early in the course of visual processing and decays with time, whereas goal-driven control comes into play later. These two mechanisms, according to the authors, are separable and independent.

Other authors argue that stimulus-driven attention is only contingent on task-relevant attentional settings (e.g. Folk & Remington, 1998, 2006; Folk, Remington, & Johnston, 1992). Based on the results of Folk & Remington (1998; 2006), the proponents of the *contingent capture*[3] perspective concluded that attentional capture to the salient stimulus should take place only if the stimulus shares characteristics with the task-relevant target item. Furthermore, several authors claim that whether effects of both the goal-oriented and the stimulus-driven control of selection, or only one of them will be observable, depends on either a strategy that participants apply in the task at hand (e.g., Bacon & Egeth, 1994), or the type of paradigm designed by experimenters (e.g., Kim & Cave, 1999), i.e., whether the paradigm was sensitive enough to capture the dynamic interplay between the top-down and bottom-up control of spatial attention.

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[3] This term was introduced by Folk & Remington (e.g., Folk & Remington, 2006).

Finally, some researchers postulate an intermediate stance (e.g., Kim & Cave, 1999). Kim & Cave (1999) argue against the "*pure capture account*"[4] (e.g., Theeuwes et al., 2000) by claiming that even at the early stages of processing, when the bottom-up mechanism is more prevailing, the top-down modulation still can take place to some extent. Hence, they argue against the strong claim of attentional capture effects being impenetrable to top-down modulation. On the other hand, they also argue against the "*contingent capture*" stance of Folk & Remington (1998, 2006) based on effects of attentional capture to a salient singleton of a dimension irrelevant to the task (Kim & Cave, 1999).

Mechanisms of selection

Kim & Cave (1999), focusing on the importance of temporal aspect of the goal-oriented vs. stimulus-driven control of selection, introduced a paradigm in which they combined a visual search task with a post-display probe detection task. The visual search task consisted in searching for the pre-defined target among distracter items. There were two types of search displays preceding the probe presentation: either a display containing two singletons (but only being relevant: the target defined by shape and the irrelevant color singleton) or a display containing only the irrelevant color singleton (the target-absent display). The display always contained only four elements positioned on an imaginary circle. After either a short (60 ms) or a long (150 ms) SOA, the search display was followed by a probe item (small filled square) at the former location of either the target item or the salient irrelevant singleton or at a location previously taken by one of the neutral distracters. The probe detection task consisted in simple detection of probe presence. Reaction times to probe detection were analyzed with respect to whether the probe was presented at the target's location, the irrelevant singleton's location or at a neutral distracter's location. Reaction times were supposed to reflect how spatial attention was allocated to particular items of the previous search display. The variable SOA allowed for investigating the temporal dynamics of bottom-

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[4] Folk & Remington (2006) used this term in order to denote the standpoint of proponents of the obligatory and automatic attentional capture effects impenetrable by top-down mechanisms.

up attentional capture to the salient but irrelevant singleton and of top-down control of spatial attention towards the less salient, but task-relevant target. Based on former results of e.g., Theeuwes (1995b), the authors expected faster reaction times to probes presented at the position of the salient irrelevant item compared to other positions in the short SOA condition. This would reflect attentional capture to the irrelevant salient singleton at the early stages of processing. In the long SOA condition, reaction times were expected to be faster for probes presented at the target position relative to other positions, which, in turn would reflect top-down control of selection of the task-relevant item at later stages of processing. Finally, no differences in reaction times across conditions would indicate that the target might be selected without spatial attention deployed to the visual scene.

In line with the expectations, Kim & Cave (1999) found that reaction times to probes located at salient irrelevant singleton locations were significantly faster compared to other neutral distracter positions in the short SOAs (60 ms). This was interpreted as an effect of bottom-up attentional capture to a task-irrelevant salient item at early stages of processing. For long SOAs (150 ms), reaction times to probes at the target location were faster compared to conditions when probe was presented at the distracters' locations. This, in turn, was interpreted as indicating that with longer time after stimulus presentation, top-down control of selection was potent enough to override the interference from the irrelevant singleton.

According to the authors, such results indicated that effects of the two control mechanisms of spatial attention revealed dynamical interplay: First the bottom-up, stimulus-driven capture mechanism was prevailing, and only then, the top-down, goal-oriented control of spatial attention could take over.

The fact that salient irrelevant distracters captured spatial attention at early stages of processing, even if they did not share the feature of the target, speaks against a strong version of "*contingent capture*" stance of Folk & Remington (1998, 2006). Additionally, the results of Kim & Cave (1999) speak also against the argument of Folk & Remington (1998) claiming that capture effects of Theeuwes (1992) were due to filtering costs but not allocation of spatial attention to irrelevant singleton (for a discussion, see Folk & Remington, 2006, 1998; as well as Kim & Cave, 1999).

However, on the other hand, in Kim & Cave (1999), the bottom-up capture effects were diminished with extensive practice. Furthermore, the authors did not find capture effects in the condition when the irrelevant singleton was located near to the target item or in the condition when the display contained only the irrelevant singleton. These results suggest that the bottom-up capture mechanism can be, to some extent, penetrable by the top-down modulation. Although at early stages of processing, when the target item was accompanied by an irrelevant salient singleton, the top-down control was not powerful enough to guide spatial attention to the target location, it seemed potent enough to reduce the distraction effects when either the irrelevant singleton was the only salient item in the display, or when it was located near to the target or, else, after extensive practice. Such result speaks against the strong "pure capture" account postulating that top-down mechanism is not potent enough to affect the bottom-up capture phenomenon.

Of the present interest was whether the behavioral results Kim & Cave (1999) observed in the long SOA condition may indeed be attributed to top-down control of focal attention. In fact, one might argue that in the paradigm of Kim & Cave (1999), in which an irrelevant singleton was always present in a search display (i.e., also in target-absent trials), participants might have developed a strategy of "singleton counting", i.e. they might have performed the task without a proper search. Instead of selecting the target based on its predefined characteristics (i.e., top-down control), participants might have selected the target simply based on the saliency signal induced by its presence. The present experimental design aimed at inducing a strong top-down bias and at discouraging the possibility of detecting the target based on bottom-up saliency signals.

Furthermore, behavioral results may not provide a detailed answer to the temporal dynamics of particular processes in the brain. On the contrary, analyzing event-related brain potentials (ERPs) as neurophysiological correlates of stimulus processing may allow for a more detailed and precise examination of temporal dynamics of processes of interest, i.e., in this case, the top-down control of allocation of attention. Since the present study aimed at answering the question of how top-down control of visual focal attention develops over time, an ERP methodology that allows for investigating attentional effects prior to response execution with high temporal resolution was applied. Importantly, the ERP methodology allows for examining particular temporal windows of the processing stream additionally to its end effects, i.e., response execution.

Experiment 3.1.

Rationale of the experiment

A paradigm that combined a visual search task with a probe detection task was designed. Four types of trials were introduced, i.e., proper blank trials (neutral distracters only), trials with irrelevant singleton only, trials in which only the target is present as well as trials in which the search display contains both the target and the irrelevant singleton. In this way, it was ensured that any effects of prioritized processing of probe located at former target position should reflect top-down control of focal attention and not detection based on bottom-up saliency signals. Moreover, 19 elements in the display were introduced in order to test how top-down control is executed in a true visual search task, i.e., where many elements are present in the visual field, which provides a closer simulation of a real search situation.

Such paradigm is well suited to investigate the effects of goal-driven control vs. stimulus-related attentional capture with the use of the ERP methodology. Examining potentials related to probe presentation (which was preceded by various types of display) allows for a comparison of neural responses to physically identical stimuli (probe) and thus, any differences should result from internal differences in processing of the stimulus and not from a difference in neural response to physically different stimuli.

Differential effects on early components, such as P1 or N1 (time-locked to probe presentation onset), were expected. These components are considered to reflect focal attention effects (e.g., Hillyard, Vogel & Luck, 1998, Hopfinger & Mangun, 1998, Luck & Hllyard, 1995). Attentional effects on the early ERP components, such as the P1-N1 complex, have been observed in paradigms where spatial attention has been manipulated. For example, in a paradigm that Mangun, Hillyard, & Luck (1993) applied, observers were fixating in the middle of the screen while a rectangle flashed in one of the quadrants surrounding the fixation cross. Observers were asked to focus their attention on only one of the quadrants. The authors found enhanced P1 and N1 components for attended vs. unattended stimuli. Also in standard cueing paradigms (see Posner, 1980), where spatial attention was directed on a trial-by-trial basis, P1 and/or N1 were found to be larger in cued locations relative to non-cued locations (Heinze, Luck, Mangun, & Hillyard, 1990; Mangun et. al., 1993; for reviews see also Hillyard et al., 1998; Luck, Woodman, & Vogel, 2000).

If top-down selection develops with time, then P1 and/or N1 should be more enhanced for probes presented at previous target locations relative to probes presented at neutral distracter locations in the long SOA, but not necessarily in the short SOA. If the effects of bottom-up driven attentional capture to salient singleton are short lived and transient, as, e.g. van Zoest et al. (2004) claimed, P1 and/or N1 might be enhanced in short SOA for probes presented at the position of irrelevant distracter.

Additionally, time-locking the event-related potentials to search display onset should allow for gaining further information about how target detection and irrelevant singleton rejection develops over time in terms of neural processes. Also for search displays proper (i.e., in trials without subsequent probe presentation), ERPs to target displays should differ from ERPs to displays containing salient distracting elements. It was assumed that due to the fact that the target is also a salient singleton, distinguishing it from the irrelevant singleton based exclusively on bottom-up saliency signals might not be possible. Therefore, displays containing a target might be discriminated from displays containing an irrelevant singleton with the help of the top-down signal which enhances the task-relevance features. Since this enhancement of processing of task-relevant features takes time to develop (van Zoest et al., 2004; Kim& Cave, 1999), neural response to target displays should differ from a response to displays containing an irrelevant salient singleton only later with time.

Method

Stimuli and apparatus

Stimuli were presented on a 17-inch computer screen (Iiyama MA 201D, Vision Master 511) with a 60 Hz refresh rate placed at a distance of 100 cm from an observer. The experiment was run on a Siemens Celsius 420 computer with a Celeron 466 MHz processor.

The search display always contained 19 items positioned on three imaginary circular arrays with diameters of 4.6°, 6.3°, 8.0° of visual angle. The outer and middle circles contained 8 elements each and the inner circle contained 3 elements. There were four possible display types: (1) a target-present display (see Figure 3.1a), (2) a display containing an irrelevant color singleton (see Figure 3.1c), (3) a display with both the target and the irrelevant singleton, (see Figure 3.1b), and (4) a blank display, (see Figure 3.1d).

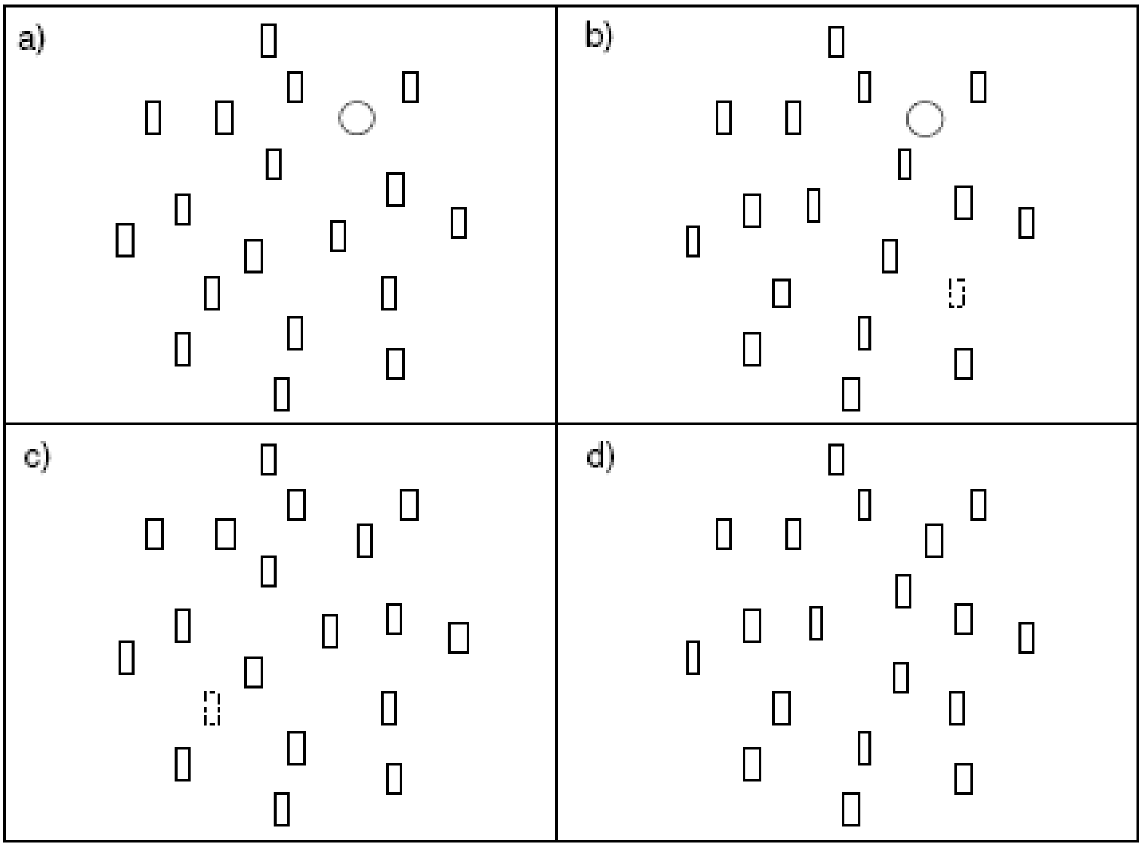

Figure 3.1. Examples of display types. The upper panels (a) and (b) show displays containing a predefined target (circle among rectangles): (a) is an example of a target-only display whereas (b) is an example of a display containing both singletons (the target and the irrelevant color singleton). The lower panels (c) and (d) show target-absent displays: (c) is an example of a target-absent display that contains an irrelevant singleton whereas (d) is an example of a blank display. Solid line represents the blue color of the target and the neutral distracters whereas the dashed line depicts the red color of the irrelevant singleton.

The target (blue outline circle, 0.57° diameter) could appear at one of four positions (upper left/right or lower left/right from the middle point) of the middle circle of the 4.57° degrees of visual angle in diameter. The target was embedded in a set of 18 blue outlines of vertical rectangles (0.28° × 0.74° of visual angle): target-only displays; or in a set of 17 blue rectangular outlines and one red outline: displays containing both the target and the irrelevant singleton. Blank trials consisted of a set of 19 blue rectangular outlines; and displays with only the irrelevant singleton consisted of 18 blue and 1 red rectangular outline. The stimuli were presented on a light-grey background. There was an equal amount of trials (25%) for each search display type (target vs. irrelevant singleton vs. target + irrelevant singleton vs. blank).

The probe consisted in a filled blue square (0.28° × 0.28° of visual angle). The probe could appear in one of the four possible target positions. It could appear either in the location previously occupied by the target, by the color irrelevant singleton or by one of the other neutral distracters.

Participants were seated at 1 m distance from the screen in a dimly lit, electrically shielded and sound attenuated chamber with response keys embedded in a response pad (ERTS ExKey) positioned under their hands. Response to the probe detection was to be executed with their dominant hand (left/right button press) and response to the search task was to be executed with the other hand (upper/lower button press).

Participants

Sixteen paid volunteers (7 female) aged from 20 to 31 years (mean age: 23.6) took part in the experiment. Two participants were left-handed, all had normal or corrected to normal vision. Visual acuity was tested with a Rodenstock R12 vision tester (stimuli 112). The experiment was conducted with the understanding and consent of each participant. None of the observers had taken part in an experiment with such a paradigm before.

Procedure

A trial started with a 500 ms fixation display (one-pixel dot in the centre of the screen). Subsequently, the search display was presented for 100 ms followed by a probe (in 60% of trials) with either a short (134 ms) or a long (234 ms) Stimulus-Onset-Asynchrony (SOA)[5]. In case of probe–present trials, probe could appear for 67 ms. During the Inter-Stimulus-Interval, a blank screen was presented. In case of no-probe trials, the blank screen was presented for additional 67 ms. Participants were asked to press one of the response keys

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[5] Note that although in the present experiment the search display was removed and followed by a blank screen before the probe was presented, the term SOA is used to denote the time interval between the onset of the search display and the onset of the probe.

positioned under their dominant hand when they detected the probe and the other key in case there was no probe; the response assignment (index vs. ring finger) was balanced across participants. Participants were asked to respond as fast and as accurately as possible. Only after participants responded to the probe detection task, a question concerning the target in the search display appeared on the screen (see Figure 3.2). Observers were to respond to this question with a yes/no response with their other hand by pressing the upper or lower response key. Also in this case, the upper/lower assignment was balanced across participants. For visualization of trial sequence see Figure 3.2.

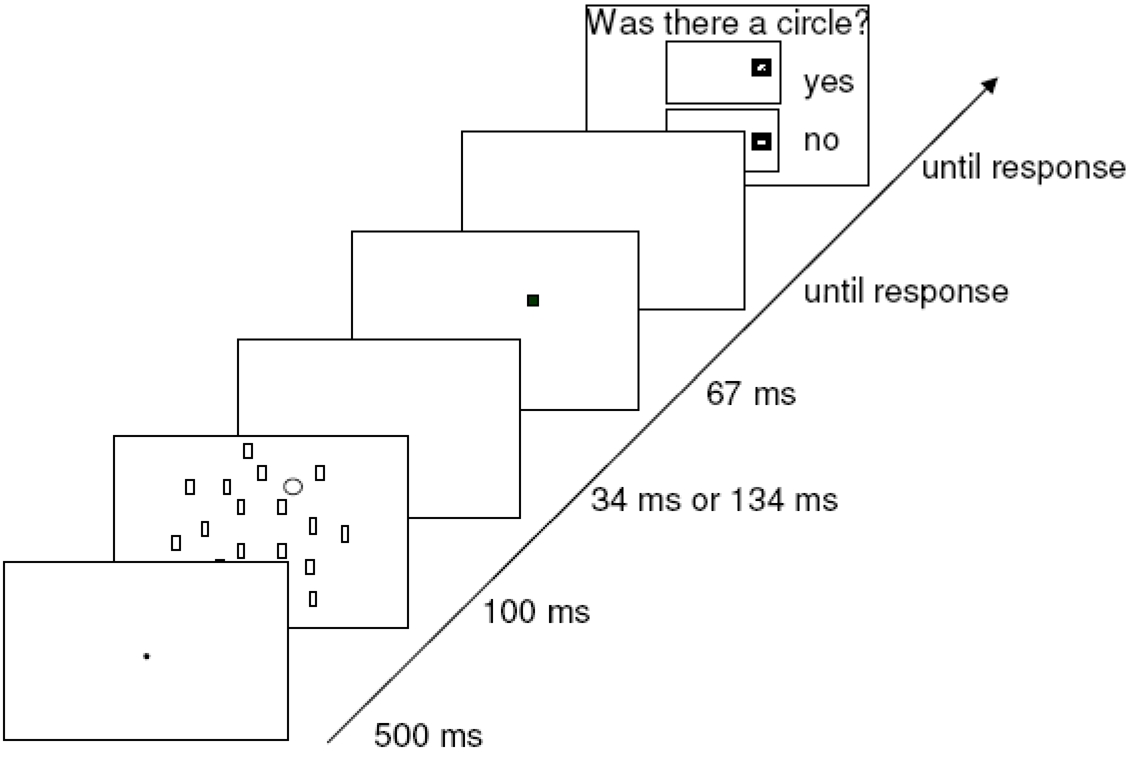

Figure 3.2. Trial sequence. Participants were asked to detect a predefined target (a circle) in a search array. Subsequent to search display presentation, a probe stimulus appeared after a variable SOA. Participants were asked to first respond with one hand to the probe task, i.e. detect the probe presence, and only then to respond with the other hand to the search task, i.e. respond whether there was the target present or not. In case of incorrect answer either to the probe task or to the search task, a verbal feedback appeared on the screen for 500 ms followed by a 500 ms blank screen.

The experiment consisted of 1920 experimental trials divided into two parts (20 blocks à 48 trials per each part) preceded by 3 blocks à 48 practice trials.

ERP recording

EEG was recorded with Ag-AgCl electrodes from 64 electrodes (according to the international 10-10 system). Horizontal and vertical EOG were recorded bipolar from the outer canthi of the eyes and from above and below the observer’s left eye, respectively. All electrodes were referenced to Cz and re-referenced offline to the average of all electrodes. Electrode impedances were kept below 5 kΩ. The signal was amplified with Brain Vision BrainAmp MR plus amplifiers produced by Brain Products GMbH. EEG signal was recorded on a DELL 4600i (Intel Pentium 4, 3 GHz; Windows XP) computer with the Brain Vision Recorder version 1.02 (Brain Products GMbH) software. Sampling rate was 500 Hz with a High Cutoff Filter of 125 Hz.

Data analysis

ERP data

Probe-locked ERPs

In this analysis, EEG was averaged offline over 1100-ms epochs including a 300-ms pre-stimulus baseline interval time-locked to the probe presentation onset. Trials with muscular and other artifacts on any recording channel (indicated by any voltage exceeding ±80 µV, voltage steps between two sampling points exceeding 50 µV, and voltages lower than 0.10 µV for a 100 ms interval) were excluded from analysis. Only probe-present trials with correct responses were analyzed.

The probe-absent trials were subtracted from the probe-present trials which allowed for elimination of overlapping potentials related to search display presentation and, in effect, for extraction of potentials related to probe presentation. The subtraction was conducted on epoched data, separately for each search display type and each SOA, time locked to the search display onset.

Analyses focused on the conditions in which the probe was preceded by a display containing either only the target or only the irrelevant singleton. The EEG signal was averaged for the two display types (target vs. irrelevant singleton), two probe positions ("On", i.e., the previous position of a singleton vs. "Off", i.e., the previous position of a neutral distracter) in both SOAs (short vs. long), which resulted in eight ERP waveforms for each participant and each electrode.

Note that the "On" position denoted previous target position in the target-present displays and previous irrelevant singleton position in the irrelevant-singleton displays.

Mean amplitude values obtained in the P1 time window (100-140 ms post stimulus onset) were subject to repeated-measures analyses of variance (ANOVAs) for electrode sites PO3, PO4, POz, PO7, PO8, O1, O2 and Oz with the factors *SOA* (long vs. short), *probe position* ("On", i.e., target/irrelevant singleton vs. "Off", i.e., a neutral distracter), and *electrode* (PO3, PO4, POz, PO7, PO8, O1, O2 and Oz).

Analogous analyses were conducted for the later differences in mean amplitude values of the negative deflection within the time window of 180 – 220 ms (N1 range) post stimulus onset.

ERPs locked to search display presentation onset

As before, EEG was averaged offline over a 1100-ms epoch including a 300-ms pre-stimulus baseline interval. However, in this analysis, epochs were time-locked to the search display onset and EEG was averaged for probe-absent trials. Trials with muscular and other artifacts were excluded from analysis on the basis of the same criteria as in the first type of analysis and only trials with correct responses were analyzed.

EEG was averaged for four display types (target display, irrelevant singleton display, display containing both singletons and blank display) resulting in four ERP waveforms for each participant and each electrode.

Repeated-measures analyses of variance (ANOVAs) were performed for the mean amplitude values obtained in the N2 time window (240–310 ms) and the P3 latency range (300–360 ms) for the posterior sites PO3, PO4, POz, PO7, PO8, O1, O2 and Oz with the factors *display type* (target vs. irrelevant singleton vs. both vs. blank) and *electrode* (PO3, PO4, POz, PO7, PO8, O1, O2 and Oz).

Behavioral data

Prior to analysis, mean response times (RT) and standard deviations (SD) were computed for each participant. Incorrect trials and trials with no responses in the search task were excluded from all further analyses. Prior to the analysis of reaction time data in the probe detection task, outliers in the probe task were also excluded from further analysis (+/- 3 SD from the overall mean of RT for each participant separately). From the remaining data, individual mean reaction times and errors for probe-present trials in the probe detection task were submitted to 2×2 analyses of variance (ANOVAs) with *SOA* (short vs. long) and *probe position* (“On”, i.e., target/irrelevant singleton vs. “Off”, i.e., a neutral distracter) as within-subject factors separately for target trials and irrelevant singleton trials. Wherever appropriate, specific sub-group differences were tested with paired-samples t-tests. An additional 2×3 ANOVA with the within-subject factors: *SOA* (short vs. long) and *probe position* (“On target” vs. “On irrelevant singleton” vs. “Off”, i.e., the previous position of a neutral distracter) was conducted for reaction times and error rates to probe detection task (probe-present trials) for trials with displays containing both the target as well as the salient irrelevant singleton.

Results

ERP results

ERPs locked to probe presentation onset

The 2×2×8 ANOVA conducted for trials in which the probe was preceded by a target display, with the factors: *probe position* (“On” vs. “Off”), *SOA* (short vs. long) and *electrode*

(PO3 vs. PO4 vs. POz vs. PO7 vs. PO8 vs. O1 vs. O2 vs. Oz) in the P1 time window (100-140 ms post-probe presentation onset) revealed that the expected interaction between SOA and probe position reached the level of significance, $F(1,15) = 8.5$, $p < .05$. Further analyses conducted separately for the two SOAs showed that in the long SOA, P1 mean amplitude was significantly larger for the “On” position of the probe ($M = 1.4$ µV, $SEM = .34$) relative to the “Off” position ($M = .02$ µV, $SEM = .36$), $F(1,15) = 11.4$, $p < .005$. This difference was not significant in the short SOA, $F(1,15) = .24$, $p = .62$ (see Figure 3.3a for Grand Averages of the ERPs time-locked to probe presentation in the target-display condition, long SOA; and Figure 3.3b for differential effects on the P1 component in the target display condition in bar-graph form). Additionally, a significant main effect of SOA was obtained, $F(1, 15) = 4.6$, $p < .05$ showing that the mean amplitudes were, on average, larger in the long SOA ($M = .9$ µV, $SEM = .3$) relative to the short SOA ($M = .1$ µV, $SEM = .2$).

Analysis with the same factors conducted for trials in which the probe was preceded by the irrelevant singleton display revealed no significant effects or interactions. Follow-up analyses conducted for the two SOAs separately showed that the difference in average amplitude between the “On” position and the “Off” position was neither significant in long SOA, $F(1,15) = 1.5$, $p = .23$; nor in the short SOA, $F(1,15) = 0.6$, $p = .8$ (see Figure 3.3c for Grand Averages of the ERPs time-locked to probe presentation in the irrelevant singleton-display condition, long SOA; and Figure 3.3d for effects on the P1 component in the irrelevant-singleton display condition in bar-graph form).

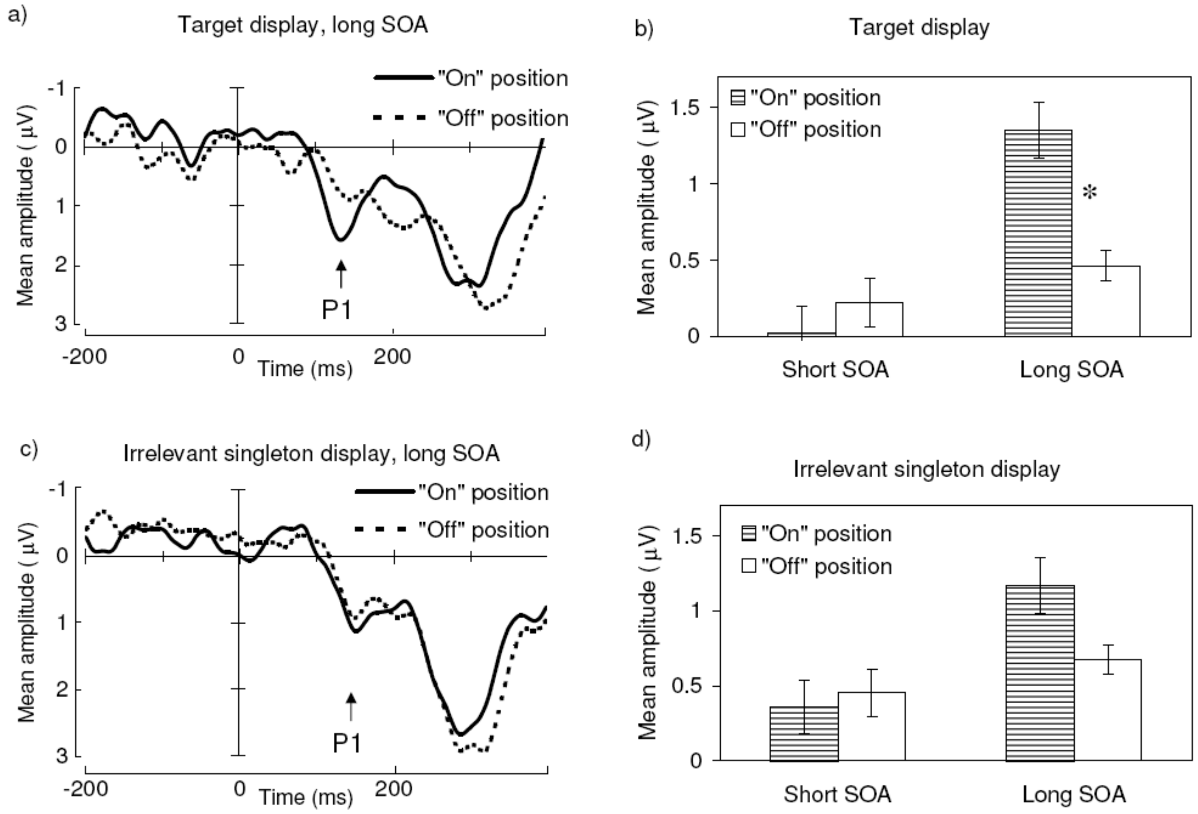

Figure 3.3. Mean amplitudes of an EEG signal time-locked to probe onset within the time window of 100-140 ms post probe onset calculated from the O1, O2, Oz, PO7, PO8, POz, PO3 and PO4 electrodes. (a) Grand Averages of the EEG signal in the long SOA condition, probe presentation following a target search display. Solid line represents the probe “On” condition whereas the dotted line represents the probe “Off” condition. Note that the baseline started 300 ms prior to probe presentation onset and that the statistical analysis was conducted on unfiltered data. Low cutoff (0.7 Hz) as well as high cutoff (20 Hz) filters have been applied to Grand Averages only for illustration purposes. (b) Differential effects on P1 amplitudes when probes were preceded by the target display. Filled bars depict mean amplitudes of the EEG signal for the probe “On” condition whereas the empty bars represent mean amplitudes for the probe “Off” condition. The star indicates a significant difference. Error bars represent standard errors of the mean.

(c) Grand Averages of the EEG signal depicted for the average of the O1, O2, Oz, PO7, PO8, POz, PO3 and PO4 electrodes in the long SOA condition, probe presentation following display containing the irrelevant singleton. Solid line represents the probe “On” condition whereas the dotted line represents the probe “Off” condition. Similar as in Figure 4a, low cutoff (0.7 Hz) as well as high cutoff (20 Hz) filters have been applied to Grand Averages only for illustration purposes. (d) Differential effects on P1 amplitudes when probes were preceded by the display containing the irrelevant singleton. Filled bars depict mean amplitudes of the EEG signal for the probe “On” condition whereas the empty bars represent mean amplitudes for the probe “Off” condition. Error bars represent standard errors of the mean.

Analogous analyses conducted for the time window of 180-230 ms (N1 time range) revealed no significant interaction between *probe position* (“On” vs. “Off”) and *SOA* (short vs. long) neither for trials in which the probe was preceded by a target display nor for trials in which the probe was preceded by an irrelevant singleton display.

ERPs locked to search display onset

The 4×8 ANOVA performed for the mean amplitude values obtained in the N2 time window (240–310 ms post-stimulus presentation onset) with the factors *display type* (target vs. irrelevant singleton vs. both vs. blank) and *electrode* (PO3, PO4, POz, PO7, PO8, O1, O2 and Oz) showed a significant main effect of display type, $F(3,45) = 3.7$, $p < .05$. Planned comparisons revealed that in the N2 time range, the blank display trials evoked a more negative amplitude ($M = -.8$ µV, $SEM = .75$) relative to all other trials: to target trials ($M = .8$ µV, $SEM = .89$), $F(1,15) = 5.1$, $p < .05$; to trials with the display containing both singletons ($M = .5$ µV, $SEM = .7$), $F(1,15) = 5.6$, $p < .05$, and to irrelevant-singleton trials ($M = .2$ µV, $SEM = .92$), $F(3,45) = 3.5$, $p = .07$, (see Figure 3.4a: Grand Average of ERPs time-locked to search displays and Figure 3.4b, left panel, for N2 mean amplitudes).

The 4×8 ANOVA performed for the mean amplitude values obtained in the later time window (300–360 ms post-stimulus presentation onset) with the factors *display type* (target vs. irrelevant singleton vs. both singletons vs. blank) and *electrode* (PO3, PO4, POz, PO7, PO8, O1, O2 and Oz) showed a main effect of display type, $F(3,45) = 5$, $p < .05$. Planned comparisons revealed that in that later time range, the trials with target displays evoked a significantly more positive amplitude ($M = 1.8$ µV, $SEM = 1.1$) relative to blank trials ($M = .08$ µV, $SEM = .87$), $F(1,15) = 11.7$, $p < .005$ and trials with irrelevant singleton displays ($M = .4$ µV, $SEM = 1.1$), $F(1,15) = 8.1$, $p < .05$. The difference in mean amplitude between target trials and trials with display containing both singletons ($M = 1.1$ µV, $SEM = .85$) did not reach the level of significance for this time window (see Figure 3.4a: Grand Average of ERPs time-locked to search displays and Figure 3.4b, right panel, for mean amplitudes 300-360 ms post-stimulus).

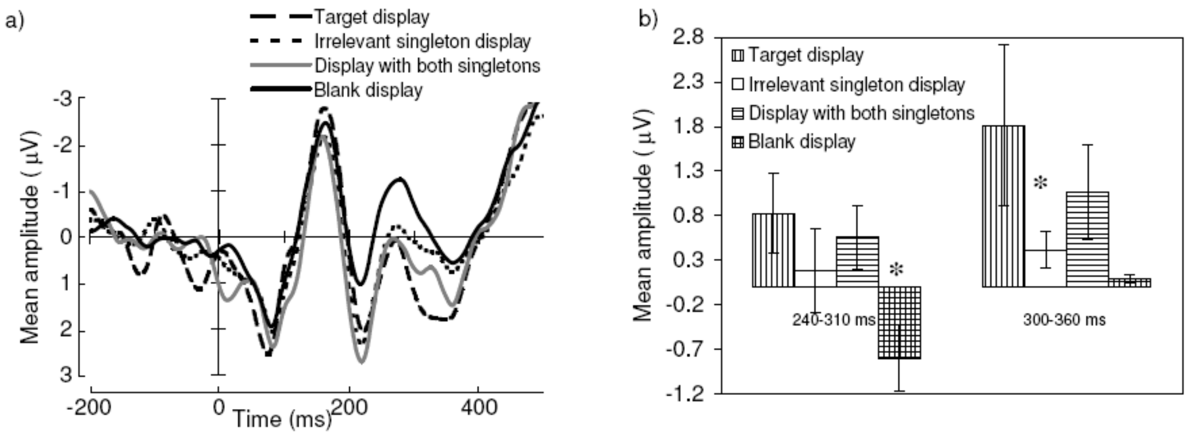

Figure 3.4. Mean amplitudes of the EEG signal calculated from the O1, O2, Oz, PO7, PO8, POz, PO3 and PO4 electrodes, time-locked to search display onset. (a) Grand Averages. Solid black line represents blank displays, dashed black line represents target displays, solid gray line reflects displays containing both singletons and, finally, dotted line stands for displays with the irrelevant singleton. Note that the baseline started 300 ms prior to display presentation onset and that the statistical analysis was conducted on unfiltered data. High cutoff (30 Hz) filters have been applied to Grand Averages only for illustration purposes. (b) Mean amplitudes of an EEG signal time-locked to the search display onset within the time range of 240-310 ms (left) and 300-360 ms (right). Differential effects on Mean Amplitudes with respect to display types. The left panel depicts mean amplitudes at 240-310 ms post-stimulus onset for blank displays (checked bar), target displays (the bar filled with vertical lines), displays containing both singletons (the bar filled with horizontal lines) and irrelevant-singleton displays (empty bar); the right panel depicts mean amplitudes at 300-360 ms post-stimulus onset for the same conditions. Stars indicate significant differences. Error bars represent standard errors of the mean.

Behavioral data

Reaction times

The 2×2 ANOVA conducted for reaction times in the probe detection task, with the factors of *SOA* (short vs. long), and *probe position* (“On” vs. “Off”) for target trials revealed a significant main effect of SOA, $F(1,15) = 6.7$; $p < .05$, with longer reaction times to probe detection in the long SOA condition ($M = 459$ ms, $SEM = 30$) relative to the short SOA condition ($M = 486$, $SEM = 36$).

To further test the differential effects with respect to probe position, paired one-tailed t-tests were conducted. For the long SOA, RTs to probes following the target displays were significantly faster when the probe was presented at the previous target position (probe “On” condition) relative to the probe “Off” condition (previous neutral distracter): Δ= 8.4 ms, *SEM* = 4, *t*(15) = 1.86, *p* < .05 (see Figure 3.5a, second panel from the left). For short SOA trials, there was no significant difference between “On” position and “Off” position (Figure 3.5a, first panel from the left).

The 2×2 ANOVA conducted for reaction times for irrelevant singleton trials revealed no significant effects or interactions, yet post-hoc comparisons (paired one-tailed t-tests) showed that for short SOAs, probe detection was faster for the “On” positions, i.e., when probe appeared at the previous position of the irrelevant singleton, relative to “Off” positions (Δ= 14.6 ms, *SEM* = 6), *t*(15) =2.4, *p* < .05. There was no significant difference for long SOAs (see Figure 3.5b, first and second panel from the left, respectively).

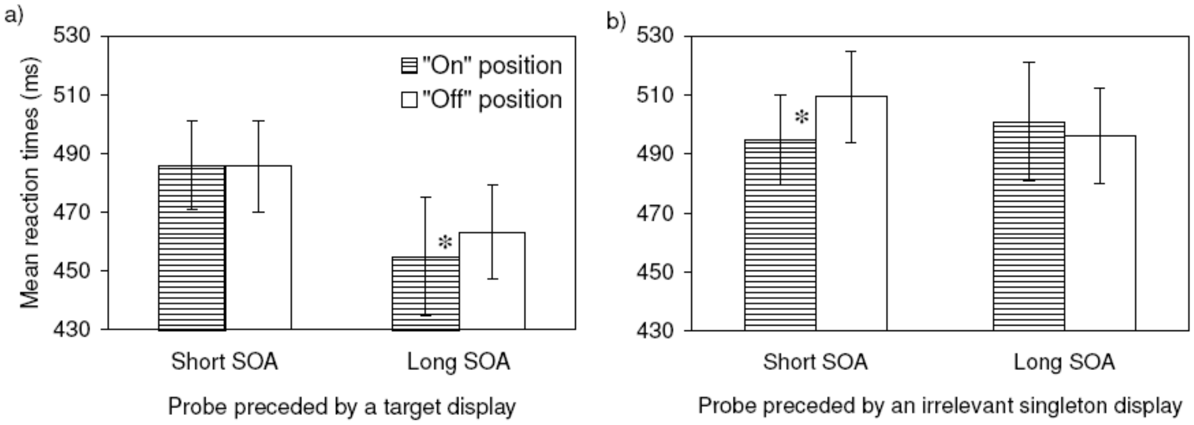

Figure 3.5. Differences in mean reaction times to probe detection with respect to probe position and SOA for target displays (a) and irrelevant singleton displays (b). Filled bars depict reaction times to probes the “On” positions, i.e., at former target positions in the target-display condition and at former positions of the irrelevant singleton in the irrelevant singleton condition. Empty bars represent reaction times to probe when it was presented at “Off” positions, i.e. the former position of a neutral distracter. The stars indicate significant differences. Error bars represent standard errors of the mean.

The 2×3 ANOVA with the factors of *SOA* (short vs. long) and *probe position* (“On target” vs. “On irrelevant singleton” vs. “Off”), conducted for trials with search displays containing both the target and the irrelevant singleton, revealed a significant main effect of SOA, *F*(1,15) = 4.97, *p* < .05 showing shorter RTs to probe detection in long SOA trials (*M* = 465 ms, *SEM* = 29) relative to short SOA trials (*M* = 479 ms, *SEM* = 33). No other effects or interactions reached the level of significance.

For the complete overview of all mean reaction times, also in the blank trial condition, see Table 3.1.

	Mean RTs (ms) and SE (in brackets)	
	Short SOA	Long SOA
Display type	Probe present	
Target	486 ms (35)	459 ms (30)
Irelevant singleton	502 ms (34)	498 ms (33)
Both singletons	479 ms (33)	465 ms (29)
Blank	503 ms (34)	504 ms (33)
	Probe absent	
Target	656 ms (41)	
Irrelevant singleton	550 ms (33)	
Both singletons	660 ms(44)	
Blank	539 ms (36)	

Table 3.1. Mean reaction times and standard errors (in brackets) in the probe detection task as a function of SOA and display type for probe present trials (four upper rows) and as a function of display type for probe absent trials (four lower rows).

Error rates

The 2×2 ANOVA with the factors of *SOA* (short vs. long), and *probe position* (“On” vs. “Off”) conducted for trials with search displays containing the target revealed a significant main effect of SOA, *F*(1,15) = 6.5, *p* < .05, indicating that long SOAs resulted in higher error rates (*M* = 4.5%, *SEM* = 1) relative to short SOAs, (*M* = 2.8 %, *SEM* = 0.8). The same analysis for irrelevant singleton trials revealed also a significant main effect of SOA, *F*(1,15) = 21.5, *p* < .001, indicating that long SOAs resulted in higher error rates (*M* = 8.5%, *SEM* = 1) relative to short SOAs, (*M* = 3.7 %, *SEM* = 0.6) and, additionally, a significant interaction between SOA and probe position, *F*(1,15) = 7.4, *p* < .05, showing that in the short SOA condition, error rates to probes at the “On” position were lower relative to the “Off” position (*M* = 2.7 %, *SEM* = 0.5 and *M* = 4.8 %, *SEM* = 0.9, respectively) whereas in the long SOA condition, the error rates did not differ (*M* = 9%, *SEM* = 1 and *M* = 8 %, *SEM* = 1, respectively).

For trials with search displays containing both the target and the irrelevant singleton, the 2×3 ANOVA with the factors of *SOA* (short vs. long) and *probe position* (“On target” vs. “On irrelevant singleton” vs. “Off”) revealed a significant main effect of SOA, *F*(1,15) = 10.74, *p* < .01 showing smaller error rates in short SOA trials (*M* = 2.3%, *SEM* = 0.6) relative to long SOA trials (*M* = 4.9%, *SEM* = 1) as well as the main effect of position, *F*(2, 30) = 4, *p* < .05 indicating larger error rates for the “On irrelevant singleton” position (*M* = 4.7%, *SEM* = 1) relative to the “Off” position (*M* = 3.3%, *SEM* = 0.6) and “On target” position (*M* = 2.8%, *SEM* = 1).

For the complete overview of all error rates, also in the blank display condition, see Table 3.2, left panel. Additionally, error rates in the target detection task are presented in Table 3.2, right panel.

	Mean error rates (%) and SE (in brackets)			
	Probe detection task		Target detection task	
	Short SOA	Long SOA	Short SOA	Long SOA
	Probe present			
Display type				
Target	3 % (.7)	4% (1)	6 % (1)	2 % (.4)
Irrelevant singleton	4 % (.6)	8 % (1)	2 % (.7)	2 % (.5)
Both singletons	2% (.5)	5% (1)	6% (1)	2% (.5)
Blank	3% (.6)	8% (1)	3% (.5)	2% (.4)
	Probe absent			
Target	10% (2)		2 % (.5)	
Irrelevant singleton	4% (1)		3 % (.5)	
Both singletons	10% (2)		2% (.6)	
Blank	4% (1)		3% (.5)	

Table 3.2. Mean error rates and standard errors (in brackets) in the probe detection task (left panel) and target detection task (right panel) as a function of SOA and display type for probe present trials (four upper rows) and as a function of display type for probe absent trials (four lower rows).

Discussion

In the present paradigm, participants were instructed to perform two tasks. The first was a visual search task, i.e., participants were asked to detect a blue circle target among blue rectangular distracters. The search display could contain either only the target (target display), or the target plus an irrelevant salient singleton (display with both singletons), or an irrelevant singleton only (irrelevant singleton display), or, finally, no singletons (blank display). The second task participants had to perform was to detect, as fast as possible, a blue square probe that appeared subsequent to the search display with a variable SOA (134 ms or 234 ms). The probe was presented at a position of either one of the singletons (“On” position) or at a position of one of the neutral distracters (“Off” position). Two SOAs were introduced to investigate the time course of attention allocation to items of the search display.

When the probe followed the target display, event-related brain responses in the time window of 100-140 ms after probe presentation were more enhanced for the probe "On" condition relative to responses to the probe "Off" condition for long SOA (see Figure 3.3a, b). This result supported the hypothesis concerning allocation of focal attention to the target item and subsequent prioritized processing of probe at that location. Interestingly, no such effects were observed for irrelevant singleton condition, even in the short SOA, where bottom-up processes may have caused allocation of attention to the singleton distracter location.

Also, reaction times to probe detection showed a similar pattern. Responses to trials in which the probe was preceded by target displays were faster when the probe was presented at a previous target location relative to a neutral distracter's location (see Figure 3.5a, second panel). This might indicate that focal attention was allocated to the target item of the search display after a sufficient time interval (of about 240 ms). However, there was no such difference in the short SOA condition (see Figure 3.5a, first panel). On the contrary, for irrelevant singleton trials, reaction times to subsequently presented probes were faster for the irrelevant singleton locations compared to neutral distracter locations in the short SOA (see Figure 3.5b, first panel). This might indicate immediate but transient attentional capture to the irrelevant singleton. In case of irrelevant singleton trials, but such an effect was not obtained in the long SOA condition (see Figure 3.5b, second panel).

ERP results time-locked to the search displays showed different processing of particular display types. In an early time window (240 ms – 310 ms) the neural responses to displays containing the target and displays containing the irrelevant singleton did not differ (see Figure 3.4a). The neural responses to blank trials, however, differed significantly from responses to trials containing salient singletons (see Figure 3.4a, solid line, and Figure 3.4b, left panel). Distinct processing of perfectly homogeneous displays relative to displays containing a singleton was expected based on earlier findings on processing of blank (target-absent) and singleton (target-present) trials (e.g., Schubö, Schröger, & Meinecke, 2004;

Schubö, Wykowska & Müller, 2007). Schubö and colleagues showed that distracter rejection in blank trials is reflected by an enlarged posterior N2 for homogeneous distracter displays, probably reflecting fast global processing mechanisms, such as perceptual grouping (e.g., Duncan & Humphreys, 1989). Distinct processing of blank displays compared to singleton displays might suggest that at early stages of processing, the system distinguished only the blank homogeneous displays from displays containing any saliency signal.

Only after a certain delay (ca. 300 ms after search display onset), also the neural responses to particular singleton displays differed: in the interval 300 ms to 360 ms after search display presentation, ERPs elicited by target displays differed from ERPs to displays containing the irrelevant singleton (see Figure 3.4a; Figure 3.4b, right panel). This result might indicate that classification of search stimuli into target and non-target categories took some time.

Top-down guided control of selection of the task-relevant stimulus

Results of Experiment 3.1 clearly showed that top-down control of selection was capable of efficiently guiding focal attention to the relevant target item in the search task but only after a certain delay. ERP data time-locked to the probe presentation onset showed that when the probe followed the target display, neural responses in the time window of 100-140 ms after probe presentation were more enhanced for the probe “On” condition relative to responses to the probe “Off” condition (see Figure 3.3a, b) suggesting allocation of attention to the target position prior to probe onset. This was observed for the long SOA condition. Importantly, this difference was obtained in a physically identical situation, i.e., when the (identical) probe item was presented after the same time interval relative to search display onset. Therefore, this effect should reflect a difference in internal probe processing caused by differences in the allocation of attention to the search display that was preceding probe presentation.

Such a positive deflection within this early time window observed at posterior electrodes is usually associated with the P1 component (see Luck, 2005 for a review). P1 has been interpreted as indicator of spatial attention (e.g., Hillyard et al., 1998; Luck & Hillyard, 1995; Luck, et al., 2000; Mangun et al., 1993). Therefore, an enhanced P1 for the probe when presented at the former target location indicated that attention had been deployed to that location before probe onset and once another stimulus (namely, the probe) appeared there, its processing was facilitated.

Hillyard and colleagues (Luck & Hillyard, 1995; Luck, Fan, & Hillyard, 1993) investigated whether same attentional processes take place in simple feature detection and discrimination of conjunction of features in visual search tasks. In their experiments, a visual search task was combined with a post-stimulus probe presentation. Participants were to either report the presence (or absence) of a target defined by color (feature detection condition) or discriminate the shape of the target (conjunction discrimination condition). Subsequently, a probe that consisted in an outline of a rectangle surrounding one of the display items was presented. The probe was not relevant to the task, i.e., participants' task was not to respond to the probe but only perform the visual search. The authors observed a larger P1 (time-locked to probe presentation onset) when a probe appeared at a target location vs. irrelevant distracter's location in the discrimination task. In case of simple color detection, no P1 effects were observed.

Interestingly, Experiment 3.1 showed that when a response to the probe was required, i.e., when probe was task-relevant, attentional effects on P1 (time-locked to the probe) were obtained in simple detection of a target defined by a unique feature (namely form).

In a discussion of studies reported later (Hillyard et al., 1998), Hillyard and colleagues argue that P1 effects might indicate an attentional gain mechanism in cases when the system needs to deal with interference whereas N1 effects are supposed to reflect discriminative processes at the attended locations. The present task did not require any post-detection discrimination process but rather required attenuation of interference due to irrelevant singleton trials that were to be rejected. These task requirements might have accounted for why an enhanced P1, but not N1, was observed to probes presented at those locations to which focal attention had already been allocated (in the search display) relative to probes presented at other, non-attended, locations.

Present behavioral results showed a similar pattern to observed effects in the ERP data, also supporting the delayed top-down control of selection. In the long SOA condition, the detection of a probe at the “On” position following the target display was faster relative to the “Off” position (see Figure 3.5a). From this result one can conclude, similar to Kim & Cave (1999), that when the target display was presented, focal attention was allocated to the target item, but only after some time - as effects were only observed in the long SOA condition. Therefore, subsequently, when the probe appeared at the former target position (where attention was allocated), processing of probe was facilitated as reflected by its faster detection.

Since no such benefit of the “On” position over the “Off” position was observed for the irrelevant singleton display trials in the long SOA condition, it was probably not the saliency itself that drew focal attention to the target location. Instead, it supposedly was top-down, goal-oriented selection that allowed for directing attention to the target.

Bottom-up attentional capture effects

Bottom-up attentional capture effects to irrelevant singletons were only observed as short-lived and transient in behavioral data but not in the ERPs. The reaction time data showed that in the short SOA condition, participants responded faster to probes presented at the previous location of the irrelevant singleton relative to probes presented at the former location of a neutral distracter (see Figure 3.5b, left panel). Additionally, error rates in probe detection were significantly higher for probes presented at the “Off” position relative to the

“On” position in the short SOA condition for irrelevant singleton displays. These effects are in line with the findings of Kim & Cave (1999) who also observed shorter reaction times for probe presented at the irrelevant singleton’s locations relative to neutral locations in the short SOA.

At the same time, the present ERP data did not show effects of transient capture of attention for the irrelevant singleton position. In the irrelevant singleton display condition, ERPs to probes presented at the “On” position did not differ from ERPs to probes at the “Off” position for either of the SOAs (see Figure 3.3c, d).

Therefore, with regard to bottom-up attentional capture to irrelevant singletons, one might conclude that in the present study, the salient irrelevant singleton may have induced a interfering signal that drew attention to its location. Later, this signal might have been overridden by a top-down control of selection of the task-relevant item (the target), as in the long SOA condition, the location of the previous irrelevant singleton was no more prioritized but, instead, attention was allocated to the target item which facilitated processing of the probe presented subsequently at its location.

However, present results do not support a strong claim of the proponents of the *pure capture* stance, i.e., the postulate that early bottom-up capture is entirely impenetrable to top-down modulation. The fact that no benefit for irrelevant singleton’s location over the other locations was observed in the ERP data may indicate that top-down control of selection had some inhibitory influence on the stimulus-driven, saliency-based attentional capture already early in time (i.e., already in the short SOA condition).

A proponent of the *pure capture* stance might argue, though, that the short SOA was long enough for rapid disengagement. As Theeuwes et al. (2000) showed, bottom-up attentional capture effects might occur only within 100 ms post-stimulus onset. In the present study, the short SOA between search display and the probe presentation was 134 ms. Such an interval might have been enough for attention to be rapidly disengaged from the irrelevant salient singleton. On the other hand, since the behavioral data did show facilitation effects of the irrelevant salient singleton location in the short SOA condition, there is some indication that if the bottom-up capture effects were to occur, the 134 ms time interval was not too long for them to be observable.

Temporal dynamics of the top-down and bottom-up control of selection

The main goal of Experiment 3.1 was to examine temporal dynamics of top-down control of visual selection, and, more precisely, the temporal interplay of top-down and bottom-up selection processes. Results provided evidence that the allocation of attention to the relevant salient (target) item through top-down control took time. Both P1 effects and reaction time differences indicating attention allocation were observed only in the long SOA condition. This might imply that the short SOA was not enough to allocate focal attention through top-down control, in a persistent way to be observable as a subsequent attention-modulated processing of probe.

Although the present results allow only for speculations on the exact nature and temporal relation of the processes underlying allocation of focal attention, some suggestions might be put forward. It might be the case that in order for focal attention to be allocated to the target, the system needs to match singletons presented in a search display to a stored target representation, such as, for example, a target template (e.g., Duncan & Humphreys, 1989) or attentional control settings formed according to task instructions (e.g., Folk et al., 1992). At the beginning of the experiment, observers probably formed a task set according to the given task instruction, that caused them to weight higher items with target-defining characteristics relative to task-irrelevant items. Additionally to this task-induced weighting that was constant across the experiment, the system may have employed a matching process within each trial. This may have become necessary as search displays with relevant or irrelevant singletons were presented randomly throughout single blocks of the experiment, causing the observer to apply the template-matching process in every single trial. When the singleton matched the stored target template, attention was allocated to its position and the singleton was selected as “target”. The template-matching process could enable selection of the relevant item and may have been necessary for guiding focal attention to the target item in a top-down manner.

As target-template matching might have required some time, it may explain why the effects of allocation of attention to the target item were observed in the long SOA but not in the short SOA. ERP data time-locked to the search display might provide further evidence for the above argumentation. Because the differential effect of enhanced ERPs for target displays relative to non-target displays (time-locked to the search display) within 300-360 ms post stimulus presentation occurred relatively late, this effect might reflect such a template-matching mechanism.

Once the stimulus was matched to the template, it might have allowed attention to be allocated to the location where a positive match was made, that is, to the relevant item (the target). In effect, subsequent stimuli presented at that location were processed in a prioritized manner due to, for example, a sensory gating mechanism (for discussion see e.g., Hillyard et al., 1998). The P1 component which was enhanced for probes presented at the target location relative to neutral distracter’s locations might reflect such a mechanism (Hillyard et al., 1998) and as such, reflect the final effect of focal attention allocated to the target item position.

Concluding remarks

In summary, the present ERP data, supported by similar result patterns in the behavioral data, showed that with sufficient time after stimulus presentation, top-down control of selection efficiently guided focal attention to the task-relevant target item. Furthermore, bottom-up capture of focal attention to the irrelevant stimulus was observable only in the behavioral data as transient and decaying with time.

Therefore, results of the present experiment support the conclusion that was put forward also by Kim & Cave (1999), namely that the debate concerning top-down, goal-directed vs. bottom-up, stimulus-driven control of attention needs to be considered in relation to the temporal dynamics of the two mechanisms and that early bottom-up capture effects are influenced by top-down modulations.

Chapter 4: Various aspects of top-down control of visual selection.

Abstract

Top-down, goal-oriented control of visual selection might become necessary when the visual system deals with strong but irrelevant interfering saliency signals presented in concurrence to signals relevant to the current task. Potency of the top-down control of selection, its possible effects on attention allocation and its time course were investigated. A paradigm combining a visual search task with post-display probe discrimination was used to examine these effects. ERPs locked to search displays allowed for investigating the development of top-down selection whereas ERPs locked to probes allowed for investigating how top-down selection affected the allocation of attention at a specific point in time, i.e., at probe onset which occurred after two SOAs. Analyses of ERPs time-locked to search displays suggested that target displays were differentiated from irrelevant displays already at an early time point (N1 component). An additional, supposedly inhibitory, mechanism was observed in the P3 time-window for color (but not shape) irrelevant singletons that might be due to the different saliency levels of color and shape singletons. Analyses of ERPs time-locked to probes revealed top-down control of focal attention independent of the SOA.

Taken together, the results show that top-down mechanisms operate already at early stages of processing when it is necessary to control selection due to interfering saliency signals.

Background of the study

The human visual system tries to focus on what is relevant at a particular moment in time, although there are always many salient, attention-capturing events taking place in our environment. Is our attention driven to the salient irrelevant signals automatically or are we able to select the relevant information and ignore what is currently irrelevant?

Proponents of a *pure attentional capture stance* (e.g., Theeuwes, 1992, 1994, 1995a; Theeuwes, Atchley, & Kramer, 2000) argue that at early stages of processing, the top-down control is not potent enough to modulate bottom-up attentional capture. According to this view, saliency signals capture attention automatically regardless their irrelevance to the task at hand. On the other hand, the *contingent capture perspective* (Folk & Remington, 1998, 2006; Folk, Remington, & Johnston, 1992; for a review of the discussion see Folk & Remington, 2006) implies that top-down control occurs also at the early stages of processing and that attentional capture to the salient stimulus takes place only if the stimulus shares characteristics with the task-relevant target item.

Some authors suggested considering the discussion between proponents of the attentional capture perspective and the contingent capture stance in the context of the time course of mechanisms occurring during visual selection (e.g., Kim & Cave, 1999). It was suggested that top-down control takes time to develop and is thus observed only after a specific time interval.

Chapter 3 describes a study (Experiment 3.1) in which the time course of top-down control of attention was examined using event-related brain potentials (ERPs). Experiment 3.1 investigated how such task-related top-down control develops over time in a situation when an additional, irrelevant (but salient) singleton might bottom-up capture the observer's attention. Experiment 3.1 was inspired by results of Kim & Cave (1999) who examined the temporal interplay between top-down control and bottom-up capture of spatial attention. Kim

& Cave (1999) used a paradigm that combined a visual search task with a post-stimulus probe detection task. They found that bottom-up attentional capture occurs early, decays with time and is, to some extent, penetrable by top-down modulation. Importantly, top-down control of spatial attention turned out to be efficient and occur after some delay. However, as Kim & Cave (1999) used a paradigm in which a singleton was always present (there were two types of display: a target plus irrelevant singleton display and a display with the irrelevant singleton only), participants might have adopted a bottom-up strategy to perform the search task, i.e., a "singleton-counting" strategy (e.g., two singletons = target present; one singleton = no target).

Experiment 3.1 of the present dissertation aimed at ensuring that a task-relevance weighting would be encouraged so that it could be tested whether the effects of Kim & Cave (1999) were not due to any bottom-up strategy. Therefore, in Experiment 3.1 also "proper" blank trials (with only neutral distracters in the display) as well as target-only trials were introduced. Moreover, an ERP methodology was applied in order to investigate the *dynamics* of top-down control of visual attention. Investigating event-related brain potentials allowed for examining the precise time course of the top-down control process. A visual search paradigm was used in which participants were asked to detect a blue circle target among rectangular distracters. The search display could contain either only the target (blue circle among blue rectangles), or the target plus an irrelevant salient singleton (blue circle and a red rectangle among blue rectangles), or an irrelevant singleton only (red rectangle among blue rectangles), or, finally, no singletons (blue rectangles only). The second task was to detect, as fast as possible, a blue square probe that appeared subsequent to the search display with a variable SOA (134 ms or 234 ms). The probe was presented either at a position of one of the singletons or at a position of one of the neutral distracters. The two different SOAs were introduced to investigate how attention allocation to items of the search display affected processing of probes appearing at a particular point in time after search display presentation.

Results showed that after a certain delay, top-down control guided focal attention to the relevant target item in the search task. This was implied by ERP results time-locked to the probe presentation onset. These results showed that when the probe followed the target display in the long SOA condition, neural responses in the P1 time window of 100-140 ms after probe onset were more enhanced for probes presented at the target position relative to probes presented at other positions. P1 has often been interpreted as indicator of spatial attention (e.g., Hillyard, Vogel, & Luck, 1998; Luck & Hillyard, 1995; Luck, Woodman, & Vogel, 2000; Mangun, Hillyar, & Luck, 1993). Therefore, an enhanced P1 for probes presented at the former target location most probably indicated that attention had been deployed to that location before probe onset and once another stimulus (namely, the probe) appeared there, its processing was modulated. The observed evidence for a top-down control of focal attention, that took time to occur, was in line with Kim & Cave's (1999) findings.

As stated above, ERPs time-locked to probe onset allowed for investigating how allocation of attention resulting from search display presentation affected attention effects measured at the moment of probe presentation. Additional information concerning the attention effects was gained by analyzing ERPs time-locked to the search display. Such analysis allowed for investigating the time course of the display-related selection processes proper.

Results of Experiment 3.1 showed that ERPs time-locked to the search displays also showed specific attention effects. After a certain delay (ca. 300 ms after search display onset), neural responses to target displays differed from neural responses to displays containing the irrelevant singleton. As there was no direct response to the search display at this time point, the authors suggested that this differential effect reflected a process that indicated the allocation of attention to the relevant item.

The present experiment (Experiment 4.1.) was designed to investigate the time course and potency of top-down modulation of visual selection in further detail and to examine how top-down control modulates attention allocation.

Furthermore, also the issue of how particular singleton types affect visual selection was undertaken in Experiment 4.1. Many authors have observed that perceptual dimensions (e.g., color vs. form or orientation) differ with respect to how fast they are detected based on the bottom-up saliency signals they induce (see e.g., Found & Müller, 1996; Quinlan & Humphreys, 1987; Theeuwes, 1991, 1992). Theeuwes (1991) showed that color targets were detected faster than shape targets when presented with the same type of background distracters. In result, color singletons, when irrelevant, became more interfering than irrelevant shape singletons. Theeuwes (1991) argued that saliency signals from the color dimension are available earlier and as such, guide attention to the color singleton faster than to the form singleton. Such interpretation should explain why color targets were detected faster then shape targets and why color irrelevant singletons interfered with the detection of (relevant) shape targets but irrelevant shape singletons did not interfere with the detection of color targets.

Therefore, as detection speed of color and shape singletons might differ, singleton's relevance (being the target or an irrelevant distracter singleton) might interact with the singleton's type (color vs. shape) in the present experimental design.

Experiment 4.1.

Rationale of the experiment

The present paradigm combined presentation of a search display with post-display probe (similar to Kim & Cave, 1999; as well as Experiment 3.1 of the present dissertation). Displays containing either a shape singleton (circular outline) among blue rectangles or a color singleton (red rectangular outline) among blue rectangles (blue outlines, see Figure 1) were presented in a random order. One of the singletons was declared a target that was to be detected. The other item was declared an irrelevant singleton that had to be rejected. Rather than using the same target type throughout the whole experiment, target assignment was blocked and changed after the first part of the experiment. For one half of all the trials, the target was defined by shape (circle) and the color singleton (red) was irrelevant and for the other half of the trials, the roles were switched, i.e., the color singleton became relevant and the shape singleton was to be rejected. In this way, conditions with physically identical displays that differed only with respect to task relevance could be compared. Experiment 4.1 aimed at pinpointing the potency of modulation of visual selection with respect to task-relevance in the situation when an attention-capturing salient singleton was randomly intermixed with the relevant item ERPs time-locked to the search display were expected to differ with respect to a singleton's task-relevance.

The paradigm consisted also of a second task, namely discrimination of probe orientation. Probe presentation should allow for investigating how the allocation of attention to particular items in the search display would influence the attentional effects related to probe processing. A probe discrimination task was used in order to encourage the observers to actually attend to the probe. Simple probe detection (being the only one stimulus in the visual field) might not employ attention to the same extent as a discrimination task and probe discrimination should enhance any attention effects. Attention effects, similarly to Experiment 3.1., should be observed as differences in processing of probes with respect to probe position in relation to the previously presented search display: Probes could be presented at the former location of one of the singletons or at a position of one of the neutral distracters. If attention was allocated to one of the singletons, processing of probes located at that position should differ from processing of probes at one of the neutral distracter's locations. The experimental question was whether such differential effect would depend on whether the singleton would be relevant (target) or irrelevant to the task.

ERPs time-locked to probes were expected to express such differences in probe processing. Based on the findings of the previous experiment and other studies showing early spatial attention effects on P1 and/or N1 (e.g., Heinze, Luck, Mangun, & Hillyard, 1990; Hillyard et al., 1998; Hopfinger & Mangun, 1998; Luck & Hillyard, 1995; Luck et al., 2000; Mangun et al., 1993; for a review see also Hillyard et al., 1998), one may expect an enlarged P1 and/or N1 component for probes presented at the target position relative to other positions.

Finally, using two types of singletons in the search display (shape and color) allowed for investigating how the type of singleton influences the processes of selection. Based on findings of e.g., Theeuwes (1991), ERPs time-locked to the search display might differ with respect to singleton type. As color was observed to be more salient than shape, top-down effects might differ for these two singleton types.

Method

Stimuli and apparatus

Stimuli were presented on a 17-inch computer screen (Iiyama MA 201D, Vision Master 511) with a 60 Hz refresh rate placed at a distance of 100 cm from an observer. The experiment was run on a Siemens Celsius 420 computer with a Celeron 466 MHz processor.

The search display always contained 19 items positioned on three imaginary circular arrays with diameters of 4.6°, 6.3°, 8.0° of visual angle. The outer and middle circles contained 8 elements each and the inner circle contained 3 elements. There were two possible display types: (1) a shape singleton (a blue outline circle of 0.57° in diameter, see Figure 4.1a) and (2) a color singleton (a red outline of a 0.28° × 0.74° vertical rectangle, see Figure 4.1b). The singleton was embedded in a set of 18 blue outlines of vertical rectangles (also 0.28° × 0.74° of visual angle) and appeared at one of four positions (upper left/right or lower left/right from the middle point) of the middle array of the 6.3° degrees of visual angle in diameter. The stimuli were presented on a light-grey background. There was an equal amount of trials (50%) with color and shape singleton displays.

The probe consisted in a filled bar oriented to the left or to the right (0.46° × 0.11° of visual angle). The probe could appear in one of the four possible target positions. It could appear either in the location previously occupied by one of the singletons or by one of the other neutral distracters.

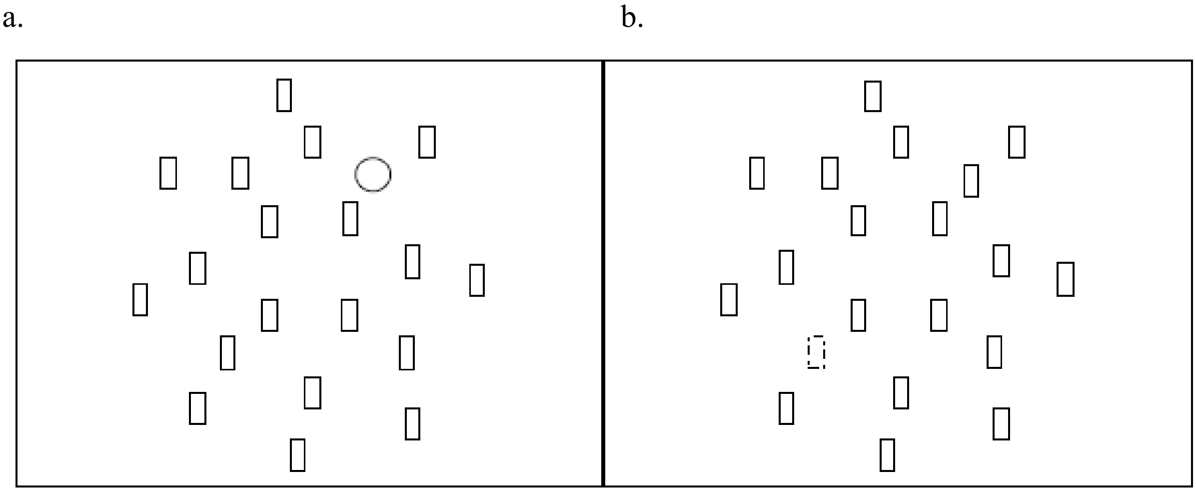

Figure 4.1. Examples of display types. The left panel (a) shows displays containing a shape singleton (circle) and (b) is an example of a display containing a color singleton (red rectangle). Solid line represents the blue color whereas the dashed line symbolizes red. Task instructions given prior to each experimental part determined which of the two types of singleton was to be selected as target and which was to be ignored. The target dimension switched after the first part of the experiment.

Participants were seated at 1 m distance from the screen in a dimly lit, electrically shielded and sound attenuated chamber with response keys embedded in a response pad (ERTS ExKey) positioned under their hands. Response to the probe discrimination was to be executed with their dominant hand (left/right button press) and response to the search task was to be executed with the other hand (upper/lower button press).

Participants

Sixteen observers (5 male) aged from 19 to 30 years (mean age: 23.4) took part in the experiment. Half of the participants were paid volunteers and the other half took part for course credits. One participant was left-handed, all had normal or corrected to normal vision. Visual acuity was tested with a Rodenstock R12 vision tester (stimuli 112). The experiment was conducted with the understanding and consent of each participant. None of the observers had taken part in an experiment with such a paradigm before.

Procedure

A trial started with a 500 ms fixation display (one-pixel dot in the centre of the screen). Subsequently, the search display was presented for 50 ms followed by a blank screen (33 ms or 133 ms). In 80% of trials, a probe was subsequently presented with either a short (83 ms) or a long (183 ms) Stimulus-Onset-Asynchrony (SOA) [6]. In case of no-probe trials (20%), the blank screen was presented for additional 50 ms. Participants were asked to press the left response key when the probe was left-tilted and the right response key when the probe was right-tilted. In case of probe-absent trials, no probe response was required. Participants were asked to respond as fast and as accurately as possible. Only after participants responded to the probe discrimination task, a question concerning the target in the search display appeared on the screen. Observers were to respond to this question with a yes/no response with their other hand by pressing the upper or lower response key. For visualisation of trial sequence see Figure 4.2.

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[6] Note that the SOAs were shorter than in Experiment 3.1. in order to circumvent a possibility that the short SOA would be too long for bottom-up attentional capture effects to be observed. In Experiment 3.1. bottom-up attentional capture effects were not observbed in the ERP data in either the short or the long SOA condition. A proponent of the *pure capture* stance might argue, that the short SOA used in Experiment 3.1. was long enough for rapid disengagement of attention to occur. The short SOA was, therefore, decreased below 100 ms in Experiment 4.1. to investigate whether the bottom-up attentional capture effects would now be present. The long SOA was also shorter than in Experiment 3.1. in order to maintain the same difference between the short and the long SOA.

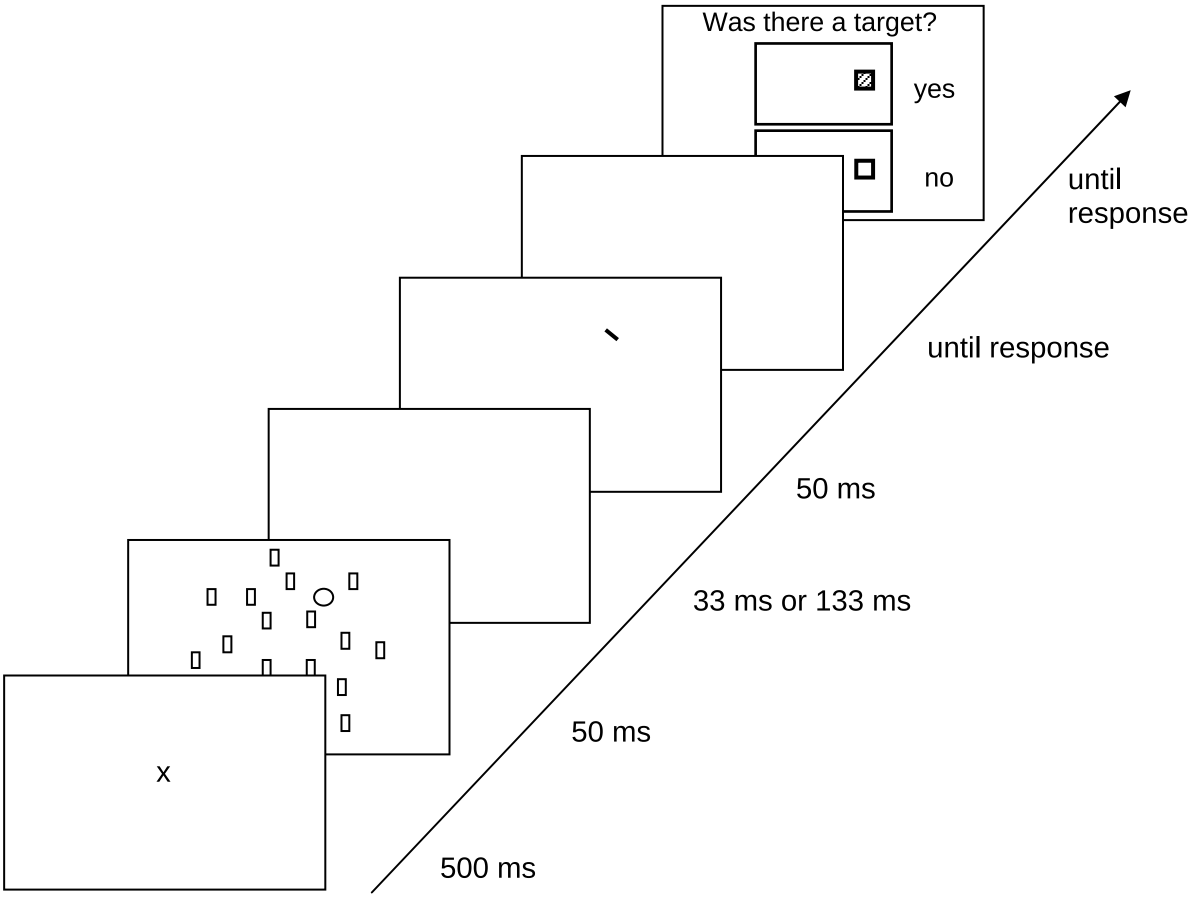

Figure 4.2. Trial sequence. Participants were asked to detect a predefined target in a search array. Subsequent to search display presentation, a probe stimulus appeared after a variable SOA. Participants were asked to first respond with one hand to the probe task, i.e. report its orientation (left vs. right), and only then, after a question appeared on the screen, to respond with the other hand to the search task, i.e. respond whether the target was present or not. In case of an incorrect answer either to the probe task or to the search task, a verbal feedback appeared on the screen for 500 ms followed by a 500 ms blank screen.

The experiment consisted of 2400 experimental trials divided into two parts (5 blocks per part with 240 trials per each block). The first part was preceded by 160 practice trials and the second part by 80.

The target assignment was blocked, i.e., in the first part (five blocks), participants were to detect one of the singletons as target (say, shape) and reject as irrelevant the other type of singleton (say, color) while in the second part, the target assignment was switched (in this case, color was the target and shape was irrelevant). The order of target assignment was counterbalanced across participants.

ERP recording

EEG was recorded with Ag-AgCl electrodes from 64 electrodes (according to the international 10-10 system). Horizontal and vertical EOG were recorded bipolar from the outer canthi of the eyes and from above and below the observer's left eye, respectively. All electrodes were referenced to Cz and re-referenced offline to the average of all electrodes. Electrode impedances were kept below 5 kΩ. The signal was amplified with Brain Vision BrainAmp MR plus amplifiers produced by Brain Products GMbH. EEG signal was recorded on a DELL 4600i (Intel Pentium 4, 3 GHz; Windows XP) computer with the Brain Vision Recorder version 1.02 (Brain Products GMbH) software. Sampling rate was 500 Hz with a High Cutoff Filter of 125 Hz.

Data analysis

ERP data

Search-display locked ERPs

For search display ERPs, EEG was averaged for probe-absent trials only over a 1000-ms epoch including a 200-ms pre-stimulus baseline interval, time-locked to search display onset. Trials with muscular and other artifacts on any recording channel (indicated by any voltage exceeding ±100 µV, voltage steps between two sampling points exceeding 50 µV, and voltages lower than 0.10 µV for a 100 ms interval) were excluded from analysis. Only trials with correct responses in both tasks were analyzed. EEG was averaged for two singleton types (color and shape) with respect to their task relevance (target vs. irrelevant singleton) resulting in four ERP waveforms for each participant and each electrode.

Repeated-measures analyses of variance (ANOVAs) were performed for the mean amplitude values obtained in the N1 time window (130-200 ms), the N2 latency range (200–270 ms) and the P3 range (270-360 ms) for the posterior sites PO3, PO4, PO7, PO8, POz, O1, O2 and Oz with the within-subject factors *singleton type* (color vs. shape), *relevance* (target vs. irrelevant singleton) and *electrode* (PO3, PO4, PO7, PO8, POz, O1, O2 and Oz).

Probe-locked ERPs

EEG was averaged offline over 1000-ms epochs including a 200-ms pre-stimulus baseline interval, time-locked to probe onset. Trials with muscular and other artifacts were excluded from analysis on the basis of the same criteria as in the first type of analysis and only trials with correct responses to probe task and to search task were analyzed.

To eliminate overlapping potentials related to search display presentation, probe-absent trials were subtracted from the probe-present trials. The subtraction was conducted on epoched data, separately for each singleton type (color vs. shape) and each SOA, time locked to the probe onset.

The EEG signal was averaged dependent on singleton type (color vs. shape) and with respect to singleton relevance (target vs. irrelevant singleton), separately for two probe positions (“On”, i.e., the previous position of a singleton vs. “Off”, i.e., the previous position of a neutral distracter) and two SOAs (short vs. long), which resulted in sixteen ERP waveforms for each participant and each electrode. Note that the “On” position denoted previous target position or previous irrelevant singleton position dependent on target/irrelevant singleton assignment.

Mean amplitude values obtained in the P1 time window (90-180 ms post stimulus onset) were subject to repeated-measures analysis of variance (ANOVAs) for electrode sites PO3, PO4, PO7, PO8, POz, O1, O2 and Oz with the within-subjects factors of *singleton type* (color vs. shape), *relevance* (target vs. irrelevant singleton), *SOA* (long vs. short), *probe position* (“On”, i.e., target/irrelevant singleton vs. “Off”, i.e., a neutral distracter), and *electrode* (PO3, PO4, PO7, PO8, POz, O1, O2 and Oz).

Reaction time data

Only reaction times in the probe task were analyzed[7]. Prior to analysis, mean response

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[7] Reaction times to search display presentation were not analysed as responses in the search task were delayed until the completion of the probe responses (in probe present trials) or until the question concerning the target presence appeared on the screen (probe absent trials).

times (RT) and standard deviations (SD) were computed for each participant. Incorrect trials and trials with no responses in the probe task or the search task were excluded from all further analyses. Outliers in the probe task (+/- 2 SD from the overall mean of RT for each participant and each block separately) were also excluded from further analyses. From the remaining data, individual mean reaction times were submitted to a 2×2×2×2 analysis of variance (ANOVA) with *singleton type* (shape vs. color), *relevance* (target vs. irrelevant singleton), *SOA* (short vs. long) and *probe position* (“On”, i.e., target/irrelevant singleton vs. “Off”, i.e., a neutral distracter) as within-subject factors.

Error rates

Mean error rates in the probe task were submitted to 2×2×2×2 analysis of variance (ANOVA) with *singleton type* (shape vs. color), *relevance* (target vs. irrelevant singleton), *SOA* (short vs. long) and *probe position* (“On”, i.e., target/irrelevant singleton vs. “Off”, i.e., a neutral distracter) as within-subject factors.

Additionally, mean error rates in the search task for probe absent trials were submitted to a 2×2 ANOVA with *singleton type* (shape vs. color), and *relevance* (target vs. irrelevant singleton) as within-subject factors.

Results

ERP results

ERPs locked to search display onset

The 2×2×8 ANOVAs performed for the mean amplitude values obtained in the N1 time window (130-200 ms post-stimulus presentation onset), N2 time window (200-270 ms) and the P3 time window (270-360 ms) with the within-subjects factors *singleton type* (color vs. shape), *relevance* (target vs. irrelevant singleton) and *electrode* (PO3, PO4, PO7, PO8, POz, O1, O2 and Oz) showed the following results:

For the N1 time window, the ANOVA revealed a significant effect of relevance, *F*(1,15) = 4.7, *p* < .05, indicating larger N1 for target trials (*M*= -1.1 μV, *SEM*= 0.6; see Figure 3a, solid line) relative to irrelevant singleton trials (*M*= -0.8 μV, *SEM* = 0.6 see Figure 4.3a, dotted line).

For the N2 time window, the ANOVA did not indicate any significant effects or interactions. Also further analyses conducted separately for each singleton type did not reveal any significant effects of relevance.

For the P3 time window, the ANOVA revealed a significant effect of relevance, *F*(1,15) = 16, *p* < .005, showing an enhanced P3 for target trials (*M*= 0.8 μV, *SEM* = 0.7; see Figure 3a, solid line) relative to irrelevant singleton trials (*M*= 0.1 μV, *SEM* = 0.7; see Figure 4.3a, dotted line). This main effect of relevance was followed by an interaction between singleton type and relevance, *F*(1,15) = 6, *p* < .05, which showed that target trials differed from irrelevant singleton trials for color singletons (color targets: *M*= 0.8 μV, *SEM* = 0.8; color irrelevant singletons: *M*= -0.4 μV, *SEM* = 0.7) but not for shape singletons (shape targets: *M* = 0.7 μV, *SEM* = 0.7; shape irrelevant singletons: *M* = 0.6 μV, *SEM* = 0.8). Additionally, a main effect of electrode *F*(7, 105) = 6, *p* < .01 was observed and a main effect of singleton type, *F*(1,15) = 9, *p* < .05, indicating that P3 was more enhanced for shape singleton trials (*M*= 0.6 μV, *SEM* = 0.7) relative to color singleton trials (*M*= 0.2 μV, *SEM* = 0.7).

Subsequent analyses conducted separately for the color-task (color target, shape irrelevant singleton) and shape-task (shape target, color irrelevant singleton) showed a relevance effect (target vs. irrelevant singleton) only for the shape task, *F*(1,15) = 25, *p* < .001 (see Figure 4.3b black lines), but not in the color task (see Figure 4.3b grey lines).

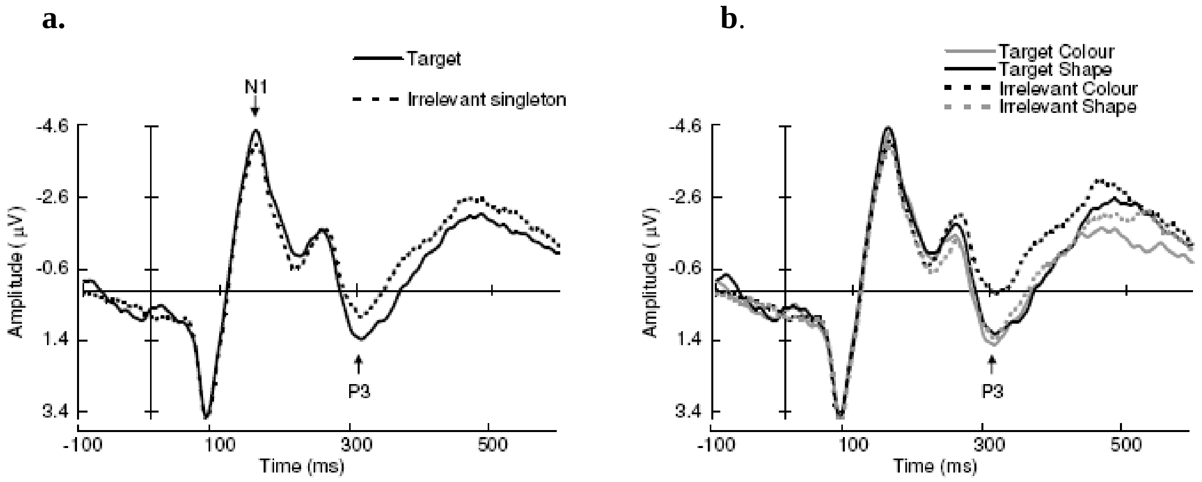

Figure 4.3. Grand Average ERPs calculated from the O1, O2, Oz, PO3, PO4, PO7, PO8, and POz electrodes, time-locked to search display onset. Note that the baseline started 200 ms prior to display presentation onset and that the statistical analysis was conducted on unfiltered data. High cutoff (30 Hz) filters have been applied to Grand Averages only for illustration purposes. (a) Grand Averages pooled across all eight electrodes and averaged across color and shape singleton trials. Solid line depicts the target trials and dotted line represents the irrelevant singleton trials. Arrows indicate statistically significant differences. (b) Grand Averages pooled across all eight electrodes separately for color singletons (black lines) and shape singletons (gray lines). Solid lines depict target trials whereas dotted lines represent irrelevant singleton trials.

In order to compare physically identical conditions that differed only with respect to task-relevance factor, subsequent analyses were conducted on the same display types.

For color singleton displays, the amplitude of P3 was significantly more enhanced for color target trials (see Figure 4a, solid line) relative to irrelevant color singleton trials (see Figure 4.4a, dotted line), $F(1,15) = 26$, $p < .001$. For shape singletons, no significant relevance effects were obtained (see Figure 4.4b).

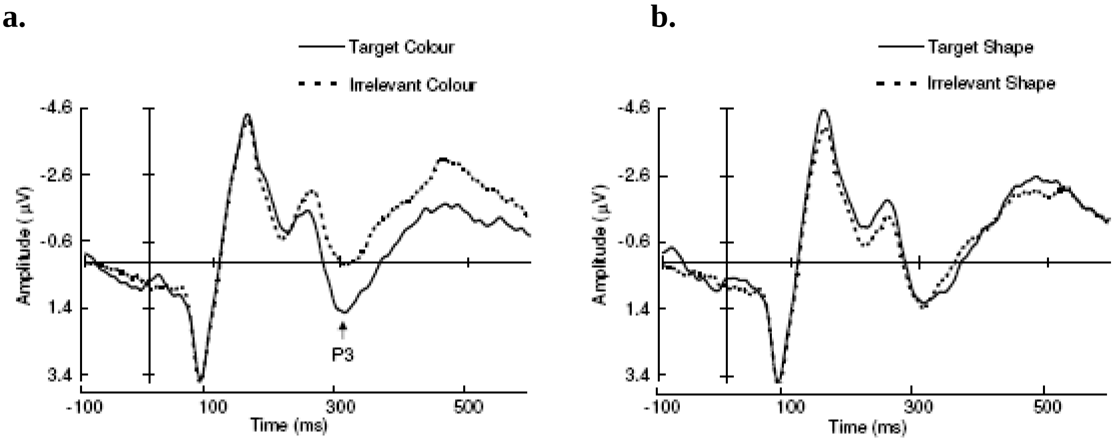

Figure 4.4. Grand Average ERPs calculated from the O1, O2, Oz, PO3, PO4, PO7, PO8, and POz electrodes, time-locked to search display onset. Grand Averages pooled across all eight electrodes. Solid black lines represent target trials and dotted black lines represent irrelevant singleton trials. Note that the baseline started 200 ms prior to display presentation onset and that the statistical analysis was conducted on unfiltered data. High cutoff (30 Hz) filters have been applied to Grand Averages only for illustration purposes. The arrow indicates a statistically significant difference. (a) Grand Averages of the EEG signal for color singletons trials (b) Grand Averages of the EEG signal for shape singletons.

ERPs locked to probe onset

The 2×2×2×2×8 ANOVA conducted for the mean amplitudes within the 90-180 ms time-window time-locked to probe onset with the factors of *singleton type* (color vs. shape), *relevance* (target vs. irrelevant singleton), *SOA* (short vs. long), *position* (“On” singleton vs. “Off”, i.e., at the position of a neutral distracter) and *electrode* (PO3, PO4, PO7, PO8, POz, O1, O2, and Oz) revealed that probes presented at the “On” position evoked a larger positivity in this time window (*M*= 1.4 µV, *SEM* = 0.1) relative to probes presented at the “Off” position (*M*= 0.7 µV, *SEM* = 0.2), *F*(1,15) = 34, *p* < .001 (see Figure 4.5). This difference was more pronounced for target trials (“On”: *M*= 1.6 µV, *SEM* = 0.2; “Off”: *M*= 0.6 µV, *SEM* = 0.2, see Figure 5, solid line) compared to irrelevant singleton trials (“On”: *M*= 1.2 µV, *SEM* = 0.2; “Off”: *M*= 0.7 µV, *SEM* = 0.2, see Figure 4.5, dotted line), as revealed by a significant interaction of relevance and position, *F*(1,15) = 10, *p* < .01.

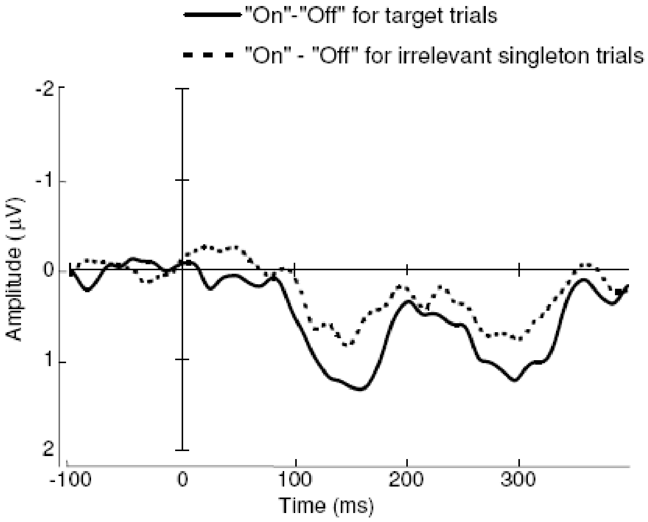

Figure 4.5. Grand Average ERPs time-locked to probe onset, calculated from the O1, O2, Oz, PO3, PO4, PO7, PO8, and POz, electrodes. Grand Averages averaged across both SOA conditions. Solid line represents the difference wave of mean amplitude of the "On" condition and "Off" condition ("Off" subtracted from "On") for target trials whereas the dotted line represents the difference wave of mean amplitude of the "On" condition and "Off" condition for trials with irrelevant singletons. Note that the baseline started 200 ms prior to probe presentation and that the statistical analysis was conducted on unfiltered data. High cutoff (30 Hz) filters have been applied to Grand Averages only for illustration purposes.

Moreover, a significant interaction between relevance and SOA, $F(1,15) = 6.5$, $p < .05$, showed that the positivity within the 90-180 ms was more enhanced for target trials in the long SOA condition (*M*= 1.3 µV, *SEM* = 0.2) compared to the short SOA condition (*M*= 0.8 µV, *SEM* = 0.1). The irrelevant singleton trials did not differ with respect to SOA (long SOA: *M*= 0.9 µV, *SEM* = 0.2; short SOA: *M*= 1 µV, *SEM* = 0.1).

Further analyses revealed that probes presented at the "On" position evoked a larger positivity within the 90-180 ms time window compared to the "Off" position in all conditions when analyzed separately for color/shape targets and irrelevant singletons (see Table 4.1).

	Color singletons		Shape singletons	
	Mean Amplitude	SE	Mean Amplitude	SE
		Target trials		
Position				
„On“	1.8	0.3	1.3	0.2
„Off“	0.7	0.2	0.5	0.2
Significance	F(1,15) = 48, p< .001		F(1,15) = 15, p< .005	
		Irrelevant trials		
Position				
„On“	1.2	0.2	1.2	0.2
„Off“	0.8	0.2	0.6	0.2
Significance	F(1,15) = 6, p< .05		F(1,15) = 21, p< .001	

Table 4.1. Mean amplitudes (in microvolts) and standard errors of the mean (SE) within the 90-180 ms time-window time-locked to probe onset as a function of probe position “On” vs. “Off” and relevance (target trials vs. irrelevant singleton trials) separately for color singletons (left) and shape singletons (right).

Behavioral data

Reaction times

The 2×2×2×2 ANOVA conducted for reaction times in the probe discrimination task, with the within-subjects factors of *singleton type* (shape vs. color), *relevance* (target vs. irrelevant singleton), *SOA* (short vs. long), and *probe position* (“On” vs. “Off”) revealed that probes presented at the “On” position were generally discriminated faster than probes presented at the “Off” position, $F(1,15) = 83$, $p < .001$. This effect occurred for target trials in short and long SOAs and for irrelevant singleton trials, short SOA (see Figure 4.6, first, second and third panels respectively). The differential effect did not occur for the irrelevant-singleton condition, long SOA (“On” position: M= 406 ms, SEM = 23; “Off” position: M= 409 ms, SEM = 24), $F(1,15) = 1.3$, $p = .26$, see Figure 4.6, fourth panel. For the overview of all RT results, see Table 4.2.

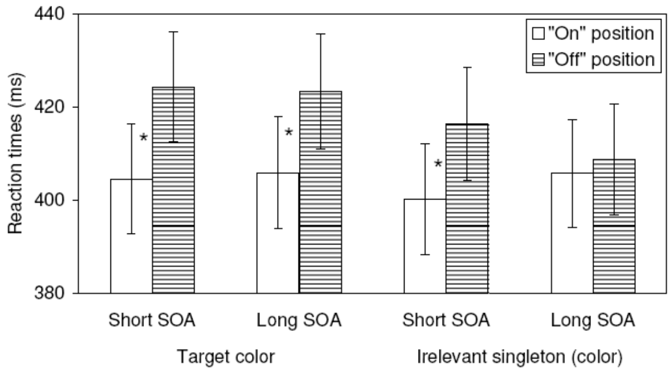

Figure 4.6. Differences in mean Reaction Times to probe discrimination with respect to relevance (target vs. irrelevant singleton displays), SOA (short vs. long), and probe position ("On" vs. "Off") for color singletons. Empty bars depict Reaction Times to probes the "On" positions, i.e., at former singleton positions (target or irrelevant singletons in target / irrelevant singleton displays, respectively). Filled bars represent Reaction Times to probe when it was presented at "Off" positions, i.e. the former position of a neutral distracter. First and second panel represent target trials whereas third and fourth panel represent irrelevant singleton trials. Short SOA condition is represented by the first and third panel and long SOA by the second and fourth panel. The stars indicate significant differences. Error bars represent standard errors of the mean.

	Color singletons		Shape singletons	
	Short SOA	Long SOA	Short SOA	Long SOA
		Target trials		
Position				
„On“	405 (23)	405 (24)	410 (24)	394 (23)
„Off“	424 (23)	423 (25)	421 (26)	412 (24)
		Irrelevant-singleton trials		
Position				
„On“	400 (24)	406 (23)	403 (22)	396 (20)
„Off“	416 (24)	409 (24)	415 (22)	413 (22)

Table 4.2. Mean Reaction Times (in milliseconds) and standard errors (in brackets) to probe discrimination as a function of probe position ("On" vs. "Off"), SOA (short vs. long), relevance (target trials vs. irrelevant singleton trials) for color and shape singleton types separately.

Error rates

Probe task

The 2×2×2×2 ANOVAs with the factors *singleton type* (color vs. shape), *relevance* (target vs. irrelevant singleton), *SOA* (short vs. long), and *probe position* (“On” vs. “Off”) revealed a main effect of SOA, $F(1,15) = 13$, $p < .005$ showing larger error rates in the long SOA condition (M= 4%, SEM = 0.8) relative to the short SOA condition (M= 2%, SEM = 0.5), and a main effect of position, $F(1,15) = 10$, $p < .01$ showing larger error rates for the “Off” (M= 3.6%, SEM = 0.7) position relative to the “On” position (M= 2.6%, SEM = 0.5).

Search task

The 2×2 ANOVA with the factors *singleton type* (color vs. shape) and *relevance* (target vs. irrelevant singleton) for probe absent trials in the search task revealed no significant effects or interactions.

Discussion

In the present paradigm, participants were instructed to perform two tasks. The first was a visual search task, i.e., participants were asked to detect a target among neutral distracters. The search display could contain either a (relevant) target singleton (target display, 50% of trials), or an (irrelevant) distracter singleton (irrelevant singleton display, 50% of trials). In irrelevant singleton trials, participants were asked to ignore the singleton and react with a target-absent response. The target assignment was switched after half of the experiment. Therefore, the singleton type (e.g., color) which was task-relevant in one part of experiment became irrelevant (and to be ignored) in another part. The second task was to discriminate, as fast as possible, the orientation (left vs. right) of probe stimulus that appeared subsequent to the search display with a variable SOA (83 ms or 183 ms). The probe was presented at the position of either one of the singletons (“On” position) or at a position of one of the neutral distracters (“Off” position).

EEG signal analysis was twofold: time-locked to search displays and time-locked to probe onset. Time-locking the ERPs to search-displays allowed for investigating the time course and development of task-related top-down selection, whereas time-locking the ERPs to probes enabled examining if such top-down modulations affected the allocation of attention measured at probe onset, after two different time delays relative to search display presentation.

The results of ERPs time-locked to the search display showed that target displays were processed differently from displays containing the irrelevant singleton (see Figure 4.3a). This indicated top-down modulation of selection in the visual search task. In particular, the top-down modulation was observed as a differential effect on the N1 component (i.e., 130-200 ms post-stimulus onset) and spread in time extending over the P2 time-window (see Figure 4.3a). In this time interval, singletons that were assigned targets elicited an increased negativity compared to the same singletons when assigned irrelevant distracters. This relevance effect was observed independent of the singleton's saliency for both singleton types.

Moreover, the P3 component (270-360 ms post-stimulus onset) exhibited effects depending on the type of singleton (color vs. shape). The results showed that in the shape-task condition, the amplitude of the P3 component was smaller for the respective irrelevant singleton (color) relative to the target (shape) trials (see Figure 4.3b, black solid line and black dotted line respectively), whereas in color-task condition, the P3 amplitude did not differ between target (color) and irrelevant singleton (shape) trials (see Figure 4.3b, gray solid line and gray dotted line respectively). Further analyses comparing the singletons directly showed that color irrelevant singletons evoked also a significantly smaller P3 compared to color targets, emphasizing the role of target-distracter assignment for singleton processing (see Figure 4.4a). Interestingly, P3 components elicited by color and shape targets as well as irrelevant shape singletons did not differ (see Figure 4.3b, solid black line, grey black line and grey dotted line). These effects might suggest that color irrelevant singleton displays were processed in a different manner compared to other types of displays which might be due to the supposedly strong saliency signals induced by the color singletons and their specific assignment as irrelevant distracters.

The second type of analyses concentrated on ERPs time-locked to probe onset. This allowed for examining whether the top-down selection affected processing of the subsequently presented probes. Two different SOAs were introduced to test how the effects of top-down modulation affected probe processing dependent on a particular moment in time after search display presentation. It was assumed that if attention was allocated to one of the singletons in the search display, processing of probes presented at the position of that item ("On" position) should be facilitated compared to other, neutral positions ("Off" positions). Based on results of Experiment 3.1 of the present dissertation as well as those obtained by Kim & Cave (1999), it was expected that also in Experiment 4.1., if top-down control efficiently guided focal attention to the relevant target, there should be a benefit of the target position relative to neutral positions whereas no such benefit for irrelevant singleton position should be observed.

The analyses of probe-locked ERPs in the time window between 90 and 180 ms revealed that probes presented at the "On" positions evoked a larger positivity compared to probes presented at the "Off" positions and that this difference was more enhanced for probes presented at target positions relative to irrelevant singleton positions, as indicated by a significant interaction of relevance and position (see Figure 4.5, solid line). This might suggest that attention had been, in general, allocated to the salient singleton's positions prior to probe presentation. However, processing of singletons was also modulated with respect to task-relevance, as the effect of position was more enhanced for target singletons relative to the irrelevant distracter singleton trials.

Behavioral data showed a similar pattern. In general, reaction times to probes were faster for the "On" position relative to the "Off" position (see Figure 4.6, panel one and two for the illustration of these effects in color singleton trials and Table 4.2 for description of shape singleton trials). This shows a benefit of the target position over the neutral positions related presumably to differences in the allocation of attention.

For color irrelevant singleton trials, responses to the “On” position did not differ from “Off” position responses for the long SOA condition (see Figure 4.6, fourth panel). This might indicate no attention-related benefit for the irrelevant color singleton position over neutral positions. The top-down modulatory effects in reaction time data were, however, observed only for color irrelevant singletons and long SOA (see Table 4.2).

Top-down modulation of early selection in a visual search task

The visual search task used in the present experiment was a relatively easy pop-out feature search (see e.g., Treisman & Gelade, 1980; Treisman, Sykes, & Gelade, 1977; Wolfe, 1994) in which participants could have detected the target-defining feature with little effort. However, additionally to the search for a target item, rejection of a task-irrelevant pop-out item was required in half of the trials.

Since both the target and the irrelevant singleton items were the only pop-out items in the displays, they both might have evoked strong saliency signals. Therefore, the visual system might have needed to assign additional weights to the relevant target item in order to select it and reject the irrelevant singleton. Results indicated that target displays evoked a more enhanced N1 component relative to irrelevant singleton displays (see Figure 4.3a). Such a relevance-related effect on N1 amplitude might have reflected that the relevant dimension was weighted higher compared to the task-irrelevant dimension.

This relevance effect observed for the N1 component provides evidence for a top-down modulation of already early stages of visual processing, even in simple feature search. As displays with identical singletons were compared that differed only with respect to their task-relevance, it is likely that top-down modulation was reflected in the differential effects observed for the N1 component and the subsequent P2 time-window (see Figure 4.3a).

Allocation of attention and its time course

ERPs time-locked to the onset of probes allowed for examining how top-down selection modulated the allocation of attention measured at probe onset, that is, after two different time delays relative to search display presentation. The allocation of attention to particular items of the search display should influence the processing of the subsequent probe dependent on its position, i.e., whether it was presented at one of the singletons' previous locations ("On" position) or at a neutral distracter's location ("Off" position). Based on the results reported in Chapter 3, as well as in Kim & Cave (1999), Luck & Hillyard (1995), or in Luck, Fan, & Hillyard (1993), any differential effects on the processing of the probe depending on its position should indicate effects of attention allocation. Therefore, P1 (time-locked to probe onset) should be more enhanced for the attended positions relative to the neutral positions, as the P1 component may be interpreted as an indicator of focal attention (e.g., Hillyard et al., 1998; Luck & Hillyard, 1995; Luck, et al., 2000; Mangun et al., 1993).

The present results showed that probes presented at the "On" position evoked a larger positivity in the P1 time range 90-180 m post stimulus compared to probes presented at the "Off" position. This result suggests that, generally speaking, both singletons attracted attention. As the singletons have been quite salient they may have captured attention, also regardless their irrelevance to the task at hand.

However, as the effect of position on P1 was more pronounced for probes following target singletons compared to probes presented subsequent to the same singletons when they were irrelevant (see Figure 4.5), it also indicates that targets and irrelevant singletons were not attended to in an equal manner. Thus, top-down control modulated the attention allocation with respect to task-relevance. Interestingly, this effect was independent of the SOA factor and was observed for both time intervals. Therefore, top-down modulation might have occurred already after a short time after probe presentation.

The relevance-related modulation of the P1 enlargement for "On" when compared to "Off" positions speaks against a strong version of the *pure capture* perspective (e.g., Theeuwes, 1992, 1994, 1995a; Theeuwes et al., 2000) which postulates that at early stages of processing, bottom-up driven attentional capture occurs automatically and cannot be modulated by top-down control. According to the present findings, top-down control of attention modulated processing of irrelevant items and this modulation was also independent of the temporal factor. This speaks against the *rapid disengagement of attention* hypothesis put forward in, e.g., Theeuwes et al. (2000). According to this hypothesis, attention should automatically be attracted to salient irrelevant singletons within the first 100 ms after stimulus presentation, but after 100 ms, might be disengaged from the irrelevant location and may switch to the relevant item. Present results showed that even within the first 100 ms of stimulus processing, top-down control already modulated the allocation of attention.

Effects dependent on singleton type

Although the relevance effect observed on the N1 component time-locked to search displays occurred for both shape and color singletons, the P3 component (also time-locked to the search display) exhibited a different pattern depending on the singleton type. In the shape-task condition (target shape and color irrelevant), irrelevant color singleton trials evoked a smaller P3 compared to shape target trials. In the color-task condition (target color and shape irrelevant), such a differential effect did not occur: The amplitude of P3 evoked by shape irrelevant singleton displays did not differ relative to color target displays (see Figure 4.3b).

Such different pattern of results for shape- and color-target conditions might be due to the different saliency level of color and shape singletons. As argued before, the red color might have been more salient relative to the circular shape, or its saliency signal might have been available earlier (for a discussion, see Theeuwes, 1991). Therefore, rejection of salient color singletons might have been difficult which is in line with former results (e.g., Theeuwes, 1991). The present results may be explained by assuming that such salient color irrelevant singletons required an additional top-down modulatory mechanism that may be reflected by the effect on the P3 component (270-360 ms).

Interestingly, the irrelevant color singleton trials evoked a smaller P3 amplitude compared to the other three conditions (i.e., shape target and distracter trials, and color target trials) that evoked similar P3 amplitudes. This suggests that irrelevant color singletons might have evoked an inhibitory process, as P3 amplitudes did not differ between the shape target trials and shape irrelevant trials and also not between shape target trials and color target trials. This speculation may also be supported by the fact that the ERPs within the time-window preceding P3, i.e., the N2 time window between 200 and 270 ms, did not differ significantly with respect to relevance. Hence, the smaller P3 amplitude for color irrelevant singletons should not be due to what seems to be a differential effect on the N2 component. Therefore, the P3 effect for color singletons may have reflected, most probably, a top-down inhibitory mechanism.

In contrast, shape irrelevant singletons might have been less salient and, therefore, such a mechanism might have not been necessary. Thus, in the color-task condition (color targets and shape irrelevant singletons), the differential effect on P3 did not occur.

Concluding remarks

Results of the present experiment showed that the human visual system is capable of modulating visual selection in a top-down manner already early in the processing stream. The neural responses to visually presented stimuli differed depending on the stimuli’s relevance to the task at hand. Such modulated processing with respect to task-relevance was observed relatively early, i.e., within the N1 time window and extended over the later P2 time-window.

ERPs time-locked to probes also revealed that attention was allocated to the singleton items in the search display and that the allocation of attention was modulated in a top-down manner.

Moreover, an effect reflecting different ways of processing of two types of singletons was observed within the P3 time-window time-locked to search display. Obtained results suggest that the effect on P3 reflected suppression of the color irrelevant singleton trials.

Although the present results do not allow for decisive interpretation concerning the exact nature of the observed top-down modulatory mechanisms, one may speculate that the early N1 effects reflect the process of assigning weights to task-relevant dimensions for the whole block of trials in accordance to experimental instructions. The later P3 effects might be related to an additional suppressive mechanism that is employed only when needed on a trial-by-trial basis.

Taken together, the present results show that although probe-locked ERPs and reaction times showed that attention was, in general, allocated to singleton items (also to the irrelevant ones), strong support was obtained for the top-down modulation of task-relevant items as observed in the ERPs time-locked to search displays and ERPs locked to probes. Therefore, the debate between the proponents of the *pure-capture* perspective (e.g., Theeuwes, 1992; Theeuwes et al., 2000) and the *contingent capture* stance (e.g., Folk & Remington, 1998, 2006) seems not to have a simple solution. Top-down mechanism might modulate processing even if attention is allocated to the irrelevant items.

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Deutsche Zusammenfassung

Theoretischer Hintergrund

Die menschliche Wahrnehumg ist kein passiver, stimulusbasierter (sogenannter „bottom-up“) Prozess. Vielmehr bestimmen verschiedene Faktoren welche der vielen potentiell interessanten Umgebungsreize nach dem ersten visuellen Eindruck weiter verarbeitet werden. Stimuli, die in unserer Umgebung besonders hervorstechen („salient“ sind), weil sie sich physikalisch stark von ihrer visuellen Umgebung unterscheiden, werden – mit großer Wahrscheinlichkeit – unsere Aufmerksamkeit auf sich lenken. Zugleich kann der perzeptuelle Input seiner Relevanz nach gewichtig werden.

Gewichtungsmechanismen in der visuellen Informationsverarbeitung

Die aktuellen Aufgaben, die ein Beobachter gerade ausführt bestimmen, zusammen mit der Relevanz, die ein Umgebungsreiz für diese Aufgaben hat, die Verarbeitung von visuellen Merkmalen (z.B. Bacon & Egeth, 1994; Egeth, Virzi & Garbart, 1984; Wolfe, 2001; Wolfe, Horowitz, Kenner, Hyle & Vasan, 2004). Möchten wir beispielsweise einen Brief aufgeben, erfahren die alle visuellen Stimuli, die in Form, Farbe und Position einem Briefkasten entsprechen, bseondere Aufmerksamkeit. Viele Theorien erklären den Effekt, das dieselebn Umgebungsreize in Abhängigkeit von der gerade auszuführenden Aufgabe unterschiedliche Aufmerksamkeit und damit Verarbeitung erfahren anhand eines Mechanismus, der die Reize bezüglich ihrer Relevanz gewichtet (sog. „biasing“, siehe Bundesen, 1990; Found & Müller, 1996; Müller et al., 1995; Wolfe, 1994).

Zahlreiche behaviorale Studien (Egeth et al., 1984; Wolfe, 2001, Wolfe, Butcher, Lee, & Hyle, 2003; Wolfe et al., 2004) und neurophysiologische Befunde (Chelazzi, Duncan, Miller & Desimone, 1998; Luck, Chelazzi, Hillyard & Desimone, 1997; Moran & Desimone, 1985; Reynolds, Chelazzi & Desimone, 1999) sprechen für die Existenz eines solchen Gewichtungsmechanismus. In einigen der oben genannten Studien wurde die Gewichtung explizit durch eine Manipulation der Instruktion (z.B., Bacon & Egeth, 1994; Wolfe et al., 2004) oder durch Hervorhebung eines Reizes oder Merkmals (Luck et al., 1997; Moran &

Desimone, 1985; Reynolds et al., 1999) eingeführt. Allerdings kann ein Gewichtungsmechanismus auch implizit induziert werden, wie beispielsweise durch sogenanntes „Primen" einer Reizdimension, die dadurch erfolgt, dass die Reizdimension über mehrere Durchgänge hinweg wiederholt präsentiert wird (Found & Müller, 1996; Müller et al, 1995).

Intentionale Gewichtung

Der Gewichtung von perzeptuellen Reizdimensionen könnte jedoch – neben der Relevanz in einer bestimmten Aufgabe - auch ein weiterer Faktor zu Grunde liegen, nämlich die Relevanz bei dem beim Planen und Ausführen von Handlungen. Wahrnehmung und Handlungsausführung sind im alltäglichen Leben nicht unabhängig von einander, sondern ihre Interaktion ist von grundlegender Bedeutung für zielgreichtetes Verhalten.

Bereits frühere Untersuchungen haben den Handlungskontext, in dem Wahrnehmungsprozesse stattfinden, herausgestellt und darauf hingewiesen, dass dieser die Informationsverarbeitung beeinflussen könnte (z.B. Allport's, 1987; Craighero, Fadiga, Rizzolatti, & Umilta, 1999; Deubel & Schneider, 1996; Fagioli, Hommel & Schubotz, 2007; Deubel & Schneider, 1996; Deubel, Schneider, & Paprotta, 1996; Hommel, Müsseler, Aschersleben, & Prinz, 2001b; Humphreys & Riddoch, 2001; Fagioli, Rizzolatti, Riggio & Sheliga, 1994 und viele andere).

Da eine starke Verbindung zwischen Wahrnehmung und Handlung existiert, ist die Annahme eines direktionalen Effekts innerhalb dieser Verbindung sinnvoll (vgl. Hommel et al., 2001b in der Theory of Event Coding). D.h. zum einen ist die Handlungsplanung offenkundig von unserer Wahrnehmung abhängig. Um Handlungen jedoch erfolgreich zu regulieren, ist es unabdinglich, handlungsr*elevante* Information aus der Vielzahl der Information zu selektieren. Daraus folgt, dass nicht nur Wahrnehmung Prozesse der Handlungssteuerung beeinflussen, sondern dass umgekehrt auch Prozesse der Handlungsplanung und Handlungssteuerung die Wahrnehmung beeinflussen sollte. Dies würde bedeuten, dass durch eine spezifische Handlungsplanung perzeptuelle Systeme solche Wahrnehmungsdimensionen höher gewichtet würden, die mit erhöhter Wahrscheinlichkeit handlungsrelevante Informationen übermitteln. Ein solch handlungsbezogener Gewichtungsprozess wurde von Hommel und Mitarbeitern (Hommel et al., 2001b) als „intentionale Gewichtung“ bezeichnet.

Das zeitliche Zusammenspiel zwischen zielorientierten und salienzbasierten Selektionsmechanismen

Ein weiterer Faktor, der einen grundlegenden Einfluss auf die visuelle Selektion, und damit auf die Aufmerksamkeitslenkung, darstellt, ist der zeitliche Ablauf zielgerichteter und salienzbasierter Selektionsmechanismen. Zahlreiche Untersuchungen hatten zum Ziel, das zeitliche Zusammenspiel zwischen den verschiedenen Mechanismen der visuellen Selektion zu verstehen (Bacon & Egeth, 1994; Folk & Remington, 1998, Müller, von Mühlenen & Geyer, 2007; van Zoest & Donk, 2006; Theeuwes, 1992, 1994). Einige Autoren (z.B. Itti & Koch, 2000; Theeuwes, 1992; 1994; 1995a) sehen die frühesten Phasen der Informationsverarbeitung, also die stimulusbasierte Salienz der Signale, als ausschlaggebend für die Aufmerksamkeitslenkung, und dies unabhängig von den durch Aufgabenrelevanz determinierten sog. „top-down“ Selektionsprozesse. Top-down basierte, also zielgerichtete Selektion (basierend z.B. auf Instruktion oder Handlungsplanung) würde erst nach der obligatorischen, stimulusbasierten Aufmerksamkeitslenkung einsetzen (Theeuwes et al., 2000).Andere Autoren argumentieren, dass sogar in den frühen, bottom-up dominierten Verarbeitungsphasen eine top-down Modulation bis zu einem bestimmten Grad möglich ist (Bacon & Egeth, 1994; Kim & Cave, 1999).

Übersicht über die Experimente in der vorliegenden Dissertation

Die in dieser Dissertation vorgestellten Untersuchungen hatten zwei Ziele: Einerseits wurde der handlungsbezogene Gewichtungsmechanismus und seine Interaktion mit der aufgabenabhängigen Gewichtung sowie mit Inter-Trial-Wiederholungseffekten untersucht.

Andererseits wurde der zeitliche Ablauf eines aufgabenabhängigen Gewichtungsmechanismus der visuellen Selektion mit Hilfe von Ereigniskorrelierten Potentialen (EKPs) ermittelt. Hierbei wurden irrelevante, saliente und damit aufmerksamkeitslenkende Reize im visuellen Feld präsentiert, die mit den aufgabenrelevanten Reizen um die Aufmerksamkeit des Beobachters konkurrierten.

Kapitel 2 beschreibt drei Experimente, in denen die Effekte von handlungsbezogener, intentionaler Gewichtung untersucht wurden. Dabei wurde untersucht, ob die Planung einer bestimmten Bewegung, d.h. entweder ein Objekt zu greifen oder auf ein Objekt zu zeigen, die Leistung in einer visuellen Suchaufgabe beeinflussen würde. Dies würde bedeuten, dass die Intention, eine spezifische Bewegung auszuführen, zu einer höheren Gewichtung solcher perzeptueller Dimensionen führen würde, die für diese spezifische Bewegung relevant sind.

Tatsächlich führte die Planung einer Greifbewegung zu einer schnelleren Entdeckung von größendefinierten Zielreizen, während die Vorbereitung einer Zeigebewegung zu einer schnelleren Entdeckung von helligkeitsdefinierten Zielreizen führte. In Anlehnung an die „Theory of Event Coding“ (Hommel et al., 2001b), wird daher vorgeschlagen, dass Handlungsplanung mit einer “intentionalen Gewichtung” von aktionsrelevanten perzeptuellen Merkmalsdimensionen einhergeht.

Daraufhin wurde der aufgabenbezogene Gewichtungsmechanismus mit dem Ziel manipuliert, die Abhängigkeit der handlungsbezogenen Effekte von aufgabeninduzierter top-down Kontrolle zu untersuchen.

Interessanterweise zeigten die Ergebnisse, dass eine handlungsbezogene Gewichtung nur dann beobachtet wurde, wenn perzeptuelle Dimensionen auch in Hinsicht auf Aufgabenrelevanz gewichtet wurden, das heißt, wenn Probanden nach dem Handlungsrelevanten Zielreiz auch in der Suchaufgabe aktiv suchten. Dies weist darauf hin, dass handlungsbezogene Gewichtungsprozesse nicht unabhängig von aufgabenabhängiger Gewichtung sind.

Zuletzt wurde der handlungsbezogene Einfluss auf Wahrnehmungsprozesse in Hinsicht auf Priming durch Inter-Trial Wiederholung untersucht. Die Ergebnisse zeigten aber, dass die handlungsabhängige Gewichtung unabhängig von Priming durch Inter-Trial Wiederholung ist. Als Erklärungsansatz für die hier dargestellten Resultate wird ein integratives Modell der visuellen Suche und der beteiligten Gewichtungsprozesse vorgeschlagen, welches den Input von Handlungsplanungsprozessen einbindet.

Kapitel 3 beschreibt eine EKP (Ereigniskorrelierte Potentiale) Studie, in der der zeitliche Verlauf der top-down-induzierten Steuerung von fokalen Aufmerksamkeitsprozessen untersucht wurde, sowie seine Ablenkbarkeit durch irrelevante, saliente Signale.

Die Methode der Ereigniskorrelierte Potentiale erlaubt die Untersuchung von kognitiven Prozessen (wie beispielsweise Prozesse der Aufmerksamkeitslenkung) mit hoher zeitlicher Auflösung, und dies bevor eine (manuelle) Reaktion auf den Zielreiz ausgeführt wird. Anhand dieser Technik kann man auf bestimmten Abschnitte innerhalb des Informationsverarbeitungsflusses fokusieren bzw. diese über experimentelle Bedingungen hinweg vergleichen. Dadurch ermöglicht die Analyse von EKPs als neurophysiologisches Korrelat der stimulusgebundenen Informationsverarbeitung eine detaillierte und präzise Untersuchung der temporalen Dynamik von Prozessen der Aufmerksamkeitslenkung.

Hierfür wurde ein visuelles Suchparadigma mit einem „Probe“-Paradigma kombiniert. Der Probe war ein einzelner Zielreiz, der einige Zeit nach dem Suchdisplay präsentiert wurde. Zwei unterschiedliche Zeitintervalle zwischen dem Suchdisplay und dem Probe ermöglichten das dynamische Zusammenspiel zwischen der stimulusbasierten und der aufgabenabhängigen Selektionskontrolle zu untersuchen. Die Verhaltensdaten (Reaktionszeiten und Fehlerraten) zeigten in Übereinstimmung mit früheren Untersuchungen (Kim & Cave, 1999), dass top-down-basierte, d.h. zielgerichtete Kontrollprozesse Zeit braucht, um sich zu entwickeln. Salienzbasierte, bottom-up Effekte der Aufmerksamkeitslenkung wurden früh beobachtet, klangen jedoch mit der Zeit ab. EKP-Daten wurden sowohl für die Verarbeitung des

Suchdisplays als auch für die Verarbeitung des nachfolgenden Probes erhoben. Analysen in Relation zum Suchdisplay zeigten, dass der Zielreiz erst relativ spät, ca. 300 msek nach Präsentation des Suchdisplays von den anderen Objekten im Display unterschieden wurde.

Analysen in Relation zum Probe zeigten eine Modulation der P1 Komponente, die in der Literatur mit der Steuerung fokaler Aufmerksamkeit in Verbindung gebracht wird. Daher wurde angenommen, dass die fokale Aufmerksamkeit effizient durch top-down Modulation zum Zielreiz gelenkt wurde. Der Einfluss der top-down Kontrolle wurde allerdings nur für die langen Zeitintervalle beobachtet, woraus geschlossen werden kann, dass diese einer zeitlichen Entwicklung bedarf. Die Annahme einer stimulusbasierten Aufmerksamkeitslenkung wurde durch die vorliegenden EKP Resultate nicht gestützt, wurde aber in den Reaktionszeitdaten beobachtet.

In Kapitel 4 wird eine weitere EKP-Studie (Experiment 4.1) zur Untersuchung des zeitlichen Ablaufs und der Stärke der top-down Modulation auf salienzbasierte Selektionsprozesse beschrieben. Ziel war es, die EKPs, die von physikalisch identischen Stimuli evoziert wurden, in solchen Bedingungen zu vergleichen, die sich einzig in Bezug auf ihre aktuelle Aufgabenrelevanz unterschieden. Solch ein Vergleich sollte es erlauben, die genaue Natur und die temporale Dynamik der top-down gesteuert Selektion zu erfassen ohne das Risiko einzugehen, differenzielle Effekte auf Grund von physikalisch verschiedenen Stimuli zu erhalten. Außerdem sollte in dieser Untersuchung die Auswirkung von Aufgabenrelevanz auf Reize unterschiedlicher Salienz untersucht werden. Probanden sollten wiederum zwei Aufgaben hintereinander durchführen: sie sollten einen vorab definierten Zielreiz entdecken und danach die Orientierung eines entweder links- oder rechtsgeneigten Probes unterscheiden. In der Suchaufgaben wurde zwei Arten von Reizen präsentiert: ein salienter Farbreiz und ein salienter Formreiz. Jeder der beiden Reize war in unterschiedlichen Instruktionsblöcken entweder Zielreiz oder irrelevanter Distraktor.

Wieder wurden die EKP-Daten sowohl für die Verarbeitung des Suchdisplays als auch für die Verarbeitung des nachfolgenden Probes erhoben. Analysen des Suchdisplays zeigten, dass diesmal der Zielreiz bereits in einem frühen Zeitfenster der (N1 Komponente, ca. 200 msek nach Stimuluspräsentation) unterschiedlich verarbeitet wurde im Vergleich zum jeweiligen irrelevante Distraktor. Dies spricht für einen frühen Einfluss des relevanz-basierten Gewichtungsprozesses. Außerdem zeigten die EKP-Analysen des Probes eine erhöhte Positivierung im P1-Bereich (90-180 ms post Stimulus) für Probes, die an der Stelle eines salienten Farb- oder Formreizes präsentiert wurden im Vergleich zu „neutralen“ Stellen. Diese Positivierung war stärker für den jeweils relvanten Zierlreiz und – auch vorhanden aber schwächer ausgeprägt – für den irrelevanten Distraktor. Dieser Unterschied zwischen Zielreiz und Distraktor weist wiederum auf den starken Einfluss top-down basierter Selektionsmechanismen auf die Verarbeitung salienter Reize hin.

Neben den Einflüssen der Aufgabenrelevanz für beide Reize gab es Unterschiede in Bezug auf die Art des salienten Reizes. In Durchgängen mit irrelevanten Farbreizen wurde eine stark verminderte P3 Komponente (270–360 ms post Stimulus) beobachtet. Dieses Ergebnis legt die Vermutung nahe, dass saliente Farbreize einer Art zusätzliche Regulation und/oder Inhibition bedürfen.

Zusammengefasst zeigen die Ergebnisse einen starken Einfluss zielgerichteter Selektion bereits während früher Verarbeitungsstufen. Dieser Einfluss scheint immer dann aufzutreten, wenn aufgrund interferierender Salienzsignale top-down Kontrolle benötigt wird.

Schlussfolgerungen

Ziel der im Rahmen dieser Dissertation durchgeführten Studien war es, das Zusammenwirken zwischen verschiedenen Quellen von Gewichtungsmechanismen zu untersuchen, welche die frühe visuelle Informationsverarbeitung beeinflussen (Kapitel 2) bzw. den präzisen temporalen Verlauf eines frühen, visuellen Gewichtungsmechanismus in Bezug auf die Aufgabenrelevanz zu untersuchen (Kapitel 3 und Kapitel 4).

Es konnte gezeigt werden, dass das menschliche Wahrnehmungssystem effiziente Wege der Informationsselektion von relevanter Information entwickelt hat. Neben Aufgabnerelevant spielt auch Relevanz in Bezug auf eine geplante Handlung eine große Rolle. Beide können bereits in frühen Informationsverarbeitungsphasen zur Gewichtung des visuellen Perzepts führen. Die Gewichtungsmechanismen scheinen nicht unabhängig voneinander zu sein, sondern interagieren. Die Art und Intensität der top-down Gewichtung hängt in signifikanter Weise von den zeitlichen Faktoren ab. Aufgabenabhängige relevanzbasierte Lenkung der fokalen Aufmerksamkeit benötigt Zeit, sich zu entwickeln. Je nach Bedarf an zielgerichteter Lenkung und Aufgabe kann aber die aufgabenabhängige Gewichtung zu einem sehr frühen Zeitpunkt auf die Informationsverarbeitung Einfluss nehmen.

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