Dimension-based Processing in Visual Pop-out Search

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The brain is wider than the sky,

For put them side by side

The one the other will include

With ease – and you beside.

Emily Dickinson

If we manage to to make an action or sensation appear nakedly

simple, it is just because we are concealing all the effort

that went into setting up the moment.

John McCrone

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1 Introduction

We are constantly confronted with an ever changing visual scenery crowded with coloured, moving or stationary, bright or dark objects of different shapes and sizes. Only some of them are relevant in order to achieve behavioural goals. However, in everyday life, we usually do not feel overwhelmed with information or a multitude of decisions what to 'see' or react upon first.

This is in part due to the fact that we can rely on a highly effective interplay between sensory (bottom-up) input to the brain and top-down processing - that is, selection of relevant signals guided by already learned and memorized knowledge about the world. Thus, we move in the environment while constantly searching, consciously and/or unconsciously, for signals or information relevant to our current situation and our behavioural goals.

A stimulus can reach significance (or become salient) mainly in two ways: *Firstly,* it is simply processed more efficiently than others. These so-called salient stimuli will, in the presence of other less salient ones, almost always be processed with

priority. For example, a large object will be seen first amongst small items, a bright object faster than a dark one, or a coloured item will win over a (non-coloured) grey one. This 'natural' salience arises from inherent properties of sensory visual processes shaped by long-term experience (Lamme, 2003).

Secondly, the stimulus is of a certain behavioural relevance. Standing in front of a vegetable area in the supermarket and looking for potatoes is successful although the potatoes might be surrounded by brightly coloured red tomatoes or yellow peppers. Despite not necessarily being equipped with 'naturally' salient properties, their presence can be detected fast and efficiently because the sensory pathways required to process a particular (non-salient) item are pre-activated in a top-down fashion by higher rather than early sensory brain areas and thus processing is facilitated.

A *third* type of mechanism rendering stimuli salient, somehow lying in between the two mechanisms described above, is referred to as priming. The processing of a given stimulus is prioritized by an event earlier in time. This might especially be the case if the previous stimulus shares properties such as size, colour, or location (Maljkovic & Nakayama, 1996) or spatial relation to other items (contextual cuing, e.g. Chun & Jiang, 1999) in the visual field. Stimuli processed earlier leave a (memory) trace of activation within the processing system and/or modulate the allocation of attentional resources. The following stimuli, matching the first in at least some characteristics (features), might benefit from this pre-activation and their processing is expedited.

An experimental paradigm which has been extensively used to address the question of how a certain stimulus is selected from a visual scene, is the *visual search paradigm*. Typically, the observer is asked to report the presence or absence of a target item within an array of multiple elements. The characteristics of the object to search for might be pre-specified, or, as it is the case in the experiments presented below, the target item differs from non-target items (distractors) in a single attribute (feature). If the target defining feature is sufficiently salient and the distractor items are homogeneous and task-irrelevant, the target phenomenally appears to 'pop out' of the display. To perform this kind of task, target identity need not necessarily be known in advance and it may vary unpredictably from trial to trial. However, the difference of one feature of a single item relative to a homogeneous set of distractor items, allows for a rapid 'self-definition' of the target in the ongoing search process.

The 'pop-out' phenomenon is central to the work presented below. Its underlying mechanisms are explored in visual detection and in a compound search task (Chapter 2), in a group of patients with an visual-spatial deficit: hemi-spatial neglect (Chapter 3), and in patients with damage to the left lateral frontopolar cortex, a structure previously found to be specifically activated during dimension changes across a sequence of trials (Chapter 4).

1.1 Theories of Visual Search

The reaction times (RT) observed in feature search experiments as described in the previous section (Treisman & Gelade, 1980) can be related to the number of items present in the display (display size). The target, carrying a unique feature seems to 'pop out' of the display and there is no or only little increase of RTs with an increasing number of elements in the display (slope $<$ 10 ms per item, that is, an increase of less than 10 ms per additional item). This finding was taken to suggest that all elements of the search display are processed simultaneously or in *parallel*. In contrast, a different search pattern was found, when observers performed a slightly different task in which the target is characterized by a specific combination (conjunction) of features (e.g. a particular shape and colour) but is not unique in any of the component features among distractors. Search for such a 'conjunction' of features (conjunction search) is effortful and RTs usually increase linearly with display size (reflected in slopes of $>$ 10 ms per item).

This RT pattern was taken to indicate a *serial* search mode involving the successive inspection of all the items of a search display. To be precise, only in negative trials, all the display items need to be examined, in target-present trials, the target is detected, on average, after n-1 items have been processed. Examples of displays used in feature and conjunction search tasks are shown in Figure 1.1.

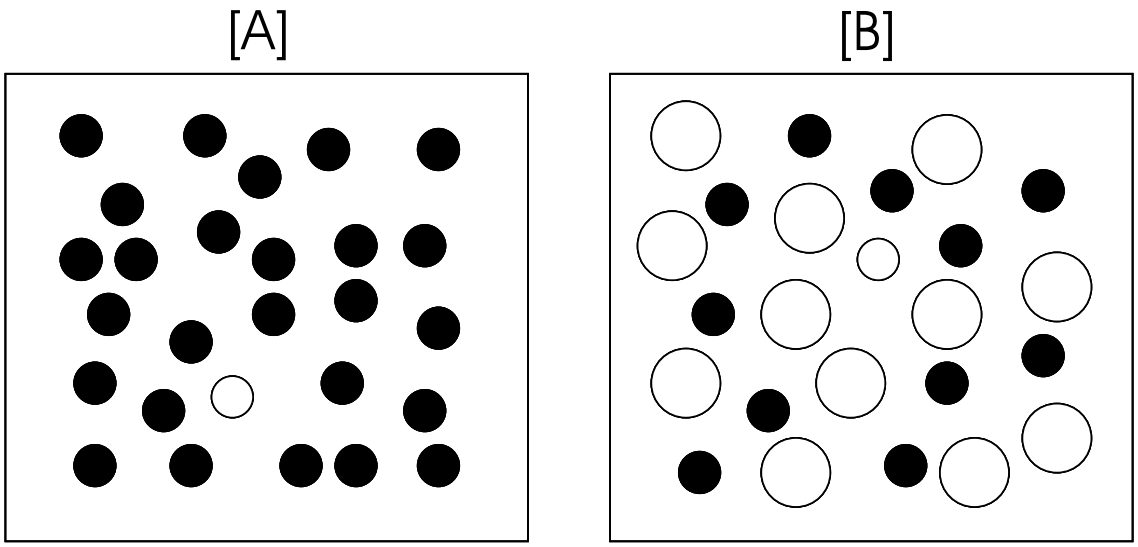

Fig. 1.1: *Example displays used in [A] a feature search task or [B] in a search for a target defined by a conjunction of features (small and white).*

1.1.1 Feature Integration Theory

One of the first and (to date) most influential accounts of how detection of target objects in a visual field is achieved is Treisman's Feature Integration Theory (FIT, Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman, 1993) . The theory is based on neurophysiological findings providing evidence that stimulus characteristics such as colour, shape or motion are processed in separate, specialized, regions of the visual cortex. This assumption, however, gives raise to the question of how these features are bound into a coherent percept (*binding problem*).

In detail, FIT proposes that a limited set of retinotopically organized feature detectors register the presence of specific features at a given spatial location in the visual field in parallel fashion. The presence of features is registered in retinotopic

feature maps and the integration of signals from each feature map is achieved by an attentional spotlight moving across a master map of locations. Selected features of the various feature maps under the attentional spotlight are bound and transferred to an object-based short-term memory for further processing. If targets are defined by feature conjunctions, subjects have to apply a serial search mode in which attention is serially directed to each stimulus location in the field and search is terminated as soon as the target is encountered.

In contrast, in the case of pop-out search, FIT proposed that when targets and distractors can be distinguished on the basis of a single *elementary feature difference* such as a unique color or shape, the presence of a particular feature is automatically registered prior to the allocation of focal attention (i.e. pre-attentively). The deployment of attention is not necessary in order to identify a given target item as no integration of features is involved in performing the task. Thus, according to FIT, (parallel) feature search would always produce flat search functions (i.e. RTs are independent of display size), whereas in serial conjunction search tasks, RTs should always increase with an increasing number of items in the display. However, subsequent studies provided evidence for conjunction searches that were performed faster than predicted by the FIT (e.g. Nakayama & Silverman, 1986; McLeod, Driver, and Crisp, 1988; Cohen & Ivry, 1991; Wolfe, 1992). Further research revealed a more complex picture of visual search: rather than falling into two separate categories, preattentive-parallel and attentive-serial, search efficiency seemed to be determined

by multiple factors and interactions. Duncan (1989), in an alternative account, suggested that search efficiency is mainly determined by stimulus characteristics such as (a) target-distractor similarity and (b) distractor heterogeneity (and their interactions).

1.1.2 Guided Search

Another account of the attentional control mechanisms underlying visual search performance is based on FIT but aimed at resolving some of its controversies raised by the predictions of the FIT. Similar to FIT, Guided Search (GS; Cave & Wolfe, 1990; Wolfe, 1994; Wolfe, Cave, and Franzel, 1989) proposed two basic stages of processing. Initially, elementary features are registered in parallel across the visual field. Following this stage, GS proposes that saliency signals (that is feature contrasts between any given display item and all the surroundings items) are computed for a limited number of visual dimensions (e.g. colour, shape or motion). Note, that, in contrast, in the FIT all the individual object features (e.g. colour: red; shape: circular, or motion: stationary) are registered (s.a. Nothdurft, 1991; Nothdurft, 1993). Saliency signals within each dimension are summed up and integrated onto a *master-map of saliency*, where in a second stage, again topographically organized, saliency activations from the various dimensions and for each display location are integrated. Attention is then directed to the display location with highest activation and the featural information present at the display location is gated to higher order

processes of, e.g., object recognition.

The idea of a 'saliency map' was first proposed by Koch and Ullman (1985) . In their view, a saliency map is a tool for summing signals from different feature maps across the visual scene while retaining visual topography. While information about the original location of the signal is still available, the resulting salience is independent of feature identity. Thus, the most salient *location*, rather than *feature map* guides the focus of attention. If a single (target) item differs from surrounding stimuli (distractors) in a basic feature, the contrast signal is larger than signals arising from distractors and attention should always be deployed to its location first.

For visual pop-out search, Koch and Ullman's account implies that attentional guidance relies solely on contrast saliency signals that are propagated to a master map in an unweighted fashion, and as such is purely driven by bottom-up information. Within this framework, RTs to trials in a visual pop-out task should be unaffected by either the observer's prior knowledge of target identity or by the trial history. That is, the identity of a target presented in the previous trial(s) should not affect target detection performance in any given trial. However, empirical findings show that search performance can be improved by observers' knowledge of the dimensional definition of the target in upcoming trials. Müller and collegues (Müller, Heller, and Ziegler, 1995; Müller & Found, 1996) investigated dimensional uncertainty in visual feature search, that is, search conditions in which the target-

defining dimension is not known to the observer prior to display onset. Two main effects of dimensional variability were observed: *(1)* RTs are increased relative to trials in which only the feature (within one dimension) changed unpredictably (*cross-dimensional search costs*) and *(2)* RT to a target in a given trial is delayed when the target-defining dimension is different from that in the previous trial whereas within-dimensional feature changes from trial to trial do not affect RTs (*dimension-specific intertrial effect*). These findings led to the assumption that saliency signals from relevant dimensions are integrated by a master map in a parallel yet attentionally weighted fashion.

1.1.3 Dimensional weighting

Müller et al. (1995), proposed an alternative dimension-based account of visual attention. That is, attentional selection is limited by a process which is required to establish the dimension of the target of a given search trial (see also Treisman, 1969; Allport, 1971) . Building upon Wolfe's Guided Search Model, Müller et al.'s account assumes that a limited "attenional" resource is required to discern the presence of a saliency signal in a given dimension. Saliency derives from the calculation of feature contrast between neighbouring items in the visual field within separate, dimension-specific input modules assumed to be topographically organized. While the original Guided Search Model is agnostic as to the role of dimensional signals for further processing, the Dimension-Weighting-Account proposes that dimensional saliency

signals are subject to a weighting process prior to their integration onto an overall saliency representation (master saliency map).

The weighting process was found to operate in parallel across stimulus dimensions (Found & Müller, 1996). However, the total amount of weight that is available to be attributed to dimensional processing is limited and, with an increasing number of relevant dimensions (in which the target stimulus might differ from non-target objects), the available weight needs to be split up and allocated to each dimension. The weight assigned to a certain dimension determines the rate at which saliency information from the individual dimensional map is generated and propagated to the master map of saliency. A high amount of weight allows speeded detection of a feature difference within a given dimension and thus, results in a higher probability for this difference to be selected for further processing.

Each feature dimension (e.g. colour, motion, orientation, etc.) can be weighted but the overall capacity of weight to be allocated to one or more dimensions is limited. Thus, if one dimension, e.g. size, is weighted, processing of orientation for all objects is facilitated whereas processing of other stimulus characteristics (motion or colour) might be slowed due to the capacity limit. It is important to note, that the dimensional weight pattern thus generated persists across search trials (intertrial effects).

Neuronal correlates of dimension-based visual search

Evidence for a neuronal implementation of dimension-based modulation of attention comes from studies using positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). When observers searched for a pop-out target that was consistently defined within one dimension, cerebral blood flow was increased in areas relevant for processing the particular dimension (e.g., V5 for motion (Corbetta et al., 1991; Pollmann, Weidner, Müller, and von Cramon, 2000). Pollmann and his colleagues (Pollmann et al., 2000; Weidner, Pollmann, Müller, and von Cramon, 2002), in a series of experiments, investigated the neural basis of feature and conjunction search tasks requiring shifts of attention across visual dimensions. Specific activations were found to be associated with the change of target-defining dimension from trial to trial. A change of target dimension (but not a feature change) activated a fronto-parietal network consisting of left fronto-polar cortex, inferior frontal gyrus, visual areas in the parietal and temporal lobes and in occipital areas. Interestingly, left lateral fronto-polar activation was specifically associated with stimulus-driven dimension-changes (e.g. induced by a color-defined target preceded by a motion-defined target) while endogenously driven dimension changes in singleton conjunction search were found to elicit increased activation in pregenual paracingulate (fronto-median) cortex. Thus, a double dissociation exists between structures involved in stimulus-driven (left fronto-polar cortex) and top-down controlled (fronto-median cortex) shifts between visual dimensions.

The results of these studies strongly indicate that shifts of attentional weight (or reallocation of attentional resources) are mainly controlled by fronto-polar cortex while parietal and temporal structures implement attentional weighting via modulation of extra-striate areas concerned with the processing of features of a particular new target dimension. The amount of weight assigned to each dimension appears to depend on stimulus characteristics and their variability across trials (bottom-up influence) but is also modulated by top-down influences (e.g. task instructions) (Müller, Reimann, and Krummenacher, 2003; Müller, Krummenacher, and Heller, 2004).

However, the influences of other characteristics of the display are less well understood. The sensitivity of the weighting process to changes in the spatial distribution of items in the field has not been investigated so far.

In **Chapter 2**, it was explored whether dimensional change effects are modulated by changes of target position within the visual field across trials (Experiment 1). In particular, one of the aims was to identify potential interactions between dimensional change effects and a change of the target's position in the visual half-field. Furthermore, effects of the distance between the location of the target in a given trial and the target location in previous trials, and their relation to effects of dimension changes were examined. In a *second experiment*, using compound stimuli that require a discrimination of the target defining feature subsequent to target detection, is was asked whether a change of response hand affects dimensional weighting

processes or not.

Challenges to the Dimension-Weighting Account (DWA). Some of the assumptions of the DWA have recently been challenged by several authors mainly focusing on the origin of the dimensional effects in visual search for singleton popout targets. While the DWA holds the assumption that attentional selection based on dimensional information is achieved at an early perceptual, pre-attentive level, there are alternative views claiming the dimensional effects arise at a late response-related, post-selective stage in the visual processing hierarchy (Cohen & Magen, 1999; Feintuch & Cohen, 2002; Cohen & Shoup, 1997, 2000) . The DWA states that when selecting a salient target from the visual scene, attentional weight is shifted towards a particular stimulus dimension and the resulting weight pattern then determines the ease of target selection in a subsequent search process. The alternative position sketched above assumes that dimension-based influences on target detection are due to the preselection of the response associated with the particular dimension rather than the processing of the stimulus itself. This controversy differs from the classic long standing debate about "early" vs. "late" selection concerning the question whether stimuli are selected by attention before or after pattern recognition (Broadbent, 1985; Deutsch & Deutsch, 1963; Duncan, 1980; Tipper & Driver, 1988; Lavie, 1995) . Here, the point of controversy is at what level processing is affected by dimension-based limited attentional resources.

One approach to decide between the two alternative accounts is the redundant

target paradigm, as response-based accounts make strong predictions concerning the nature of the integration of multiple dimensional signals. Although the DWA is theoretically well founded and its predictions have been tested in a number of experiments using psychophysical procedures as well as psychophysiological and imaging methods such as EGG or fMRT, the number of studies using an neuropsychological approach is very limited at best.

1.1.4 Biased Competition (Desimone & Duncan, 1995)

One of the most influential parallel models of attention is the Biased Competition theory (BC) by Desimone and Duncan (1995) . Biased Competition suggests that neuronal responses are determined by competitive interactions. A central assumption of the BC account is that visual input elicits activity, in parallel, in several areas of the brain, each of which is specialized for the analysis of different stimulus attributes, e.g. shape, colour or motion. Selection for further processing of a certain object is achieved by the integration of competitive activity across multiple areas. This selection is, however, not achieved by competition of independent objects. Rather, features of the same object reinforce each other while suppressing activations of other objects, thus forming a stable state of activations belonging to one object over a time course of several hundred milliseconds. Concerning selection mechanisms in visual search, the biased competition account proposes two main sources of attentional control: stimulus-driven ('bottom-up') information from

stimuli presented in the scene and 'top-down' feedback mechanisms that arise from current behavioural goals (Desimone & Duncan, 1995). The latter gain influence by (a) increasing the maintained activity of visual cortical neurons or by (b) an increase in sensory-evoked responses. Further, competition of object features can be modulated independent of spatial constraints: Processing can be biased in favor of stimuli possessing a specific characteristic (e.g., colour, shape, etc.) in parallel throughout the visual field as well as occupying a specific spatial location (e.g. made relevant by task instruction). However, competition between two stimuli is assumed to be strongest when the two stimuli are at the same location and, thus, activate cells in the same local region of cortex (Desimone, 1998). The biased competition approach has been influential particularly with regard to mechanisms that might underlie neglect or other neuropsychological deficits of attention. The 'theory of visual attention' (TVA, Bundesen, 1990) , which represents a mathematical framework of 'biased competition', provides highly differentiated methods of assessment of attentional deficits of various aetiology (Duncan et al., 1999; Habekost & Bundesen, 2003; Peers et al., 2005) .

1.2 Target redundancy in visual search

Research into the phenomenon of pop-out provided new insights in how the visual system deals with a single salient object presented amongst less salient items in the visual field. While some accounts assume that the selection of the effective

stimulus is based on the computation of contrast-based saliency signals (e.g. Wolfe, Friedman-Hill, and Bilsky, 1994; Müller, Heller, and Ziegler, 1995), others suggest there is competition for representation from which features of the stronger stimulus gradually emerge while others are suppressed (Desimone & Duncan, 1995). Both mechanisms result in the allocation of attentional resources to the stimulus that now enters awareness and becomes available for report. However, how is selection achieved when two or more equally salient items amongst homogeneous context items are presented? Is the time required to detect salient stimuli similar to that observed with a single-target display because single target RTs are so fast that there is no room for further improvement? Is detection expedited, although, if features are registered in parallel across the whole field, no RT difference should be expected between conditions containing one or two similarly salient items? How are (saliency) signals propagated and made available to processes of attentional control?

1.2.1 Redundancy of number or modality

Originally, the *redundant signal effect (RSE)* was found in tasks in which observers had to respond to signals presented in different modalities, such as vision and audition. When asked to respond as fast as possible to a visual stimulus, an auditory stimulus or the redundant presentation of both, reaction times were on average faster to the combined visual-auditory stimulation than those to either the single visual or the single auditory stimulus (e.g. Raab, 1962; Giray & Ulrich, 1993; Miller, 1982).

Subsequent studies proved the RSE to be a more general phenomenon. Robust RSEs were also found within a single sensory modality, that is faster reaction times to the presentation of two stimuli compared to a similar single stimulus (e.g. in the visual domain, Pollmann & Zaidel, 1999).

Several approaches to explain the RSE exist today. To account for the effect, Raab (1962) first proposed a simple *race model* in which the two targets engage in a race for the control of the response. In some conditions, the effect is consistent with the race model, in other conditions, however, the RSE exceeds the predicted RT gain, implying some form of (neural) interaction between the two signals.

Alternatively to Raab's race horse model of separate activations, there is the possibility of an interaction of the two signals. Miller (1982) suggested that, in some conditions, the two signals are integrated in an 'over-additive' fashion and that the resulting co-activation at an ensuing processing stage speeds the response. Miller's suggestion was based on the observation that, according to the horse race model, responses to redundant signals must be no faster than the fastest RTs to non-redundant (single) signal presented in isolation. Thus, the race model explanation would not hold for a redundancy gains exceeding this limitation. Rather, co-activation of signals would be the primary alternative. Thus, the redundant signal paradigm allows insight into the mechanisms underlying processing of multiple target displays. Gains in RT might simply be the result of a race between to independent processes. On the other hand, gains that exceed a limit predicted by the race model indicate an (over-

additive) interaction between signals most likely to elicit a response in a co-active manner. Violations of Miller's (1982) race model inequality, and thus redundancy gains consistent with a co-activation explanation, have been repeatedly observed in patients with impaired inter-hemispheric connections. These patients, lacking the corpus callosum due to surgery (split-brain) or agenesis, have been found to produce increased redundancy gains that also violate the race model inequality (Corballis, Funnell, and Gazzaniga, 2002; Barr & Corballis, 2003; Corballis, Corballis, and Fabri, 2004) . These findings were taken as evidence for pronounced (subcortical) interhemispheric interactions that might usually be inhibited by the corpus callosum in normal, non-impaired, observers.

Further, the redundant signal effect can occur when one stimulus in a pair is not consciously detected. This was observed in studies with hemianopic patients (Marzi, Tassinari, Aglioti, and Lutzemberger, 1986; Tomaiuolo et al., 1997) as well as with patients suffering from extinction. Marzi et al., (1996) presented brief light flashes in the left or right visual field or simultaneously in both fields to brain damaged patients with or without visual extinction. Observers had to respond to the presence of a stimulus as well as to indicate the location and number of flashes. All patients exhibited a RSE, even in the absence of conscious perception of one stimulus in bilateral stimulation. The RSE observed in right-brain damaged patients with extinction violated the race-model inequality and was thus assumed to result from co-active processing of the two signals. In contrast, no violations of the RMI

were found in the RSE of right-brain damaged patients without neglect, suggesting a parallel race mechanism underlying the RSE. Redundancy gains from double stimulation perceived as a single item was also found in healthy subjects. Savazzi & Marzi, (2002) investigated effects of target redundancy in normal observers with a variation in the degree of visibility of one stimulus in a pair. Subjects were instructed to report the presence of a single or, alternatively, double squares presented with a luminance above (99% detection rate), below (<1% detection) or far below (0% detection) the individual detection threshold. A redundancy gain was found for the following conditions: double stimulation with both of the two stimuli above detection threshold (explicit redundancy gain) and target pairs perceived as a single stimulus due to the reduced luminance of one of the two stimuli (implicit redundancy gain). Miller's (1982) race model inequality was violated in both conditions. Therefore, the authors assumed the redundancy gain to be based most likely on a co-activation mechanism.

1.2.2 Dimensional Redundancy

In the studies described above redundancy gains either resulted from comparisons of RTs to unimodal vs. bimodal stimuli or to unilateral vs. bilateral stimulus presentation. However, expedited RTs can also arise when a single target in a visual search display is redundantly defined by two features from different feature dimensions rather than one single feature. Thus, amongst several homogeneous

distractor items, a single target differing from all other stimuli in two features from separate dimensions (e.g. colour and orientation) is detected faster than a single target defined in only one dimension (e.g. colour, or orientation). Here, redundancy is based on the number of dimensional signals rather than the mere number or laterality of targets in the field.

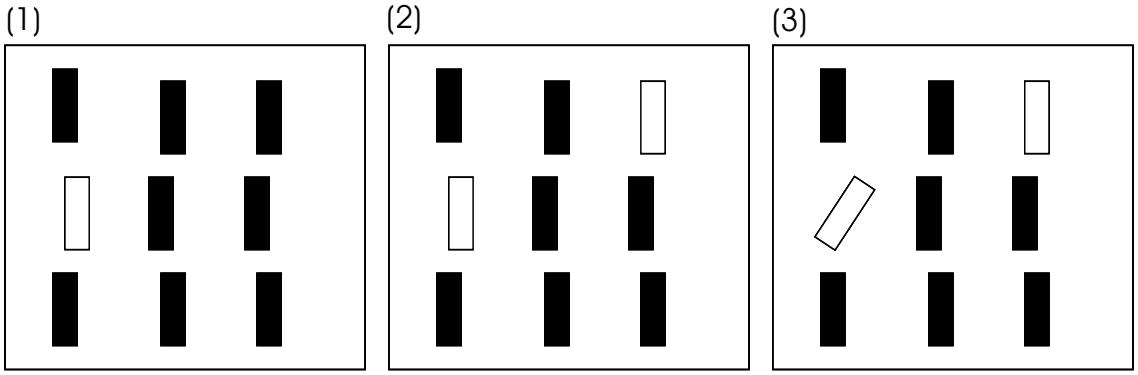

Fig. 1.2: *(1)Single feature target display, (2) numerical redundant target, and (3) dimensional redundant target display.*

According to accounts of visual search like Guided Search (e.g. Wolfe, 1994), stimulus features are registered in parallel across the visual field and separately processed in dimension-specific maps, respectively. A feature singleton is thought to generate a saliency signal, that after being transferred to an overall-saliency map guides attention and allows target detection. In the case of a single target redundantly defined by two features from different dimensions, the way signals are conveyed to the master saliency map is not as clear. Signals from dimension-specific maps might be transmitted separately, either serially or in a parallel race, with only

one of them at a time gaining influence on the overall-saliency stage. Alternatively, individual saliency signals from multiple dimensions might converge and co-activate units at the master saliency map level.

Evidence for the latter mechanism underlying dimensional redundancy gains comes from a series of experiments by Krummenacher and colleagues (Krummenacher, Müller, and Heller, 2001, 2002a, 2002b) . When a single target was defined in two features from different dimensions, detection was expedited relative to a single non-redundant target. Similarly, two (dual) targets in the display each defined in a different dimension produced redundancy gains. In both conditions, the RT gains violated Miller's (1982) race model inequality suggesting a parallel co-active registration of the two signals. Dual targets defined by features from the same dimension produced a (small) RT gain which, however, did not violate the limits set by the race model inequality.

However, co-activation of redundant signals was found to be restricted by spatial limitations: Violations of the RMI in conditions with two salient targets defined in different dimensions (thus generating two dimensional saliency signals) were more robust for single targets (joined spatial location). With increasing spatial distance between two (redundantly defined) targets in the field, a decrease of RT redundancy gain was observed, further, violations of the race model limit were manifest only when the two items were placed in relatively close spatial proximity (Krummenacher et al., 2002a, Experiment 2). Further, signal integration appeared to be

sensitive to intertrial effects. Evidence for coactivation was stronger for the second of two repeated redundantly defined targets relative to the second and first of two repeated singly defined targets. In contrast, variability of target definition across trials reduced the strength of redundancy gains.

There is also evidence that coactive dimensional redundancy gains are not critically dependent on spatial attention. When areas (upper, lower, left, right quadrant) of the display were cued prior to target presentation, a single redundantly defined target produced coactive gains in RT independent of whether it appeared in a precued (attended) region or uncued (unattended) part of the display (Krummenacher et al., 2002a, Experiment 3).

In Chapter 3, patients with unilateral neglect performed a visual search task for single and dual targets presented in either the left, right or both visual half-fields of the display. Single targets were defined by one feature from the colour or orientation dimension. Dual targets were either each defined by a feature from the same dimension or by features from different dimensions.

There is evidence that coactive dimensional redundancy gains are not critically dependent on spatial attention. When areas of the display were cued prior to target presentation, a single redundantly defined target produced coactive gains in RT independent of whether it appeared in a precued (attended) region or uncued (unattended) part of the display (Krummenacher et al., 2002a, Experiment 3). Thus, it was possible to investigate both what in the remainder of the present paper referred

to as 'numerical redundancy' (i.e., single vs. multiple [dual] targets, irrespective of their dimensional definition) and 'dimensional redundancy' (dual non-redundant targets vs. dual redundant targets) in a single task.

1.3 Spatial Aspects of Visual Search

1.3.1 Visual spatial hemineglect

Studies with patients suffering from various attentional deficits due to a brain lesion have a long history in the neural sciences. A particularly well-studied example in the field of attention research is the syndrome of unilateral neglect. Unilateral neglect is generally defined as a failure to report, respond or orient to the side of space contralateral to a brain lesion in the absence of a sensory or motor deficit (Heilmann & Valenstein, 1979). Neglect can affect a single sensory domain (e.g. vision) as well as more than one domain (multimodal neglect), leaving patients highly disabled and exposed to various sources of physical injury. Neglect is often accompanied by anosognosia, i.e., reduced or missing acknowledgment of the presence of an impairment (Starkstein et al., 1992; Vallar, Bottini, and Sterzi, 2003). Anosognosia slows rehabilitation and its severity is a main predictor of low quality of outcome after stroke (Jehkonen, 2000).

While early studies described neglect as a sensory deficit, it is now widely agreed that its symptoms result from impaired attentional mechanisms (see, however, Bisi-

ach, Luzzatti, and Perani, 1979; Heilmann, Valenstein, and Watson, 1985; Bisiach, Geminiani, Berti, and Rusconi et al., 1990 for alternative accounts). An attentional deficit causal to the symptoms to neglect is implicated by a variety of clinical observations and experimental findings: *Firstly*, primary sensory structures (e.g. VI , occipital cortex) as well as motor areas are typically intact in patients with neglect. Therefore, the symptoms can not be accounted to an underlying sensory or motor deficit. *Secondly*, the observed contralesional deficit can be overcome by specific cuing (Karnath, Fetter, and Niemeier,1998) or by special emphasis to attend to the neglected side. *Thirdly*, more indirect evidence comes from a strong component of 'extinction' that often accompanies neglect. Detection performance of stimulation within the contralesional side deteriorates with presence of additional ipsilesional stimulation. This has been suggested to indicate competition for attentional resources (Desimone & Duncan, 1995; Duncan et al., 1999) or the inability to withdraw attention from ipsilesional events (Posner, Cohen & Rafal, 1982).

Although many attempts have been made to identify the brain region responsible for the symptoms of neglect in humans, there is still a debate about several canditate structures. One reason might be the extreme variability of lesion size and location between individuals as well as the existence of different types of neglect (Bisiach & Vallar, 2000;Halligan et al., 2003). The same variability can be found when comparing the methods used to characterize the anatomy of neglect. A majority of studies identified the right inferior parietal lobule and the right temporal-parietal junction

(TPJ) as the most common areas of damage (Vallar, 2001; Mort et al., 2003) . Neglect following lesions of the superior posterior temporal lobe, the inferior parietal lobe and frontal areas was found less frequently. Lesions of the pulvinar, the putamen and, but not as often, have also shown to result in neglect behavior. Based on a series of studies (Karnath, Ferber, & Himmelbach, 2001; Karnath, Brotz, & Gotz 2001; Karnath & Niemeier, 2002) using a method of lesion overlap with fMRI in various samples of neglect patients and patients with visual field defects, Karnath and colleagues suggested the superior temporal cortex to be the critical neuro-anatomical substrate for spatial neglect in humans. This was in contrast to the classic assumption that the crucial lesion sites for neglect are the inferior parietal lobule and the temporal-parietal junction (TPJ). Recently, Karnath, Fruhman-Berger, Kuker, and Rorden, 2004 compared the lesion sites of two large groups of right hemisphere stroke patients with and without neglect using voxel-wise statistical tests. Other than in previous studies, no selection criteria, e.g. primary visual field defects, overall lesion size, were applied. Again, the middle part of the superior temporal gyrus (BA 22) was found to be the area of greatest lesion overlap. Despite the intense debate about the exact location of brain damage most likely to cause hemispatial neglect, there is agreement that it is most commonly observed after lesions to the right hemisphere of the brain and more persistent with cortical than with subcortical lesions (Ringman et al., 2004) . Lesions to critical structures within the left hemisphere result in only weak and more transient symptoms of neglect (Maguire & Ogden, 2002) .

An account alternative to the debate about the precise locus and the attempt to identify a single structure responsible for neglect is the assumption that damage to various sites and components of a network of structures, responsible for attentional control, is causal for as heterogeneous a condition as neglect. In line with this, it was recently suggested that different forms of neglect are associated with different sites of dysfunctional structures (Hilli, Mordkoff, and Caramazza, 1999) . Thus, neglect is increasingly considered to consist of a number of component deficits with the specific combination determined by the exact location and extent of brain damage in each patient (Parton, Malhotra, and Husain, 2004). Similarly, the impaired mechanisms leading to neglect symptoms are not unique for neglect but might occur in other conditions as well: Thus, it is a combination of spatial and non-spatial attention-related deficits that cause the typical picture referred to as neglect.

1.3.2 Neglect and Performance in Visual Search

The rather broad definition of neglect proposed in the previous section is mainly based on results from clinical testing using 'paper & pencil' procedures with little control of display viewing and presentation timing conditions. Experimental approaches to describe neglect behaviour have yielded a more detailed picture. Visual search tasks, which require the ability to explore the ipsilesional and contralesional space, are among the most sensitive tests for neglect and therefore the one of the main paradigms used to investigate the disorder.

The most evident deficit when patients perform a visual search is their inability to explore the contra-lesional part of the visual field. As a result, most of the target items located there are typically missed. If detected, the latency of the response is severely prolonged compared to response times to targets in the ipsilesional field. Furthermore, patients were found to use a disorganized scanning strategy during search. Other than normal subjects, neglect patients direct their first saccade toward the right, ipsilesional visual half-field (Sprenger, Kömpf, and Heide, 2002), they make fewer saccades with reduced amplitudes to the left side, and they generate longer visual fixation times on right-sided targets (Weintraub & Mesulam, 1988; Behrmann, Watt, Black, and Barton, 1999; Mesulam, 1999) .

Various attentional theories have been proposed to explain the deficit in directing attention to the left side half of space. Kinsbourne (1987) suggested an intrinsic graded bias towards the right damaged hemisphere (ipsilesional hyperattention). Posner and Driver (1992) proposed a deficit in disengaging and shifting attention from an ipsilesional focus towards a new stimulus on the contralesional side. Alternatively, it was suggested that neglect reflects competitive interactions between targets and distractors in which unilateral brain damage biases attentional competition in favour of stimuli presented in ipsilesional space (Desimone & Duncan, 1995; Duncan, Humphreys, and Ward, 1997) .

In recent studies, there is growing evidence that, in addition to a bias to the contralesional side, non-spatially lateralized deficits of attention also contribute to

pathological search patterns in neglect patients. An impaired short-term memory capacity was found to cause an inability in discriminating old vs. new locations and entail multiple re-fixations of already scrutinized stimulus locations (Husain et al., 2001; Malhotra, Mannan, Driver, and Husain, 2004) . Mannan et al. (2005) tracked the eye movements of 16 neglect patients during search, and also asked them to click a response button only when, by their own judgment, they were fixating a target for the very first time. "Re-clicking" on previously found targets indicated that patients erroneously responded to these as new discoveries. Re-click deficits correlated with degree of leftward neglect and error probability increased with time since first discovery. Further impairments include reduced sustained attention (Maguire & Ogden, 2002), slowed attentional blinks (Husain, Shapiro, Martin, and Kennard, 1997), reduced arousal (Robertson, Mattingley, Rorden, and Driver, 1998) and bilateral deficits in visual processing capacity (Duncan et al., 1999).

Moreover, studies even suggest impaired stimulus processing in the ipsilesional hemi-field with neglect patients relative to healthy controls although this deficit is more subtle than in the contralesional side of space (Eglin, Robertson, and Knight, 1989; Posner & Cohen, 1984; Robertson et al., 1998) . In contrast, early stimulus processing, prior to deployment of focal attention and awareness seems to be preserved in neglect patients. Thus, substantial implicit stimulus processing has been shown to affect the patient's behaviour, and even neural correlates of this processing have been found in the form of cortical activation elicited by neglected stimuli (Rees

et al., 2000; Vallar et al., 1994).

These findings imply that simple feature search, assumed to be performed pre-attentively should be unaffected by neglect. However, there are divergent findings concerning visual feature search performance in neglect patients. While some authors (e.g., Riddoch & Humphreys, 1987; Eglin, Robertson, and Knight, 1989 or, more recently (Pavlovskaya, Ring, Groswasser, and Hochstein, 2002; Behrmann, Ebert, and Black, 2004) reported slowed RT and/or increased error rates in the contra-lateral search performance of patients with neglect, others (Arguin & Bub, 1993; Aglioti, Smania, Barbieri, and Corbetta, 1997; Esterman, McGlinchey-Berroth, and Milberg, 2000) found that performance in feature search tasks was not impaired. (Behrmann et al., 2004, compiled a list of potential factors contributing to the discrepancy between findings.)

Little is known whether or not dimension-based processing is directly affected by lateralized and non-lateralized attentional deficits contributing to neglect. In terms of the Dimension Weighting Account, a number of questions arise: Does neglect affect the weighting of dimensional saliency signals prior to the integration into an saliency map? Is there a specific deficit in the processes involved in shifting attentional weight from one stimulus dimension to another? And, is it the initiation of shift or its implementation which would be more likely as frontal areas are mostly spared in participants of this particular study? Further, does search performance of patients with neglect improve when they are presented with redundant information

in a visual search task? If the answer is yes, are redundancy gains observed in conditions with 'numerical redundant' targets (single vs. dual targets), in conditions with 'dimensionally redundant' targets (dual targets defined within a single dimension vs. dual targets defined in different dimensions) or is patients' performance best when they are presented with both numerically and dimensionally redundant information?

To answer these questions, as reported in Chapter 3 below, visual pop-out search for single and dual targets either defined in a single dimension or in different dimensions was investigated in group of patients with unilateral neglect.

1.4 Masking and Visual Search

An important approach into the investigation of stages of stimulus processing that mainly operate without (direct) access to awareness is referred to as masking. Similar to real world perception in which only a small part of sensory information reaches awareness but nonetheless is capable of influencing behaviour, masking procedures prevent the generation of awareness of objects or, alternatively, of certain parts of a stimulus field under experimentally controlled conditions. Backward masking of visual stimuli is achieved in a procedure in which the short presentation of a test stimulus (often for less than 50 ms) is temporally closely followed by another stimulus (mask). While the target stimulus, when presented in isolation, can be easily perceived and identified, the presentation of a mask up to 100 ms after the offset

of the target, markedly reduces response accuracy. As performance improves with longer delays between target onset and appearance of the mask, backward masking has been used throughout the history of experimental psychology to interrupt information processing at different stages and, thus, to investigate the time course of information processing and the influence of stimulation that is prevented from reaching awareness but nevertheless has an impact on the information that is consciously perceived.

For the visual domain, masking is defined as reduction in visibility of a target object by presenting a second object (the mask) in temporal and/or spatial proximity to the target. The aim is to prevent access of processing mechanisms to the target stimulus for a controlled time interval (Breitmeyer & Ogmen, 2000). Based on the spatial relation between target and mask, two main types of masking have been described: *pattern masking* refers to a spatial overlap between mask and target. The mask occupies the same spatial location as the target either presented shortly before or after presentation of the target stimulus. In *metacontrast masking*, reduced awareness of the target is achieved by presenting mask and target in close proximity but without spatial overlap (Enns & DiLollo, 2000).

1.4.1 Mechanisms of visual pattern masking

If, as in pattern masking, target and mask stimuli occupy the same spatial location, the mask's impact is thought to unfold in two ways, depending on the temporal

relation between target and mask. Either, both (target and mask) stimuli are perceived as part of the same pattern (*integration masking*) due to the limited precision of the resolution of the sensory system. That is, in early stages of representation, the (target) signal is mixed with noise (mask). As a result, the two spatially and temporally neighbouring stimulus events are integrated into a single percept. This form of masking is most effective with a stimulus onset asynchrony (SOA) of 0 ms, while presentation of the mask more than 100 ms before or after the target onset leaves perception (of the target stimulus) unaffected.

In contrast, *interruption masking* only occurs when the mask is presented after the target has appeared (backward masking) and is almost fully processed. However, with the onset of the mask, processing of the target stimulus is abandoned and left unfinished. Consequently, perception of the first stimulus is impaired (Kahneman, 1968). Masking is strongest with SOAs greater than 0 and declines with longer SOAs. Neurophysiological support for the mechanisms suggested to underlie this type of masking comes from a study using single cell recordings to investigate the effects of masking on neuronal responses to a target stimulus. Rolls, Tovee, and Panzeri (1999) measured the responses of single neurons in the macaque inferior temporal visual cortex during visual backward masking. A test stimulus (a face) presented for 16 ms was followed by a mask (overlapping letters N and O) with randomly varied SOAs (ranging from 20 to 1000 ms). Responses of a single neuron to the target stimulus presented alone were produced with a latency of approximately

75 ms and lasted for 200 to 300 ms. When the stimulus was followed by the mask within 20 ms from onset, neuronal firing was limited to 30 ms. Thus, the effect of the backward mask on cortical information processing was to dramatically limit the neuronal response by interrupting neuronal firing. Interestingly, it was the part of firing selective for the target stimulus that was especially attenuated by the mask (Rolls et al., 1999).

Despite this clear evidence that neuronal activity elicited by the mask severely interferes with target processing at an early level, studies using 'masked priming' suggested that processing of masked targets continues to semantic levels of processing. That is, priming effects observed with non-masked primes also occurred in masked priming. Rolls et al. (1997) used the same set of stimuli as in their single cell recording study (Rolls et al., 1999) for a psychophysical experiment with human observers that required forced-choice judgments about the identity of the faces. Performance at a SOA of 20 ms was better than chance, however, subjects were not consciously aware if their choice was right or wrong. Rolls (2003) concluded that a stimulus presentation duration of 30 ms might be sufficient for a neuron to perform enough computation to enable its output to be used for identification. Thus, masking renders a visual stimulus invisible. However, the masked stimulus, although not reaching awareness, still evokes widespread selective activity in visual areas and is influential to the observers behaviour even at very short exposure durations (Lamme, Zipser, and Spekreijse, 2002).

1.4.2 Role of attention in masking

It is a matter of debate whether attention is involved in visual masking. There are studies that claim the strength of masking might be influenced by the attentional state of the observer. The visual representation of an unattended target might be decreased to the extent that even a weak mask renders it insufficient to allow perception. In contrast focused attention might boost the targets representation and prevent the mask from having an impact (Enns & DiLollo, 1997; Shelley-Tremblay, J., 2000; Tata, 2002).

Enns and DiLollo (2000) recently reported a new form of masking that was found highly susceptible to the attentional state of the observer. In a display of several items detection of a target was severely impaired when it was framed by four dots that remain visible after the target is extinguished. The authors proposed an object-substitution theory in which the visual system initially forms a representation consisting both of the target and (four-dot) mask. When extinguished from the screen with a common off-set, there is no imbalance in activity between representations of target and mask and both are identified as a result of iterative comparisons between higher extrastriate visual areas and low-level activity in V1.

In contrast, if the four-dot-mask remains visible on the screen after the target has disappeared, there is a mismatch between the re-entrant signal (originating from higher levels of processing) and low-level sensory activity. As a consequence, the initial representation of target *and* mask is replaced by a representation containing

only the four-dot mask. The influence of attention is demonstrated by the following restrictions to the efficiency of the four-dot mask: The impact of the mask (in the study of Enns and DiLollo) was strongly reduced when (a) there was only one target object, (b) the target was a pop-out, (c) the mask preceded the target and thus acted as a spatial cue to the target location. Thus, if focal attention can be directed to the target before the mask's representation can replace the picture of target and mask, masking fails. Enns and DiLollo suggest that the core mechanism, iterative comparisons between higher and lower processing levels in which the initial representation of a visual scene is discarded if inconsistent with a subsequent attention-based analysis, is shared by all forms of backward masking.

Indeed, attention was found to be involved in pattern masking. For example, variations in set size have been shown to modulate the strength of pattern (interruption) masking (Spencer, 1970). Recently, Vidnyanszky (2002) showed that focal attention reduces the effects of interruption masking in an orientation discrimination task with spatial cues. At target-to-mask SOAs of 100 ms, the effect of the cue in reducing the effect of masking was strongest, whereas at shorter and longer SOAs, attentional modulation was only weak. Furthermore, there is evidence from psychophysiological studies that masked stimuli, despite the absence of awareness, contribute to attentional guidance or might even be object of the allocation of attentional resources. For example, Jaskowski et al.(2002) reported that a lateral posterior electroencephalogram (EEG) component, typically reflecting shifts of at-

tention, was evoked by laterally presented masked shapes which were task-relevant. When, in subsequent trials, target position and identity were repeated and a shift of attention became unnecessary, the component was not observed. Also, masked priming effects have been widely reported (Debner & Jacoby, 1994; Breitmeyer, Ogmen, and Chen, 2004a; Breitmeyer, Ro, and Singhal, 2004b).

Moreover, the effects of masking exhibit striking similarities to observations in clinical populations. For example, patients suffering from damage to the primary (striate) visual cortex are not able to consciously report visual stimuli. Yet, when asked to make a forced-choice judgment, discrimination of stimulus properties such as motion (Azzopardi & Cowey, 1998; Zeki & ffytche, 1998), wavelength (Brent, Kennard, & Ruddock, 1994) or form (Weiskrantz, Cowey, and Hodinott-Hill, 2002) is above chance. Further, reflexive sensory-motor responses such as pupil changes resulting from varied illumination (Stoerig & Cowey, 1993) or eye movements in response to the presentation of moving stimulus patterns (Heide et al., 1990) have been observed. Thus, these patients exhibit a phenomenon which is referred to as blindsight, that is reasonable residual visual capacities in the absence of awareness. They can even direct attention towards the stimuli they deny having seen. Similarly, patients suffering from neglect, do not consciously perceive stimuli presented within the contralesional half of space. However, there is extensive evidence for residual processing of neglected stimuli up to semantic levels of processing.

In series of experiment not reported in this thesis aimed to 'model' neglect in

healthy observers. A pattern mask was used to cover one half-field of the search display in each trial in order to reduce awareness for targets presented there. Results indicated that (a) reaction times are slowed to targets detected despite masking, and (b) a dimension-based change effect can be observed for non-masked targets when preceded by a a masked target defined in a different dimension.

1.4.3 General Outline of the Thesis

The following section gives a short summary and overview over the experimental work presented in the thesis.

The aim of the experiments presented in **Chapter** 2 was to determine the potential interaction between change effects of the target-defining dimension and change of relative position of a pop-out stimulus (within and across display half-fields) across subsequent trials. In *Experiment 1* observers carried out a visual search for single pop-out targets defined in two different dimensions a various locations within a virtual matrix of homogeneous distractor items. Across trials, targets could change their location so that, in a given trial, the target-stimulus appeared at the same location or at a different location relative to the target in the preceding trial with the distance varying from 0 to 5 cells of a virtual matrix. In addition to the distance between target positions in subsequent trials, a change of location could either involve a variation of the hemi-field in which the target was presented: the hemi-field remained either the same (left - left; right - right) or it could change (left - right;

right - left). Further, the target-defining dimension (colour or orientation) varied unpredictably from trial to trial. The main interest was to investigate inter-trial effects of target-defining dimension and a potential influence of half-field position of the target stimulus and distance between targets in subsequent trials on detection times; that is the potential modulation of dimension-change effects by spatial factors.

In *Experiment 2* the experimental procedure was varied in order to answer the question if the results are modulated by task demands. Similar to Experiment 1, participants performed a visual pop-out search for single targets defined in different dimensions placed at varying positions amongst homogeneous distractor items. However, in addition to target detection, observers were required to discriminate the target item in order to assign it to the correct response. They had to decide whether a small gap was located at the top or bottom end of the stimulus. This so called 'compound' task is assumed to require allocation of focused visual attention and therefore provides a strong test for the susceptibility of dimensional intertrial effects to spatial factors.

The study presented in **Chapter** 3 used a different approach to investigate spatial influence on dimension-specific search processes. Patients with visual-spatial deficits due to visual neglect performed a pop-out search task for a single or dual (two) targets presented in the left or right half-field of the display or in both simultaneously. Further, targets were either defined in a single dimension or redundantly in two di-

mensions. The aim of this study was to to examine dimension-based intertrial effects and the influence of the target half-field location in a given trial on performance in a subsequent trial in patients with neglect. Further, visual search for dimensionally defined pop-out targets in patients with unilateral neglect was investigated to explore the effects of numerically and/or dimensionally redundantly defined target items on search compared to results obtained with normal participants who had shown to benefit from redundant information.

Chapter 4 was concerned with the neural implementation of dimension-specific visual processing. Two groups of patients with *(a)* left lateral fronto-polar (LFP) lesions, *(b)* fronto-median lesions and *(c)* healthy control subjects performed a visual search task for pop-out targets with the target-defining dimension either remaining the same or changing unpredictably from trial to trial. In previous event-related fMRI studies of visual singleton feature search with non-brain-lesioned participants the LFP has been found to show dimension-change-related activation. This was taken to hypothesize that LFP actively supports changes of attention from the old to the new target-defining dimension in singleton feature search. LFP patients were therefore expected to exhibit impaired performance specifically in trials associated with a change of target dimension. Thus, the present experiment aimed to provide further evidence for an active involvement of fronto-polar structures in the control of attentional shifts.

2 Intertrial effects in pop-out and compound search: Role of target dimension, halffield position and relative distance

2.1 Introduction

Visual pop-out search for targets of variable dimensional definitions requires observers to deal with an uncertainty on what exactly to search for in an upcoming trial. Rather than being able to focus on a particular object feature to look for in the field, observers must wait for the display to appear to be able to decide whether any of the display items qualifies as a potential target. Nevertheless, such a task is performed rapidly and seemingly without any effort. However, it was found that the visual system aims at overcoming, at least partly, the disadvantage arising from dimensional uncertainty. It uses as much information as possible in order to start

information processing in search for a target item in the upcoming trial in an optimal fashion.

Two main effects have been observed in the investigation of cross trials effects in visual pop-out search tasks with variably defined single feature targets (Found & Müller, 1996; Müller et al., 1995; Treisman & Gormican, 1988). *Cross-dimension search costs* (i.e., slowed RTs) were observed when the target dimension was unpredictable in a given trial (cross-dimension condition with dimensional uncertainty) relative to conditions, in which the target dimension was static, but the target feature value was uncertain (within-dimension condition) or in which both target dimension and feature value were pre-defined.

Further, a *dimension-specific intertrial effect* was found: If the target-defining dimension of the present trial *N* changed from the preceding trial *N-1*, target detection (in trial *N*) was delayed compared to trials with either a feature, but no dimension, change relative to the preceding trial, or to trials in which the feature value was repeated across trials (i.e., the no-change condition).

The two were explained by an attentional weighting process taking place prior to the integration of saliency signals onto a master map of saliency (Müller et al., 1995). In order to assess the dimension containing a saliency signal, a limited processing resource needs to be allocated to the dimensional modules computing the saliency signals; the limited resource is referred to as 'attentional weight'. The pattern of dimensional weight generated in a given trial persists into the next trial and allows

for rapid target detection, provided the target-defining dimension remains constant. In case of a dimension change, however, search involves a time-consuming shift of weight to new target-defining dimension.

Pop-out detection

Search for a pop-out targets is thought to operate without involvement of spatial attention (Treisman & Gelade, 1980; Cave & Wolfe, 1990; Wolfe, 1994b). Features are registered in parallel across the visual field and, via the computation of local feature contrasts within dimension-specific maps, saliency signals are generated and then transferred in a weighted fashion to a topographically organized overall saliency map with the weight pattern depending on the target definition in a previous trial (Wolfe et al., 1989). The Dimension Weighting model proposes that a target-absent / -present response can be based on the output of this processing stage, that is, activation on the saliency map exceeding a certain threshold (Müller et al., 1995) . Subsequently, spatial attention may then be allocated to the location of the most salient item if further processing, for example an explicit representation of the target feature value, is required to perform the task (Found & Müller, 1996; Müller et al., 2004) .

Within this theoretical framework, the spatial location of a target in a visual search display should not affect detection, and thus, RT time. Similarly, as the weighting process is assumed to operate prior to signal integration on the saliency map, dimension-based intertrial effects are not expected to be modulated by the

spatial distribution of a target items in consecutive trials.

In line with these predictions, the weighting process has been shown to be independent of specific objects (Müller & O'Grady, 2000). That is, if, for example, attentional weight has been shifted to the colour dimension, colour processing is facilitated for all objects in the field. Moreover, (Hopf et al., 2004) showed that task-relevant features presented in different regions of a display elicited brain activity (event-related potentials, ERPs) independent of the specific target position within the field. The ERP activity preceded lateralized brain activity known to reflect the allocation of attention to a specific location (N2PC).

However, there is research, mainly from neuropsychology, that led to the suggestion that attentional mechanisms are lateralized within the brain. For instance, it is well known that the ability of left and right cerebral lesions to produce hemineglect for the contralesional space differs, with more severe and long-lasting neglect signs after right-sided than after left-sided parietal lesions (Gainotti et al., 1972). Further, it was shown that shifting attention within either visual field activates the right parietal lobe, but that the left parietal lobe is activated only during attention to the left field (Pardo et al., 1991; Posner et al., 1988). This was confirmed by Corbetta et al. (1993) who identified two distinct regions in the right superior parietal lobe for attention to both the left and the right visual fields whereas in the left parietal lobe one region was active only for attention to the right visual field. Only recently, Chokron et al. (2000) demonstrated that when selective attention is required to

identify a visual target surrounded by flankers, reaction times are shorter in the right than in the left visual field. This was taken as support for a left hemisphere advantage for filtering irrelevant information and analyzing the local features of a visual scene.

Given this evidence for hemispheric asymmetries of attentional mechanisms, it can not be ruled out that a target's position within the display, in particular with respect to its half-field location, can affect the allocation of attention.

In ***Experiment 1***, it was investigated whether spatial characteristics of the search display, namely, *(1)* spatial distance between targets in subsequent trials, and, *(2)* a change of the target's half-field position across trials, affect detection times. Further, it was investigated whether potential effects of the spatial arrangement of targets across trials interact with dimension-based intertrial effects reported in the literature (e.g., Found & Müller, 1996).

Compound search

A second experiment reported in the present section, employs a task different from simple visual search (Duncan, 1985). In a compound search task, observers initially search for a pop-out target amongst distractors, however they are not required to indicate its presence or absence, rather, the response involves a decision about a response-relevant feature different from the feature(s) identifying the target. Thus, the feature dimension that defines the target (e.g. colour: red target among green distractors) is different from the feature to be reported (e.g. big or small gap).

Duncan (1985) suggested that in compound search, in addition to a pre-attentive search component that allows the detection of the singleton (i.e. an "odd-one-out" element in an array of elements), focused attention is necessary to analyze the response-relevant feature.

Compound search tasks allow for a clear separation between perceptual and response selection mechanisms underlying search performance. Employing this task makes it possible to determine whether the dimensional change effects described above are sensitive to changes in response conditions or not.

With regard to dimension-based intertrial effects in compound search tasks, there are results in the literature contradicting the position elaborated above and advocated by Müller and colleagues in their Dimension Weighting Account.

Kumada (2001, Experiment 1b) failed to find a dimension-based intertrial effect in a compound task. Observers searched for a pop-out target either defined by orientation, colour or size and responded to the orientation (left or right) of an arrow-shape (<,>) located on the target. The response was given by a button press with the left or right index finger, respectively. Furthermore, Theeuwes et al. (in press) did not observe dimensional cuing effects in a compound task. Recently, Mortier et al. (2005) reported similar results with a non-search compound task with centrally presented targets of variable dimensional definition.

These findings were attributed to a response-based mechanism of target detection assuming that each feature module has its own response selection process (Cohen

& Magen, 1999; Cohen & Shoup, 1997). In case of a distinction between target-defining feature and the feature to be responded to, an advantage based on inter-trial priming might produce no reaction time advantage as response selection processes might not have access to the saliency-based information.

On the other hand, Krummenacher et al. (2002b) found dimension-specific intertrial facilitation in a compound task requiring discrimination of left and right pointing stimuli. Also, Wolfe et al. (2003, Experiment 5) reported a similar effect both in an easy compound task (decision on whether a red target, presented among green distractors, carried a white dot or not) and a compound task rendered more difficult due to increased target-distractor similarity.

The potential causes for these diverging results are a matter of current debate. Another aspect that makes compound tasks special in comparison to popout tasks, is that in addition, and independent, to changes to the response-relevant feature dimension, there is a change of hands associated with each response change.

In ***Experiment 2***, it was investigated whether dimension-specific intertrial facilitation is indeed eliminated in a compound task. Further, the role of hand changes and their influence on intertrial effects is explored. Also, in order to compare the results of Experiment 2 with those of Experiment 1, spatial aspects, such as changes of the target's half-field position and the distance of target locations between trials are taken into account.

2.2 Experiment 1: Visual search for a single feature target

Experiment 1 was designed to test whether intertrial effects of the target-defining dimension are affected by the half-field of the target stimulus and the distance between target locations within the search array of subsequent trials. Observers performed a visual search for a target either uniquely defined by colour (red vertical bar) or by orientation (green bar, 45° tilted to the right) amongst homogeneous distractors (green vertical bars). The target item could appear in the left or right half-field of the display and, relative to a preceding trial, *(a)* at the same position, *(b)* an adjacent location, i.e., a translation of the target position by one cell of the virtual matrix underlying the display, or *(c)* a translation of the target location by 1 to 3 cells relative to the original target location. As efficient pop-out search is assumed to be independent of spatial attention, no or only little influence of spatial display characteristics was expected to be observed.

2.2.1 Method

Participants. Twelve observers (eight female and four male), all students at the Ludwig-Maximilians-University Munich with a mean age of 28 years (range 22 to 34 years) participated as paid volunteers or in partial fulfillment of an undergraduate psychology course requirement. All participants reported normal or corrected-

to-normal visual acuity. None of them showed deficits in colour-perception in a screening test (Ishihara Colour Test; Ishihara, 1917).

Apparatus. Participants were seated inside a dimly illuminated, sound shielded cubicle. They viewed the display from a distance of approximately 57 cm; viewing distance was controlled with the use of a chin and forehead rest which also served to prevent head movements during the experiment. Stimuli were presented on a Sony 15" colour monitor (with a frame rate of 60 Hz) controlled by a HP Vectra series 3 5/75 PC. Observers responded by pressing the left or right mouse button with the index finger of their left or right hand, respectively. Response errors were indicated by a computer-generated acoustic signal.

Stimuli. The search display always consisted of 100 stimuli arranged in a 10x10 matrix (see Figure 2.1). Stimulus position was randomly jittered by 0.5° to 1.0° of visual angle in the vertical and horizontal directions. Vertical green bars (VGA graphics adapter RGB values of 0,248,0) served as distractors. The target stimulus was either a vertically oriented red (RGB values 255,0,0) bar or a green bar tilted 45° to the right. Stimulus colours (red and green) were matched for luminance at 3.8 cd/m^2. The screen background was black.

The size of an individual bar was 0.2° x 1° of visual angle in width and height, respectively. Horizontal and vertical distances between stimuli ranged from 1.5° to 2.0° and from 0.5° to 1.5° of visual angle, respectively, with horizontal and verti-

cal stimulus centers separated by equal distances. The area covered by the whole stimulus matrix subtended approximately 17° x 19° of visual angle. However, target items only appeared within the inner 8x8 matrix to avoid edge effects.

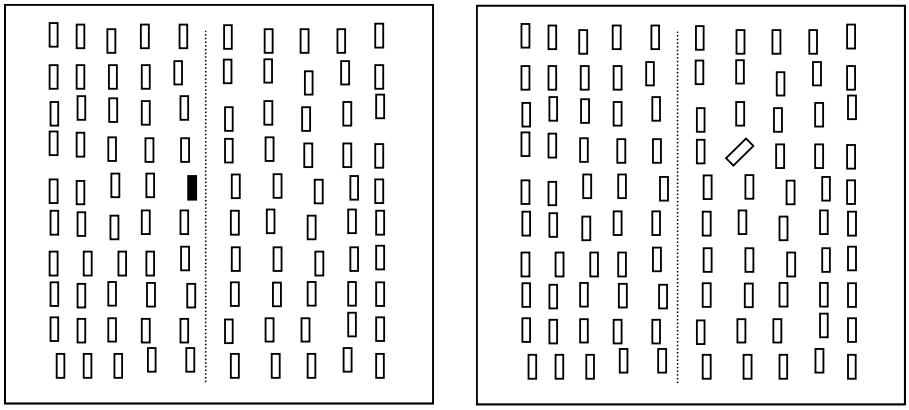

Fig. 2.1: Schematic view of two target-present displays presented in Experiment I. The colour-defined (left) and orientation-defined targets (right) were shown amongst green distractors on a black background.

Design & Procedure. There were four experimental conditions: [1] *display type* (target-absent or target-present), [2] *target dimension* (colour: red or orientation: right-tilted), [3] (target) *half-field position* (left or right), and [4] *target location translation*, i.e., the distance between the location of the target in a given trial N relative to the target location in the previous trial N-1 [same location, adjacent location, translation of 1 to 3 cells (gap 1-3)].

Thus, in target-present trials, a target item was either defined by its colour (red target among green distractors) or by its orientation (45° tilted target among ver-

tical distractor), i.e. distractors always were homogeneous green vertical bars. The target-defining dimension changed unpredictably from trial to trial. The target was either presented in the left or the right half-field of the search display; with respect to the location of a target stimulus in the preceding trial, the target appeared at the same, an adjacent, or with gaps of 1 to 3 cells. A target was present in 50 % per cent of all trials with the colour and orientation target being shown equally often.

A trial started with the simultaneous onset of all items of the stimulus array. The subject's response (press of mouse button) cleared the screen of the display and after an inter-stimulus interval of 400 ms with a blank screen the next trial started. Observers indicated the absence or presence of a target stimulus by pressing the left or right mouse button with their left and right index finger, respectively. Hand-response mapping was balanced across sessions and subjects such that six of the 12 observers responded present with right mouse button and absent with the left button in sessions 1 and 3 and vice versa in sessions 2 and 4. The remaining six participants were assigned target-present /-absent and response hand association in reverse order.

Observers were instructed to respond as quickly and accurately as possible. An acoustic feedback signal was given in the case observers made an erroneous response (i.e., a miss or false alarm). At the end of each block a rest period followed. Participants pressed the space bar as soon as they felt ready to proceed with the next block of trials.

In total, observers participated in four consecutive experimental sessions. In each session they performed 10 blocks of trials comprising 64 trials each. Overall, there were 2560 trials and the entire experiment (4 sessions) took approximately 80 minutes to complete.

2.2.2 Results

Reaction Time Analyses. Only reaction times (RTs) of target-present trials that were responded to correctly were included in the analyses. In terms of intertrial effects this means that only sequences of trials with correct responses were analyzed. Further, RTs outside a range between 200 ms and 1000 ms were discarded as 'outliers' ($< 1\%$ of all trials).

The overall mean RT of Experiment 1 was 423 ms. Colour-defined targets were detected faster than orientation targets (413 ms vs 433 ms, respectively). A paired-samples t-test revealed the difference (20 ms) to be significant [$t(11) = -4.44; p = .001$]. Further, there was a small, but significant RT advantage for targets presented in the left half-field of the display (438 ms) compared to targets in the right half-field (443 ms)(paired-samples t-test [$t(11) = -2.34; p = .039$]). Overall mean error rate was 3.2 %.

To examine the effects of the dimension defining the target in trials *N-1* on target detection in subsequent trials *N*, a repeated-measures analysis of variance (ANOVA) was conducted with the factors *intertrial transition* (colour-colour, orientation-colour,

orientation-orientation, colour-orientation), *half-field change* (no change vs. change) and *target location distance* (gaps 1, 2, 3, 4). Trials with the target presented at the same location were excluded from analysis as in this condition there are no changes of half-field included. The analysis revealed the two main effects to be significant: inter-trial transition [$F(3, 33) = 23.42; p = .000$] and distance ([$F(1.5, 33) = 4.28; p = .041$]; (Greenhouse-Geisser corrected df)). Figure 2.2 illustrates the mean RTs for all conditions.

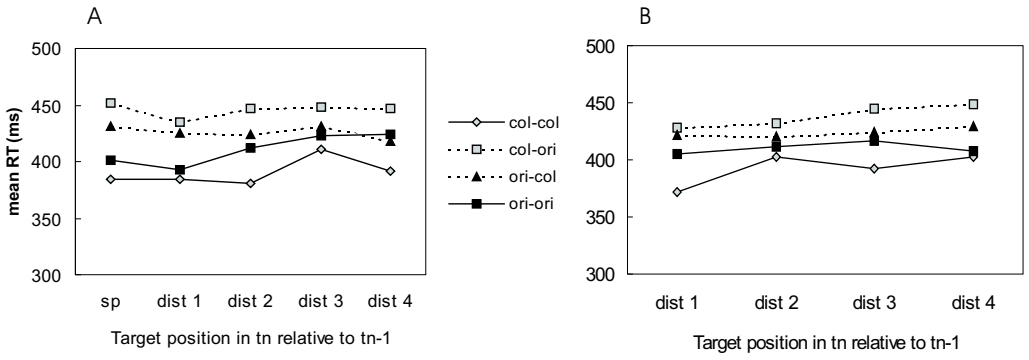

Fig. 2.2: Mean reaction times of the four possible inter-trial transitions of target dimension from trial N-1 to trial N (col= colour; ori= orientation) plotted separately for the target location distances (sp = same position; distl-4 = distances (gaps) 1 to 4, including adjacent position) separately for trial sequences with *no half-field change* (panel A) and for sequences with *half-field change* (panel B).

Intertrial transition: Target dimension. The main effect of dimensional inter-trial transitions was further analyzed in order to determine whether it was based on the main effect of target dimension (colour targets were responded to faster than

orientation trials) or dimension change or an interaction of both effects. An ANOVA with repeated measures with two factors *target dimension* (colour vs. orientation) and *dimension change* (change vs. no change) revealed the main effects of both factors to be significant, target dimension [$F(1, 11) = 19.95; p = .001$], as well as dimension change [$F(1, 11) = 43.87; p = .000$].

There was no significant interaction [$F(1, 11) = .216; p = .651, n.s.$]. The main effect of target dimension was due to the fact that colour targets were consistently detected faster than orientation-defined targets (413 ms vs. 433 ms, respectively). The main effect of dimension change confirmed that detection of a given target was speeded when it was preceded by a target defined within the same feature dimension. A colour target preceded by a target that was also colour-defined (colour-colour) was detected fastest (397 ms). Detection was slowest for an orientation target if it was presented after a colour- target trial (447 ms). The mean RT difference between no change and change (of dimension) conditions was 30 ms. This result replicates earlier findings (Found & Müller, 1996) of prolonged RTs caused by unpredictable changes of the target-defining dimension, an effect thought to be due to time consuming attentional switch processes during target selection. Figure 2.3 displays both of the main effects reported above.

Target distance. The main effect of target location distance, that is the distance of the location change of a target item in a given trial N relative to target location

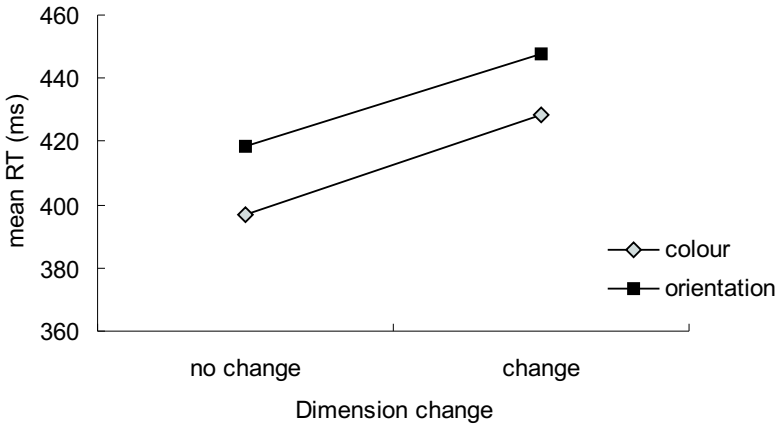

Fig. 2.3: Mean reaction times (RT) in milliseconds (ms) to the conditions no change and change of the target dimension from trial N-l to trial N plotted separately for colour- and orientation-defined targets.

in the preceding trial *N*-1, was mainly due to a significant difference between distance 1, i.e., targets presented at locations immediately next to the location of the target of the preceding trial, (mean RT = 408 ms) and distances 3 (424 ms) and 4 (421 ms). No other comparison reached statistical significance. The RT differences were confirmed by LSD post-hoc tests and are illustrated in Figure 2.4. Interestingly, a repetition of the target location, such that a target in trial *N* appeared at the same position as in the preceding trial *N-1*, did not yield the fastest RT of all distance conditions. Rather, the distance condition entailing the fastest RTs (distance 1, 408 ms) appeared to be a target located at a position in the immediate neighbourhood of the target in the preceding trial [i.e., in one of the (virtual) cells next to the cell containing the target]. However, only mean RTs for the distance 1 con-

dition were significantly different from distances 3 and 4 ($[t(11) = -5.983; p < .01]$, $[t(11) = -3.489; p < .01]$, respectively).

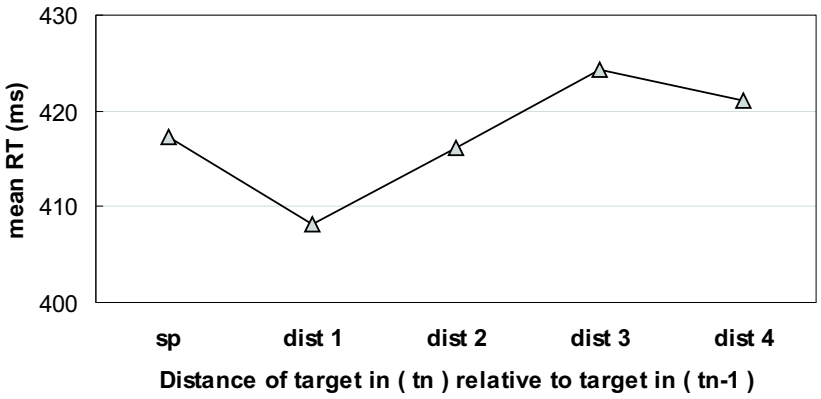

Fig. 2.4: Mean reaction times (RT in ms) for all distances of target locations for targets presented in subsequent trials. (sp = same position; dist = distance)

A factor inherent in the characteristics of the display used in Experiment 1 and thus potentially causal for the pattern of results described above is *eccentricity*. It is well known that attention and/or gaze direction are preferentially directed to the center of the screen (e.g., Carrasco et al., 1995) or, in the experiments presented here, the center of the stimulus matrix. Therefore, targets presented at various positions within the matrix are located either close to the center or rather distant from the midpoint. The characteristics of an individual target in terms of eccentricity are different compared to the distance between the location of targets in consecutive trials (s. above), as a target presented at a given eccentricity is not necessarily more

distant to a target of a preceding trial than one located close to the midpoint. However, eccentricity and target location distances between subsequent targets might be related or interact.

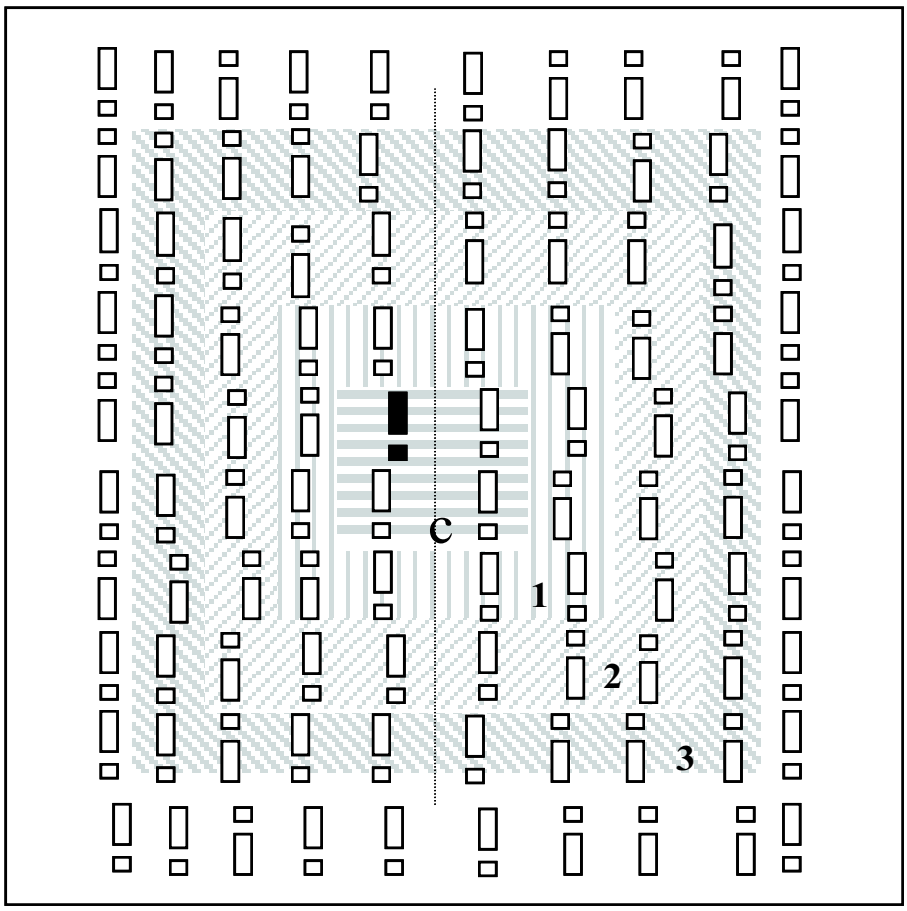

Fig. 2.5: Schematic illustration of target eccentricity in displays used in the present experiment. Distance from the midpoint of the display (eccentricity) is indicated by areas of different texture. (c =central positions, 1 to 3 =eccentricity 1 to 3)

For this reason, an ANOVA with the factors *location distance* (0 to 3), *dimension change* (change, no change) and *target eccentricity* (center, eccentricity 1, 2, and 3)

was conducted. Each target position in the display was classified according to its distance from the *center* of the display. Four positions around the central midpoint of the display were labelled as 'central'. With increasing distance, the remaining positions where allocated to eccentricity 1 to 3 (see Figure 2.5). The ANOVA revealed the main effect of eccentricity $[F(3, 33) = 33.774; p < .01]$ to be significant. Importantly, however, neither the interaction of target eccentricity with distance nor the interaction of eccentricity and dimension change was statistically significant ($[F(9, 99) = .827; p = .593, n.s.]$ and $[F(3, 33) = .771; p = .591, n.s.]$, respectively). Thus, the 'within-trial' effect of target eccentricity, that is its distance of the target location to the center of the display, seems to be indeed independent to the inter-trial effect of location distances of targets in consecutive trials.

As illustrated in Figure 2.6 increasing eccentricity of target positions relative to the center of the display was accompanied with slower RTs. The fastest RTs were found for the central locations and the longest ones for targets with the greatest eccentricities. RTs to both central and eccentric targets were significantly different from RTs to targets at intermediate eccentricities.

Presentation half-field. Presentation half-field. As reported above, there was a small effect of the half-field within which a target was presented in a given trial (paired-samples t-test $[t(11) = -2.34; p = .039]$). There was an RT advantage for targets placed in the left half-field of the display. However, there was no main effect

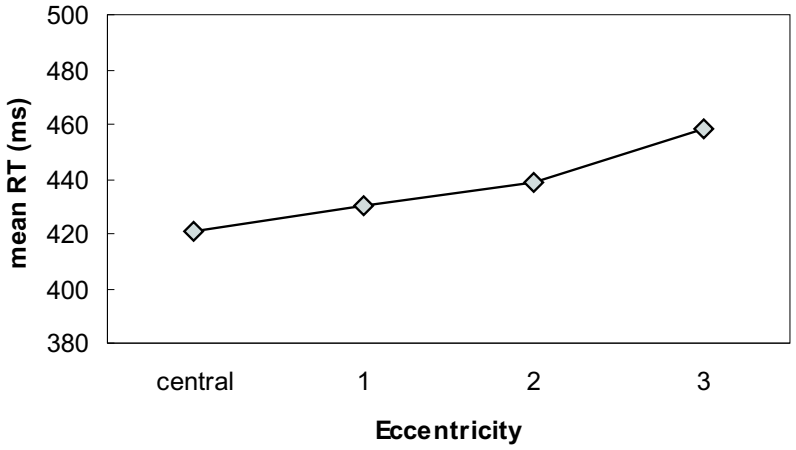

Fig. 2.6: Mean reaction times (RT in ms) for all target location eccentricities (relative to the center of the display).

of half-field change ($[F(1,11) = .678; p = .428, n.s.]$), that is, a change of the half-field relative to a preceding trial did not influence target detection times in current trials. Further, no interaction between the factors half-field change (change vs. no change) and change of the target-defining dimension (change vs. no change) across trials was found ($[F(1,11) = 11.367; p = .06, n.s.]$).

2.2.3 Discussion

In a simple visual search for dimensionally defined targets changing their dimensional definition unpredictably across trials, detection of a target was expedited when it was preceded by a target defined in the same dimension. Thus, there was a clear dimension-specific intertrial effect consistent with previous studies reporting inter-

trial facilitation in feature search with variable target definitions (e.g. Müller et al., 1995; Found & Müller, 1996). Further, target detection was slowed with increasing distances between target locations in consecutive trials. Interestingly, RTs were not fastest when the target in a given trial appeared at the same location as in the previous display. Rather, targets in locations adjacent to the preceding target position were detected fastest. One possible mechanism underlying this pattern of results is inhibition of return (IOR) of the just inspected item location (Klein, 1988; Klein, 2000; Müller & von Mühlenen, 2000;see section 2.3.3 below for further discussion of this issue).

There is evidence in the literature indicating priming effects of target location in feature search. Maljkovic & Nakayama (1996) found facilitation of target detection when the location of a target was repeated in consecutive trials. Effects of eccentricity have already been reported for feature search. Carrasco (1995) attributed the effect that targets near fixation were found more efficiently than targets located peripherally to an attentional bias which allocates attention preferentially to central items. This interpretation was challenged, however, by Wolfe et al. (1998), who replicated Carrasco et al.'s findings but argued that eccentricity effects might be a result of the observers' strategy to search from central locations (near fixation) towards more eccentric locations.

The third factor of potential influence on search performance investigated in Experiment 1, namely the target's half-field position was found to affect RTs only

within a given trial. Targets presented in the left half of the display were detected more rapidly than those appearing in the right half-field. This result might be due to a general bias in the observers' search strategy with a tendency to start search in the upper left quadrant of a display (similar to reading a text from a page). In contrast, a change of target position across the vertical meridian, that is, a change of halffield position from a trial *N-1* to a trial *N* in subsequent trials did not affect RTs and there was no interaction with dimensional change effects. However, both effects were independent of whether the target location changed within one display half-field or whether a location change comprised a half-field change. Also, there was no interaction between target location distance and change of the target-defining dimension across consecutive trials.

Targets defined by colour (red, vertical items) were detected faster than targets defined by orientation (45° right-tilted, green items). With respect to dimension-specific processing, differences between the colour and orientation dimension have been reported in the literature. Müller et al. (1995) found feature-based intertrial facilitation for targets defined within the colour dimension but not for orientation-defined targets. This result was replicated by Found & Müller (1996). Found and Müller argued that colour is a 'special dimension' in the sense that the three primary colours (red, green, and blue) might be processed by specialized 'sub-dimensions' of the colour dimension allowing for even faster detection of colour features compared to other basic features.

In summery, in a simple efficient visual search for a target differing from distractors in a single salient feature changing unpredictably across trials, the spatial location of targets had only little influence on detection efficiency. Targets located in the left half-field were detected faster relative to those presented in right field, and, targets located close to the centre of the display were processed faster than those located in the periphery of the display. In subsequent trials, detection of targets located adjacent to the target's previous position was expedited. A change of the half-field containing the target did not influence RTs. However, the dimension-based inter-trial effects reported in the literature (Müller et al., 1995; Found & Müller, 1996) remained unaffected of spatial characteristics of the targets.

2.3 Experiment 2: Visual search for compound targets

In Experiment 1, dimension-specific intertrial facilitation appeared to be largely independent of the spatial location of the target within the search display. Although target detection was slowed by greater distances between target locations in subsequent trials, dimensional change or repetition effects remained unaffected.

In a second experiment, again the visual search paradigm was used. However, compared to Experiment 1, the observers' task comprised two components: they first searched for a unique (target) item in an array of homogeneous distractors (*target detection*); having found the target stimulus, they decided on the position (top or bottom) of a small gap within the target item (*response feature discrimination*). A target was defined by either its colour or by its orientation, and, in a block of trials, the target-defining dimension changed unpredictably across trials. As in Experiment 1, target locations of consecutive trials changed with targets presented at either the same location, or translated by 1 to 3 cells (of the virtual display matrix) within or across half-fields. According to the position, top or bottom, of the gap within the target stimulus, the response was indicated with the index finger of the right or left hand, respectively. Thus, in consecutive trials, a change in target configuration (gap position) could be accompanied by a change of response hand.

2.3.1 Method

Participants. 12 observers (3 male), all students at Ludwig-Maximilians-University Munich with a mean age of 28.3 years (age range of 21 to 44 years) participated as paid volunteers or in partial fulfillment of an undergraduate psychology course requirement. All participants reported normal or corrected-to-normal visual acuity. None of them showed deficits in perceiving colours in a screening test (Ishihara Colour Test, Ishihara, 1917).

Stimuli. Participants searched for a single red vertical bar (colour-defined target) or a single green, tilted bar (45° tilted to the right, orientation-defined target) amongst green vertical distractor bars. All bars had one small gap in their lower or upper part (resembling an upright or inverted exclamation mark, respectively, see Figure 2.7). The colours red (VGA RGB values: 255,0,0) and green (RGB values: 0,248,0) were matched for luminance (3.8 cd/m^2). The screen background was black.

As in Experiment 1, a display consisted of 100 items arranged in a virtual square 10 x 10 matrix with targets presented only in the inner 8x8 cells (observes were not informed of this restriction). The size of an individual bar was 0.2° in width and 1.0° in height of visual angle including the gap; the gap was a 0.1° in width and 0.2° in height located at the top or bottom end of the bar, respectively, through which the background was visible. Distance between individual items was slightly jittered (0.5° to 1.0° of visual angle in any direction).

Apparatus. The experimental setting and material were similar to Experiment I.

Design & Procedure. As in Experiment 1, there were four experimental conditions: [1] *display type* (target-absent, target-present), [2] *target dimension* (colour, orientation), [3] (target) *half-field position* (left, right), and, [4] *distance of the target locations* in trial *N* relative to the location of the target in the previous trial *N-1* [same position, neighbouring position, and, 1 to 3 location distances (gap 1-3)]. All the trials of Experiment 2 were 'target-present' trials and the number trials with a colour or an orientation target was equal. In 50 % of all trials the target was located in the right or in the left half-field, respectively.

The procedure was similar to that of Experiment 1, except for the following changes: Participants performed a search for a pop-out target defined by color (red) or orientation (45° right-tilted). Other than in experiment 1, the observer's task was not to detect the presence or absence of the target only, but to discriminate the position of a small gap in the object (located in the upper or lower half of the bar stimulus). A response was given by pressing the right mouse button with their right and the left button with their left index finger if the gap was in the upper and lower half of the bar stimulus, respectively . A gap was also present in each of the distractor elements with an equal proportion of upper- and lower-half gaps randomly assigned to distractor items.

Similar to the procedure of Experiment 1, hand-response mapping was balanced across sessions and subjects: six observers responded with the index finger of the

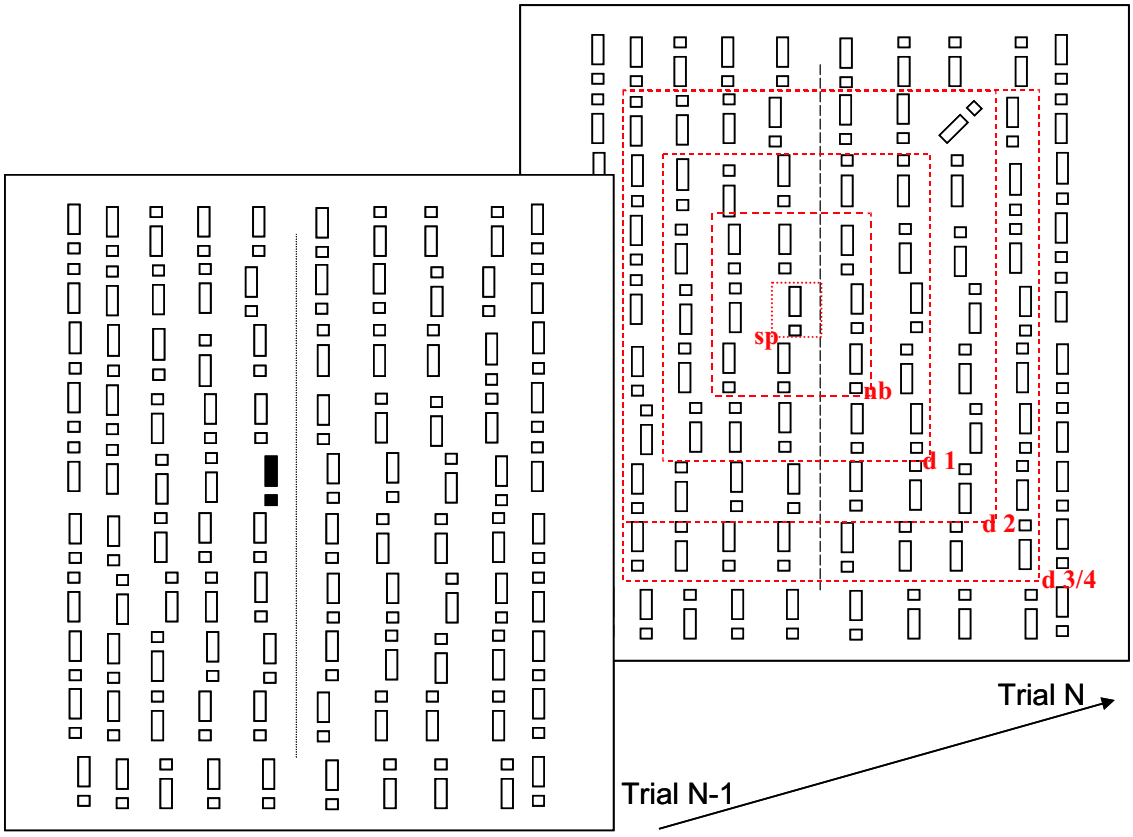

Fig. 2.7: Schematic illustration of a trial sequence shown in Experiment II: A colour target in trial *N-1* is followed by an oriented target in trial *N*. Spatial relation (distance) between targets is indicated by red dotted lines (sp= same position, d1 to d4= distances 1 to 4). Note that the vertical lines indicating the two halffields of the display were not present in the experiment.

right hand if the gap was located in the upper half of the item and with the left index finger if the gap was in the lower part of the target stimulus in sessions 1 and 3, the reverse gap-position to response hand association was used in sessions 2 and 4. The remaining six participants performed the sessions in reverse order. In total, observers took part in four consecutive sessions and performed 8 blocks of trials comprising 84 trials each. The total number of trials was 2688 which took approximately 90 minutes to complete.

2.3.2 Results

As in Experiment 1, only trials that had been responded to correctly, or, for the intertrial analysis, sequences of correct-response trials were included in the reaction time (RT) analyses. Likewise, RTs were restricted to the range between 200 ms and 1000 ms, RTs faster or slower than the lower or upper limits were excluded from analysis as 'outliers' (3.7% of all trials). Mean overall error rate was 3.9%.

RT analysis. The overall mean RT in Experiment 2 was 636 ms. Colour-defined targets (red: 634 ms) were detected faster on average than orientation-defined targets (right-tilted: 652 ms). A paired-samples t-test revealed the difference (18 ms) to be significant $[t(ll) = -4.24; p < .01]$. There was no RT difference with respect to the target's half-field (635 ms and 637 ms to targets located in the left and right hemi-field, respectively).

RT intertrial analysis .

In order to examine intertrial transition effects, an analysis of variance (ANOVA) with repeated measures was conducted with the factors *intertrial transition* (colour–colour, orientation–colour, orientation–orientation, colour–orientation), *half-field change* (no change, change) and *target location distance* (location translations of 1, 2, and 3 cells relative to the target location in the preceding trial). (Same position repetitions were excluded from analysis because they occurred only if the target did not change its half-field.)

The results revealed two main effects to be significant: intertrial transition [$F(3, 33) = 17.79; p < .01$] and distance [$F(3, 33) = 69.30; p < .01$]. In addition, the interaction between the factors half-field change and target location distance was significant ([$F(2.3, 26) = 21.14; p < .01$], Greenhouse-Geisser corrected df). This is illustrated in Figure 2.8.

Inter-trial transition: Target dimension. The main effect of inter-trial transition of the target-defining dimension from trial *N-1* to trial *N* [$F(3, 9) = 10.05; p = .001$] was due to faster RTs to targets preceded by same-dimension relative to different-dimension trials [637 ms vs. 648 ms, (see Figure 2.9). Fastest RTs were found if colour-defined targets were presented in two subsequent trials. Detection of an orientation-defined target preceded by a colour target was slowest. A paired-samples t-test comparing the two dimension change conditions (no change vs. change) re-

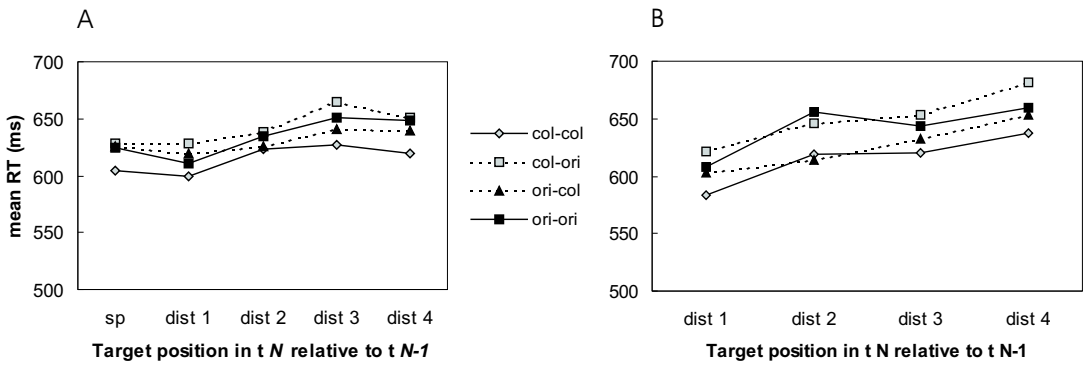

Fig. 2.8: Mean reaction times (ms) to four possible dimension transitions from trial N-l to trial N (col-col: colour to colour; col-ori: colour to orientation; ori-col: orientation to colour, and ori-ori: orientation to orientation) plotted separately for the various target distances (target position in trial N relative to target position in trial N-l: sp= same position; dist 1-4= distance 1-4). **Panel A** shows RTs for trials *not* preceded by a halffield change; **Panel B** displays RTs for trials accompanied by a halffield change of target position.

vealed the difference to be significant $[t(ll) = -4,45; p < .01]$. Thus, dimension-based intertrial facilitation was found in the compound task.

Target location distance. Overall, there was a monotone increase in RTs with increasing distance between targets in subsequent trials $[F(4,44) = 83.166; p < .01]$. The only exceptions were the two smallest distances: RTs to locations translation of distance 1 (neighbouring position relative to the target of the preceding trial) were fastest (609 ms), followed by RTs to trials in which target position was repeated (same position, 621 ms). Slowest RTs were found for targets with the most distant locations relative to the target location in the previous trial (distance 4, 649 ms).

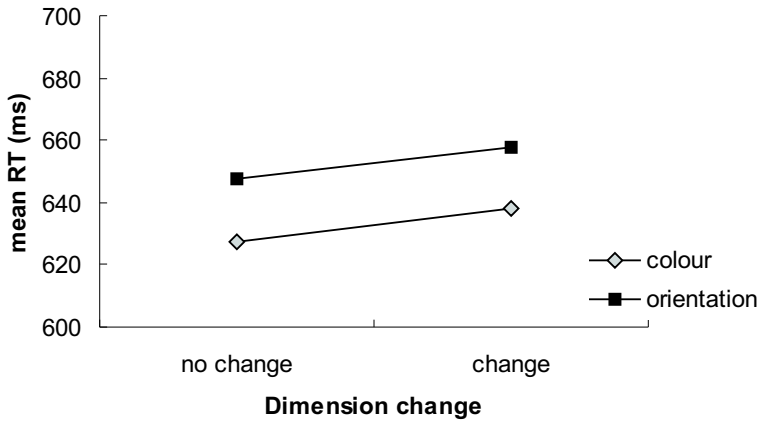

Fig. 2.9: Mean reaction times (RT) in milliseconds (ms) to no change vs. change of the target-defining dimension from trial *N-l* to trial *N* plotted separately for colour- and orientation-defined targets.

Post-hoc paired-samples t-tests revealed significant RT differences between all distance levels. Figure 2.10 illustrates the results.

Interaction of target distance and halffield change. Despite the fact, that there was no effect if RTs on a given trial *N* were analyzed with respect to the half-field position of a target, there was a significant interaction of whether there was change vs. no change of a target's *half-field position* across trials with *target distance*. As depicted in Figure 2.11, RTs are expedited by a half-field change (relative to the no change of half-field condition) when subsequent targets are located close to each other (distance level 1, that is, the neighbouring position relative to the target location of the previous trial). This might be due to effects of eccentricity that are

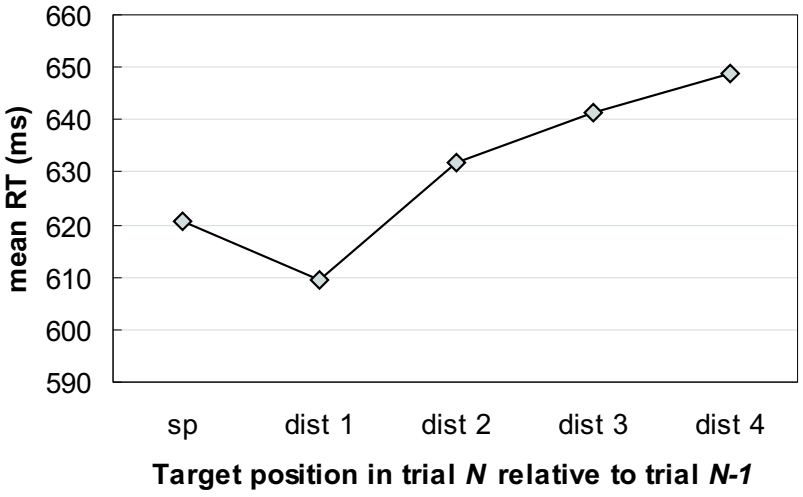

Fig. 2.10: Mean correct reaction times (RTs in ms) to targets in trial N by target location distance relative to the target location in the previous trial N-l (sp= same position, dist 1-4 = location translation distances 1 to 4).

inherent to the experimental design and difficult to avoid: A pair of targets located close to each other in consecutive trials but, and, in addition, placed in two different half-fields was always also located near the horizontal center of the display. In contrast, location distance 3 (a translation of 3 cells of target location in consecutive trials) always involved at least the target item in one of two consecutive trials to be in the (relative) periphery. Trials involving a half-field change of the target location showed a greater increase in RTs than trials without an accompanying half-field change. Thus, with increasing target location distances (especially with distance 3), the facilitatory effect of a half-field change is inverted and RTs are slowed when associated with a half-field change compared to targets located at a similar distance

but within one and the same half-field.

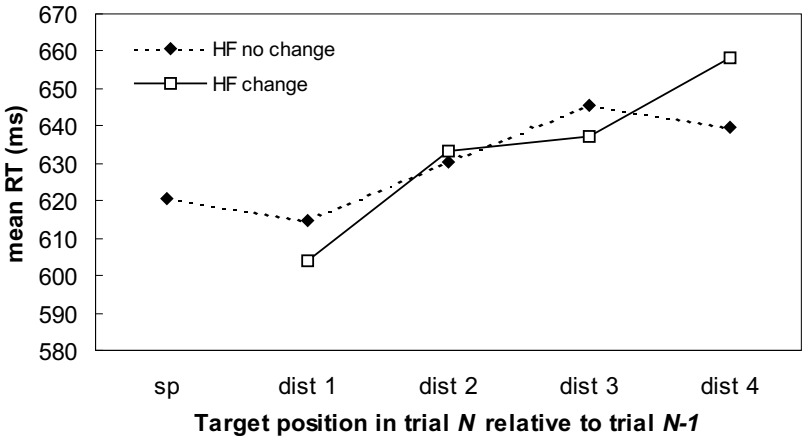

Fig. 2.11: Mean correct reaction times (RTs in ms) to targets in trial N plotted for the various target location distances relative to the target location in the previous trial N-l (sp= same position, dist 1-4 - distance 1 to 4) separately plotted for the conditions half-field change vs. no change.

To test the influence of eccentricity, an ANOVA was conducted with the factors *half-field change* (no change vs. change), *hand change* (no change vs. change), *dimension change* (no change vs. change) and *eccentricity* (center, 1, 2 and 3). The main effect of eccentricity was statistically significant $[F(3, 33) = 168.993; p < .01]$, however, none of the interactions of eccentricity with any of the other factors was significant(half-field change:$[F(3, 33) = 2.101; p = .119, n.s.]$, hand change $[F(3, 33) = 2.538; p = .073, n.s.]$, and dimension change: $[F(3, 33) = 2.727; p = .060, n.s.]$). Thus, targets located close to the midpoint of the display (center eccen-

tricity and 1) were detected faster than more peripherally presented targets (eccentricity 2 and 3). However, this did not affect intertrial effects of half-field position, response hand, and target dimension.

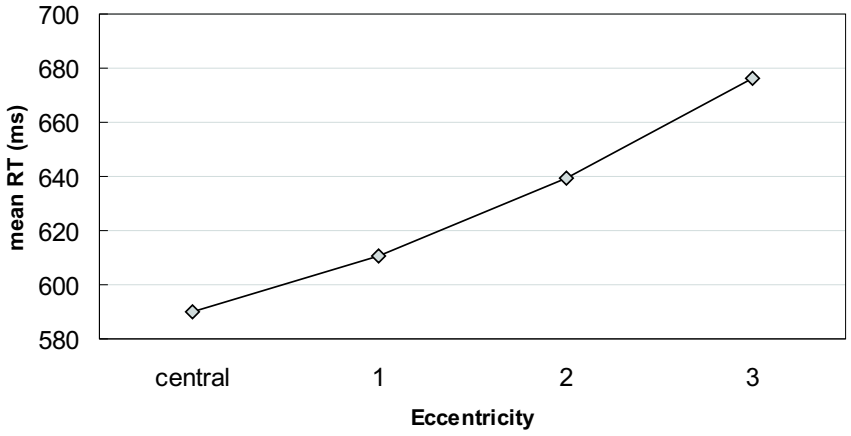

Fig. 2.12: Mean correct reaction times (RTs in ms) to targets shown at central position of the display (central) and to targets with increasing distance from the center (eccentricity 1 to 3)

Response hand. Other than in Experiment 1, the task required observers not only to search for a pop-out stimulus but also to discriminate and indicate the location of a gap within the (upper or lower part of the) target item. The response was given by pressing the left or right mouse button according to the task instructions. Thus, the configuration of a given target (gap position) indicated the hand with which to respond. Stimulus-response mapping was counter-balanced across exper-

imental sessions. However, within sessions, the mapping was consistent such that, for example, observers responded with the left to a gap in the lower and the right hand to gap in the upper half of the target object throughout an entire session and in reversed order in a different session. If, in a sequence of trials, there was change of target configuration (e.g., from a gap in the lower half in trial *N-1* to a gap in the upper half of the object in trial N), the response hand also changed.

In order to examine potential effects of response hand in a given trial N, an ANOVA with the factors (1) *half-field position* (left, right), (2) *response hand* (left, right), and (3) *target dimension* (orientation, colour) was conducted. There was a single main effect, for target dimension, $[F(l, ll) = 17.06; p = .002]$, that reached statistical significance. The significant effect was due to faster detection of colour-defined compared to orientation-defined targets (s. above, 2.3.2).

In a subsequent analysis, to explore similar effects but in terms of intertrial transitions, an ANOVA with the factors (1) *change of response hand* (no change, change), (2) *dimension change* (no change, change) and (3) *half-field change* (no change, change) was conducted. The results revealed main effects of all three factors ($[F(1, 11) = 21.306; p < .01]$; $[F(1, 11) = 42.966; p < .01]$; $[F(1, 11) = 6.949; p = .023]$, respectively) and, in addition, a significant interaction between the factors response hand change and dimension change ($[F(1, 11) = 136.321; p < .01]$).

Interestingly, the main effect for the factor change vs. no change of response hand was significant $[F(l, ll) = 21.30; p = .001]$. There was a marked increase in RTs

associated with a change of response hand from trial *N-1* to trial*N* relative to the use of the same hand in subsequent trials (662 ms vs. 639 ms, respectively).

Further, a significant interaction was found between the factors dimension change and change of response hand [$F(l, ll) = 136.32; p = .000$]. While the typical dimension-change cost (of 26 ms) was manifest, if the response hand remained the same in two consecutive trials (no change), a change of the response hand was not only associated with no dimension change costs, but rather a RT advantage (of 11 ms, see Figure 2.13).

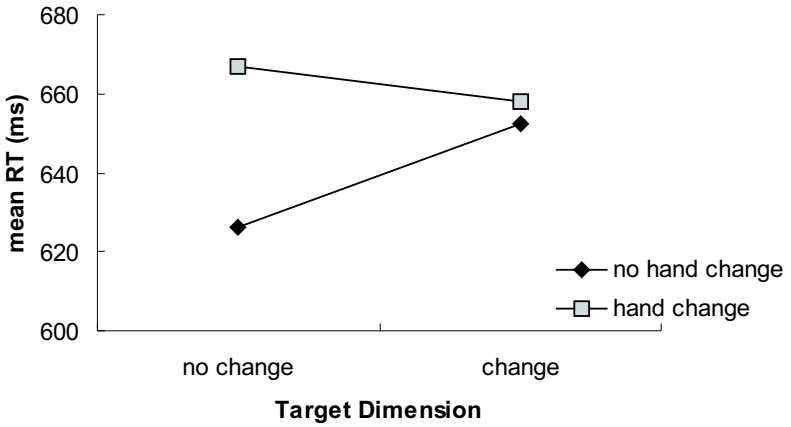

Fig. 2.13: Mean reaction times (RT) for the no change versus change of target-defining dimension conditions from trial *N-1* to trial *N* plotted separately for the no hand change and hand change conditions.

2.3.3 Discussion

To summarize, main effects were found for intertrial transitions of the target-defining dimension and the target location distance between targets presented in subsequent trials; that is, a change of the target-defining dimension was associated with RT costs, and, RTs were slower with increasing distances between target locations translations from trial *N-1* to trial *N*. Further, two interactions reached statistical significance: Firstly, if the half-field changed in consecutive trials, targets presented at locations (in trial *N*) neighbouring the location of the target in the preceding trial (*N-1*) were detected faster, with increasing distances, however, there were RT cost associated with a half-field change. Secondly, a change in the target-defining dimension across trials reduced the RT costs observed in connection with a change of the response hand. The hand change cost was only present if the target dimension remained constant across two consecutive trials.

Dimension based intertrial facilitation in a compound task

In contrast to Kumada (2001), a dimension-specific intertrial effect was observed in both tasks, feature search in Experiment 1 and compound search in Experiment 2. However, intertrial facilitation in the compound search task was found to be substantially reduced compared to the feature search (11 ms vs. 30 ms, respectively).

This difference could, in part, be attributed to an effect of response hand: a change of response hand in subsequent trials modulated the effect of slowed or speeded RTs

associated with a change or, respectively, no change of the target-defining dimension.

Interaction dimension change and response hand The task in Experiment 2 required observers to perform two separate operations: In order to solve the task, they first searched for a singleton (i.e., an odd-one-out) target either defined by colour or orientation amongst distractor items. Having found the target, they subsequently reported its specific (spatial) configuration (gap in the upper or lower half) by pressing a pre-defined response button with the left or right hand. Thus, target dimension and response (hand) were not confounded, that is, the dimensional definition of the target provided no information concerning the response (hand).

Within a given trial *N*, there was no difference between RTs for either hand. Further, no interaction between response hand and the target's half-field or dimensional definition was observed. However, an inter-trial analysis revealed an interaction between dimension change and the change of response hand in consecutive trials: if the target dimension remains the same in trials *N-1* and *N*, there is a strong effect of hand change. That is, RTs are faster when there is no change in response hand than if there is a change. In contrast, a change of the target defining dimension results in a strongly reduced hand change effect, so that there is no longer any difference between RTs for changed vs. unchanged response hands. Where, i.e., at what processing stage, does this interaction arise? If, in a given trial, a singleton target is detected (and responded to with one hand), dimensional weight is allocated accordingly to the target-defining dimension. In the subsequent trial, the persist-

ing weight pattern modulates the detection of the compound target defined either within the same or a different dimension. However, only after the search process has been completed, target discrimination allows to decide on the specific configuration of the stimulus and hereby to select the appropriate response (hand).

When observers search for the singleton target item, the two possible, response-relevant, configurations of the target item (and thus the two response hands) are equally probable (gap in the lower or upper part of the target bar). Kingstone & Klein (1991) found that targets appearing at an uncued location were responded to slower when their shape corresponded to the shape that was expected at the previously cued position. To explain these slowed RTs, the authors proposed a *hierarchical processing hypothesis* which states that the more rapidly resolved expectancy (in their case target location rather than shape) is the controlling factor of the RT inhibition effect. That is, target position is resolved faster than shape and therefore, confirmation or disconfirmation of the position expectancy influences the attentional weight placed on a shape expectancy. Similar inhibition effects were observed for expectancies for target colour and shape as well as target onset time and shape (Kingstone, 1992).

Given that, in the present Experiment 2, observers expected target-defining dimension and response hand to remain constant rather than to change across trials, it appears that, the disconfirmation of the expected target dimension diminished/abolished any expectancy for the response hand. That is, the disconfirma-

tion of one expectancy in earlier stages of information processing in a trial (the perception-related target-defining dimension) renders the expectancy for the hand to be used irrelevant.

Intertrial effect of the distance of target translation

A main effect of the distance of target translation was found in both experiments with the fastest RT manifest, if targets in consecutive trials appeared at neighbouring locations (relative to the target location in the preceding trial) and slowest detection times were observed if the distance between target locations in subsequent trials was maximal (distance 3). Thus, there was a monotone increase of RTs with greater distance except for the first two distance levels. Interestingly, in contrast to expectation, a repetition of target position did not result in fastest target detection. Similar results have been reported in the literature on the orienting of attention, e.g., in slowed responses to targets appearing at a location previously occupied by a target or cue (Posner et al., 1982; Posner et al., 1985; Klein, 2000). Typically, this so-called *inhibition of return (IOR)* is observed using a cuing paradigm in which a cue and a target are presented successively and response times to the target are measured. With a short stimulus onset asynchrony (SOA) between cue and target (shorter than 300 ms) facilitation of target detection is observed whereas longer SOAs entail prolonged response times, i.e., IOR (Lupianez, 1997; Posner & Cohen, 1984). It has been proposed that the function of IOR is to facilitate visual search by inhibiting orienting to previously searched locations. IOR has not yet been observed

(or investigated) within the methodological framework of intertrial analyses. However, as in the present experiment the inter-trial interval was 400 ms, the pattern of distance effects falls in the time range in which IOR is frequently observed.

Experiments 1 vs 2: feature search vs. compound search

The main difference between Experiments 2 and 1 was the overall RT. Not surprisingly, to find *and* discriminate a target took longer than to simple detect a target (636 ms vs. 423 ms, respectively). Other than in Experiment 1, in the compound task of Experiment 2, a change of half-fields across subsequent trials slowed RTs when the distance of the target translation was large relative to when targets were presented at locations close to location of the target in the previous trial. Thus, while in feature search there was an influence of distance of target detection but the half-field change had no effect, in a task in which spatial focused attention needs to be directed to the target item in order to identify the specific position of the small gap, half-field change do seem to play a role. However, in both tasks, a dimension-based intertrial RT effect was observed. In feature search, it was independent of spatial aspects of the display, whereas in a compound task there was an overall reduction of the effect and an interaction with response hand change was evident.

3 Effects of numerical and Dimension-based redundancy: Evidence from neglect patients, healthy elderly and young observers

3.1 Introduction

Although neglect can affect all sensory modalities, the visual domain has been most extensively investigated. One of the procedures shown to be especially sensitive in revealing visual neglect is the visual search of patients. Despite the obvious difficulties associated with the combination of findings from investigations into as heterogeneous a disorder as neglect into one coherent picture (mainly due to the variability of cortical lesion sites and the problems involved in precisely assessing the extent of the lesion), neglect patients do show common characteristic deficits in visual search performance (e.g. Sprenger et al., 2002).

3.1.1 Visual search performance and neglect

The visual search paradigm has been widely used over the past decades as a source of insights into the mechanisms of visual processing and, especially, the role of attention on the various levels of the processing hierarchy. Based on a sound theoretical underpinning (e.g. Treisman & Gelade, 1980), visual search has become increasingly attractive for researchers examining patients with various neuropsychological deficits.

Two main types of visual search have emerged: search for a target item differing from distractor items in a single basic feature (feature search) and search for a target item defined by a unique combination, or conjunction, of two (or more) features amongst distractors also defined by feature combinations. Feature search is

fast with RTs independent of the number of distractor elements in the display and is assumed to be independent of capacity-limited focused attention. In contrast, conjunction search is more demanding in terms of capacity with, RTs increasing with an increasing number of distractor items in the search display and performance is limited by the serial allocation of attention to each display item (e.g. Wolfe et al., 1994).

One of the cardinal symptoms of patients suffering from hemi-spatial neglect is their inability to voluntarily direct their attention to the contra-lesional visual half-field, it has been hypothesized that processes of pre-attentive feature search might be intact in neglect patients whereas conjunction search, dependent on processes of attentional deployment, might be impaired (Esterman, McGlinchey-Berroth & Milberg, 2000). However, the role of attention in feature search is currently a matter of debate and theoretical development is highly likely to affect accounts of potential effects of impaired attentional control in visual spatial neglect (see Behrmann et al., 2004 for a review of the current debate). While some authors (e.g. Riddoch & Humphreys, 1987; Eglin et al.,1989; 1991), or more recently Pavlovskaya et al. (2002) reported slowed RT and/or increased error rates in search for feature targets in the contra-lesional hemi-field in neglect patients, others (Arguin & Bub, 1993; Aglioti et al., 1997; Esterman et al., 2000) found that performance in feature search tasks was not impaired. (Behrmann et al. (2004) compiled a list of potential factors contributing to the discrepancy between findings.)

Almost all of the studies mentioned above used the approach traditionally taken in assessing search performance, namely the comparison of various search conditions averaged across trials. Recent studies, however, show that search performance in a given trial N is affected by the (dimensional) definition of the target in the previous trial N-1 (e.g., Maljkovic & Nakayama, 1994, 1996, 2000; Found & Müller, 1996). These effects are referred to as (dimension-based) 'intertrial effects' and have been taken as the basis of a Dimension Weighting Model of visual search (Müller et al., 1995). Analyses of intertrial effects (e.g., search performance in trial N dependent on whether the target in a given trial N-1 was presented within the same or different hemi-fields) might provide and additional powerful and sensitive analysis tool for investigations into the search performance of neglect patients.

There is growing evidence that stimuli presented in the contra-lesional, impaired, visual half-field receive considerable processing (even if patients are not able to consciously reported them) and can influence the response to another item the patient is aware of (Marzi et al., 1996; McGlinchy-Berroth et al., 1993; Driver et al., 1992).

However, less is known about how the mechanisms involved in the processing of stimuli presented in the impaired contra-lesional field in neglect patients are affected by the intertrial history and how effects commonly observed in healthy observes relate to patient performance. In visual pop-out search with the target-defining dimension varying on a trial-by-trial basis, normal observers show dimension-specific facilitation (i.e., expedited RTs) if the target dimension in a given trial N is defined

on the same dimension as the target of the preceding trial (Found & Müller, 1996; Müller et al., 1995; Treisman, 1988).

3.1.2 Redundant information and search performance

In visual search, performance, i.e., search RT, can be also influenced by the amount of information provided within a given trial. Detection of two target signals, e.g., an auditory and a visual signal presented within the same trial, is expedited relative to a single target signal, e.g., single auditory or a visual signal. Expedited RTs to multiple, and thus, redundant signals, are referred to as the redundant signals effect (RSE) and the effect has been explained either by a parallel race model (Raab, 1962) or by co-active effects of the two target signals on an ensuing processing stage (Miller, 1982). To test between the two accounts if a redundant signals advantage, or a RT redundancy gain has been observed, Miller (1982) demonstrated that the following a race model inequality [$P(RT < t|T1 \,\&\, T2) = P(RT < t|T1) + P(RT < t|T2)$] must not be violated for a race model to hold; violations of the race model inequality, on the other hand, are indicative for coactive processing. In other words, applied to the entire distributions of RTs to single and redundant targets, if target signal are processed in (serial) race, the inequality requires that the fastest RTs to redundant target displays should be no faster than RTs to single targets; violations of the inequality, however, constitute evidence against a race model and are taken to indicate coactive processing.

In pop-out feature search, the target differs from distractor items in one salient feature. Target items, e.g., a red vertical bar, can rapidly be discerned from distractor items, e.g., an array of green vertical bars. RTs in this type of search task are independent of the number of items in the search display, i.e., there is no increase in RTs with an increasing number of display items. Thus, a single feature that defines a particular target on a given trial suffices to generate very fast responses times. However, in a condition with targets redundantly defined by two (or more) dimensional signals (e.g. a red horizontal bar among green vertical bars) RTs are expedited relative to conditions with targets defined only in one of the two dimensions, i.e., color only, or orientation only. Further, the RT redundancy gains have been shown to be based on coactive processing of dimensional signals, that is, there were violations of Miller's race model inequality (RMI). RT redundancy gains and violations of the RMI were also evident if the two dimensional signals were presented at different display locations using dual targets. Further, RT redundancy gains were also observed, if dual targets were redundantly defined within a dimension, (a red and a blue target); however, in these conditions there were no violations of the RMI, that is, processing of multiple signals within dimensions does not give raise to coactive processing. To summarize, popout search for singleton targets multiply defined on different dimensions is based on coactive processing even if the target signals arise from different locations in the display (Krummenacher, Müller, & Heller, 2001; Krummenacher, Müller, & Heller, 2002a).

Marzi and colleagues (Marzi et al., 1996) used the redundant signals framework to investigate potential effects of implicit stimulus processing in patients with unilateral extinction. Extinction refers to a deficit in patients to report a contra-lesional stimulus in the presence of an ipsi-lesional item with unimpaired detection of a single stimulus on either side. In one search condition, a briefly flashed light stimulus was presented to either the left or the right visual hemi-field, in another condition, two stimuli were presented simultaneously, one to the left and one to the right hemi-field. The observers' task was to report the number of objects displayed and the location(s), i.e., left, right hemi-field, where the objects were presented. As expected, RTs were faster for bilateral, left and right, stimulation, if observers reported to having seen two stimuli. More interestingly, faster RTs were observed in trials in which the stimulus presented to the contra-lesional field was extinguished; i.e., only the stimulus of the ipsi-lesional field was reported. That is, despite consciously reporting a single flash of light while being presented with bilateral stimulation, RTs were speeded relative to trials with unilateral stimulation. In addition, the authors found evidence for coactivation underlying the RT redundancy gains in patients with extinction (Marzi et al., 1996).

However, Marzi and colleagues, in their studies, use a definition of redundancy gains based on the redundant signals effect (Raab, 1962) which is different from the (implicit) notion of (dimensional) redundancy gains proposed by Krummenacher and colleagues (Krummenacher et al., 2002a; see also Miller, 1982; and Mordkoff

& Yantis, 1991). Marzi et al.'s (1996) definition of redundancy gains refers to the number of objects presented in the visual field, it will be referred to as 'numerical redundancy gain' in the remainder of the present paper. Marzi's definition is contrasted to the 'dimensional redundancy gain' observed in Krummenacher et al.'s studies. The procedure developed by Krummenacher et al. (2002a) allows for a separate analysis of location-based and feature-based effects in redundant target processing.

A detailed investigation of the performance of single and dual redundantly defined targets in patients with neglect is very likely to provide new insights into the mechanisms involved in visual information processing in neglect patients.

3.1.3 Overview of the present study

In a visual search task, single and dual targets defined in one or in two different dimensions were either presented within one hemi-field (left *or* right) or in both hemi-fields (left *and* right). Experimental conditions resulted from the combination of three factors: (1) *display type* with the alternatives (a) no target, (b) single feature target, or (c) dual feature targets, (2) *target location* with (a) target in the left half-field, (b) right half-field, or (c) left & right half-field and (3) *target dimension* with (a) orientation target(s), (b) color target(s), or (c) orientation & color targets. Ten observers with visual neglect in the left hemi-field were asked to indicate, in a visual search task, the presence or absence of one or more target item(s) by a button press,

irrespective of whether displays contained single or dual targets and irrespective of the dimensional definition of the target(s).

Effects of target redundancy. The present experiment was designed to explore the effects, in patients with neglect, of the presentation of singly or redundantly defined colour and orientation targets to either the ipsi- or contra-lateral hemisphere or (simultaneously) to both hemi-fields. The main research focus of the study was whether neglect patients' search performance improves if they are presented with additional information in the form of numerical redundancy (single vs. dual targets) or dimensional redundancy (dimensionally singly vs. redundantly defined dual targets). If redundancy gains of (any manner) would be observed, a further question is, whether the effects of redundant target presentation are similar in both half-fields?

Previous work (Krummenacher, 2002a, 2002b) with healthy subjects showed RT benefits for single and dual redundant targets relative to targets defined in only one feature dimension (s. above). Since pre-attentive processing is assumed to be mainly intact in patients with neglect, it was expected to find results similar to healthy subjects within this population.

RT intertrial effects. Additionally, the design of the present experiment allows to test for the presence of dimension-based intertrial effects in the search performance of patients with neglect. As processing of contra-lesional stimuli is known to be impaired, this impairment might also affect the persistence of the weights generated

in the search process across trials. Based on evidence in the literature (Müller et al., 1995; Found & Müller, 1996) that the locus of the weighting process is at an early perceptual processing level and prior to allocation of spatial attention, intertrial effects are expected to be present in neglect patients.

In summary, the aim of this study was threefold: [1] to investigate visual search for dimensionally defined pop-out targets in patients with unilateral neglect, [2] to explore the effects of numerically and/or dimensionally redundantly defined target items on search performance in neglect patients, and [3] to examine dimension-based intertrial effects and the influence of the target half-field location in trial N-1 on performance in trial N. The question was whether redundant signals (numerical and/or dimensional redundancy) are beneficial to the participants' performance in a similar way as it has been shown in healthy participants as well as to explore the influence of stimulus definition across trials despite potentially impaired processing at early stages in patients.

3.1.4 Persistence of neglect

The neglect syndrome is commonly observed after damage to the right hemisphere of the brain and results in a pronounced deficit affecting both the perception and reaction to stimulation within the left side of space of a patient or an inability to initiate voluntary actions directed towards the left side of (external or bodily) space. Although spatial neglect is a transient phenomenon in most patients, a

proportion of patients suffers from symptoms of neglect for a period of more than three months and, in some of the patients, the condition persists. Linden (2005) tested 138 patients 20 months after they had suffered from a stroke in order to investigate the prevalence of visual neglect from a longer term perspective. 15 % of the patients examined showed neglect symptoms in a cancellation task, and more than half of the patients were classified as showing symptoms of severe neglect (see also Stone et al., 1992) . In this condition of chronic neglect, symptoms might not be as overtly observable as in the acute stage of the illness when patients tend to bump into objects to their left, orient to the right when approached from the left or eat food only from the right side of their plates. However, detailed examination does reveal more subtle deficits of stimulus processing within the left side of space (e.g. Heide & Kömpf, 1998; Sprenger et al., 2002).

Chronic neglect is more often found in patients with extensive lesions entailing impairment of several cognitive functions (Maguire & Ogden, 2002). In line with this, it has been argued that with an increasing number of deficits contributing to neglect , particularly spatially non-lateralized components, the condition is more severe and recovery is delayed (Robertson, 2001; Samuelsson, 2002; Husain & Rorden, 2003).

Thus, neglect, diagnosed at least three months after the onset of a stroke, is very likely to persist for an even longer period of time. Also, a patient might acquire strategies to compensate for the handicaps associated with neglect. However, the

spontaneous exploration of space is mainly affected and often is accompanied by reduced awareness of remaining deficits and, therefore, hard to compensate for by the patient themselves without external encouragement. Patients recruited for the present study were tested positive for neglect symptoms prior to their participation in the present experiment with a mean time interval of 5.6 months (with at time range from 0 to 20 months). However, all of the patients had presented with neglect symptoms for longer than at least 3 months after the onset of their illness. That is, the shortest interval between stroke onset and last testing for neglect was 3.5 months.

3.2 Methods

3.2.1 Participants

Experimental group: Neglect patients. Ten patients, three women and seven men, with symptoms of visual neglect in their left hemi-space at the time last tested participated in the visual search experiment. Their age ranged between 44 and 76 years (mean age was 63.2 years). All participants had been patients of the Universitätsklinikum Aachen and had agreed to take part in studies for research purposes. At the time of the examination, their brain lesions dated back 4 to 26 months. A summary of demographic and clinical characteristics of all patients is shown in Table 3.1. All participants gave their informed consent to take part in this experiment.

Table 3.1: Demographic and clinical characteristics of the participants.

PATIENT	*Age*	*Sex*	*Etiology*	*Lesion location*	*Months since lesion*	*Time since last testing*
1	76	F	Infarct (thromboembolism)	R t-p	6	10 d
2	45	M	Infarct (thromboembolism)	R f-t-p	19	300 d
3	78	M	Infarct (haemodynamic)	R t-p-o	17	540 d
4	71	F	Infarct (thromboembolism)	R t-p	12	0 d
5	70	F	Infarct (thromboembolism)	R f-t-p	26	600 d
6	72	M	Infarct (thromboembolism)	R f-t-p	4	1 d
7	48	M	Infarct (thromboembolism)	R f-t-p-o	9	75 d
8	44	M	Infarct (thromboembolism)	R f-t-p	22	8 d
9	68	M	Infarct (thromboembolism)	R	6	90 d
10	60	M	Infarct (haemorrhage)	R f-t	14	60 d

Note: **F**: female, **M**: male; **R**: right hemisphere lesion; **f**: frontal; **t**: temporal; **p**: parietal; **o**: occipital; **d**: days

Control Group I: Healthy age-matched controls. Thirteen observers, six women and seven men with no history of neurological disease, and ages similar to the sample of neglect patients (age range 45 to 79 years, mean age: 64.9 years) participated in the experiment as a control sample. Their vision was normal or corrected to normal. The participants were recruited by advertisement and received 8 Euro per hour for their participation.

Control Group II: Young healthy controls. Ten observers, nine of them female with an age range of 22 to 42 years (mean age = 29.1 years) participated in the experiment for payment or course credit. All of them were right-handed and reported correct or corrected to normal vision (including colour vision). Participants were paid at a rate of 8 Euro per hour (with the exception of those who received course credit).

3.2.2 Neuropsychological performance

All participants in the experimental group (i.e., the patients) had been tested positive for symptoms of neglect in at least one standard test of neglect during the acute phase (within 1 to 4 days after onset) as well as in the chronic phase [more than 3 months after the lesion (see Kerkhoff, 2004) of their illness. Only the results of the most recent tests are reported here. The time interval between the last test for neglect and the present experimental examination ranged between 0 days (i.e., testing was performed on the same day as the search experiment) and 20 months

(with a mean interval of 5.6 months). In the following, a short description of the tests applied is given.

The Neglect-Test (Fels & Geissner, 1996). This test battery uses various approaches to identify and characterize in detail symptoms of neglect in patients suffering from a brain lesion. The 17 subtests involve mainly 'paper and pencil' procedures (e.g., cancellation and copying tasks) but performance in every-day behaviour is also tested (e.g., reading a clock and coin sorting). The patient group performed the subtests listed below.

1. Letter, Star and Line Cancellation: A large number of different figures (letters, stars or lines) are randomly distributed on a A4- sized paper and all of them have to be cancelled out by the participant. The number of omissions to the left and/or right of the vertical midline is scored. Typically, neglect patients miss most of the items in the field contra-lateral to the brain hemisphere containing their lesion site.

2. Line bisection: Predefined lines with lengths of a minimum of 20 cm have to be marked at the location subjectively perceived to be the line's midpoint by the patients. Neglect patients tend to deviate from the objective midpoint to the contra-lesional part of the line.

3. Free Drawing: The task is to freely draw a figure or a clock. Neglect is manifested by distorted drawings, e.g. a human figure is drawn only partly with

one missing arm and one leg.

4. Clock test: The patient is asked to fill in the numbers and hands in a predefined, schematic clock face. Neglect patients often draw all numbers into one half of the clock face.

5. Article: The participant reads aloud from a standardized newspaper article. Words to the left margin of a column are often missed.

Test for Attentional Performance TAP (Zimmermann & Fimm, 1992). The TAP test battery was developed for the assessment of attentional deficits in patients with cerebral lesions taking into account the various aspects of attention. It comprises 12 sub-tests, most of the reaction time tasks of low complexity. Responses are indicated by a simple manual motor response. To test for neglect, patients performed the following TAP subtests: *'Visual Field Examination'*, *'Neglect'*, and *'Visual Scanning'*.

1. 'Visual Field Examination': The main purpose of the test is to provide a coarse assessment of the patient's visual field characteristics. Flickering numerals are presented at random locations in the central visual field for a maximum time of 3 seconds. Observers are asked to respond with a button press as fast as possible whenever they detect a stimulus.

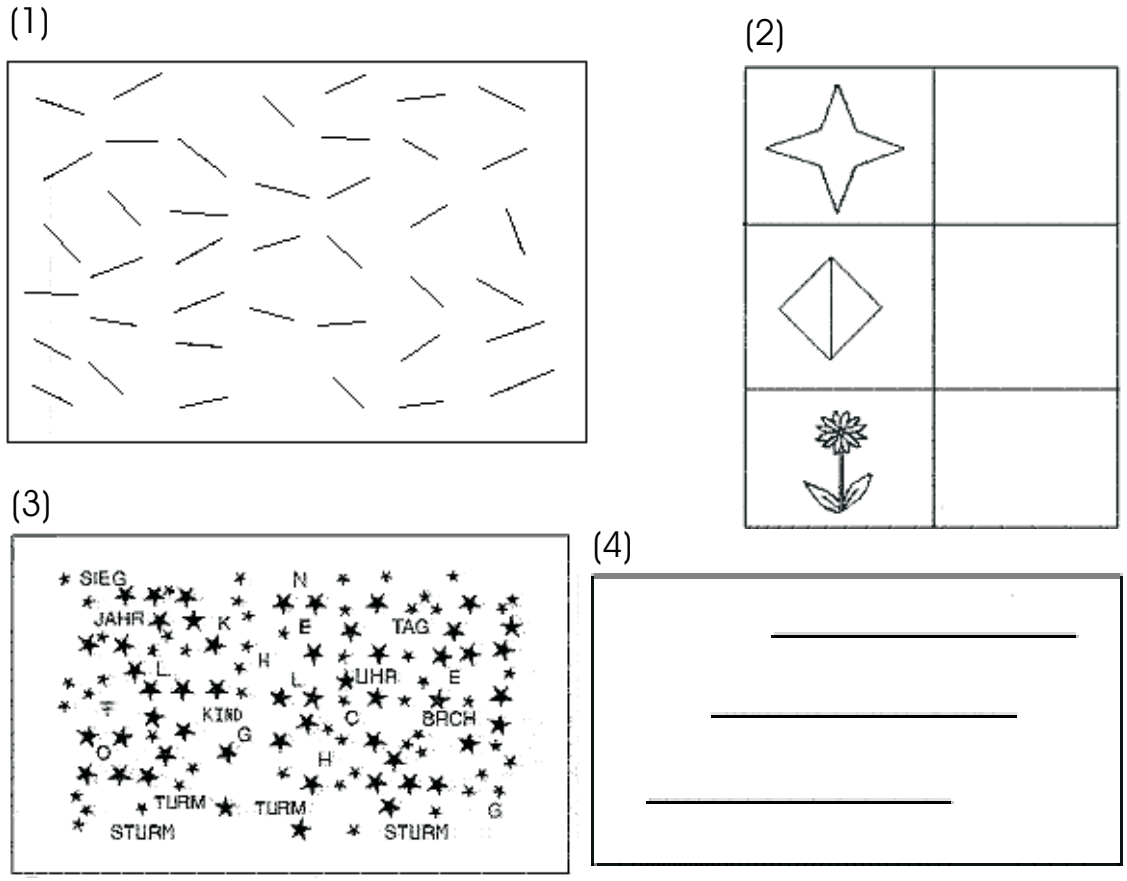

Fig. 3.1: Examples of the material used to test for neglect: (1) Line cancellation, (2) Copy task, (3) Star cancellation, and (4) Line bisection.

2. 'Neglect': The neglect test is a slightly altered version of the *Visual Field Examination test* with additional distractor items (numerals) presented in the four quadrants of the visual field allowing to discriminate between patients suffering from hemianopia and patients with neglect. While hemianopic patients are reliably unable to respond to stimuli presented in their blind field, neglect patients only exhibit a one-sided deficit for stimuli simultaneously presented in corresponding locations (i.e., quadrants) in the left and right visual fields.

3. 'Visual Scanning': This subtest investigates patients' capacity to actively scan the visual field. A target object, a square with a gap on the upper side, has to be detected in a 5 * 5 array of squares with gaps randomly located on any of the other sides. The test reveals the lack of a systematic scanning strategy typical of neglect patients.

The results of the neuropsychological examination for each of the patients are summarized in Table 3.2 and 3.3. As can be seen, each participant in the patient group showed impaired performance in at least on subtest of the 'Neglect Test' or the 'TAP'. The degree of impairment can be described as medium for participants 1, 3, 5, 7, and mild for the remaining patients who showed neglect like performance in not more than 2 subtests.

Table 3.2: Summary of patients' performance in the subtests selected from 'The Neglect-Test' (Fels & Geissner, 1996). Numbers indicate test scores within normal range (0) or a score indicating neglect (1); n. p.: not performed.

	SUBTEST						
PATIENT	*Line bisection*	*Star cancellation*	*Letters*	*Line cancellation*	*Article*	*Drawing*	*Clock*
1	1	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	0	0	0	0	1	1	1
4	0	0	0	0	1	0	n.p.
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	1
7	0	0	0	0	1	1	1
8	0	0	0	0	0	0	0
9	0	1	0	1	1	1	1
10	0	0	0	0	0	1	0

Table 3.3: Summary of patients' performance in the neglect tests from the TAP test battery (Zimmermann & Fimm, 1992). Numbers indicate test scores within normal range (0) or a score indicating performance outside the normal range (l); n. p.: not performed.

	SUBTEST		
PATIENT	***Visual field***	***Neglect***	***Visual scanning***
1	1	1	1
2	0	0	1
3	0	0	0
4	0	0	0
5	1	1	1
6	0	0	1
7	0	1	0
8	0	1	0
9	0	1	n.p.
10	0	0	0

3.2.3 Stimuli

Rectangular bars of approximately 1° visual angle in height and 0.25° in width served as stimuli and were presented in an array of 8 x 8 items forming the cells of a virtual matrix underlying the display. The complete stimulus array covered an area of 20° x 20° of visual angle. Green and vertically oriented bars always served as distractor (nontarget) items. Target items differed from distractors in a single basic feature either defined in the color dimension (red vertical or blue vertical bar) or the orientation dimension (green 45°-left-tilted or green 45°-right-tilted bar). In *target–absent* trials all matrix positions were occupied by green vertical distractors, in *target–present* trials one target (*single target condition*) or two target items (*dual target condition*) replaced one, or two, respectively, of the distractor items within

the inner 6 x 6 matrix. A single target could be defined either within the color or the orientation dimension. In the dual target condition, both targets were defined either in the same dimension (*dual target same dimension*) or each of dual targets was defined in different dimensions (*dual target different dimension*).

The location(s) of the target(s) within the search array was controlled. Target items could be presented in the left only, the right only or in both half-fields of the display. This resulted in the following target conditions: *display type [3]* (target-absent trials, single target (-present) trials and dual (-present) target trials); *target dimension [3]* (targets defined by orientation, colour, or, redundantly, by both colour and orientation compared to the distractor items), and *half-field [3]* (target(s) located on the left, the right or in both visual half-fields). A schematic illustration of experimental conditions is shown in Figure 3.2.

A complete experimental session comprised of 480 target-absent trials, 240 single orientation target trials, 240 single colour target trials, 60 dual orientation target trials, 60 dual colour target trials, and 120 dual target trials with one orientation-and one colour-defined target. Of these 1200 trials, in 320 trials target(s) were presented within the left half of the display, in 320 trials target(s) were presented in the right half and 80 trials consisted of two targets presented one in each hemi-field.

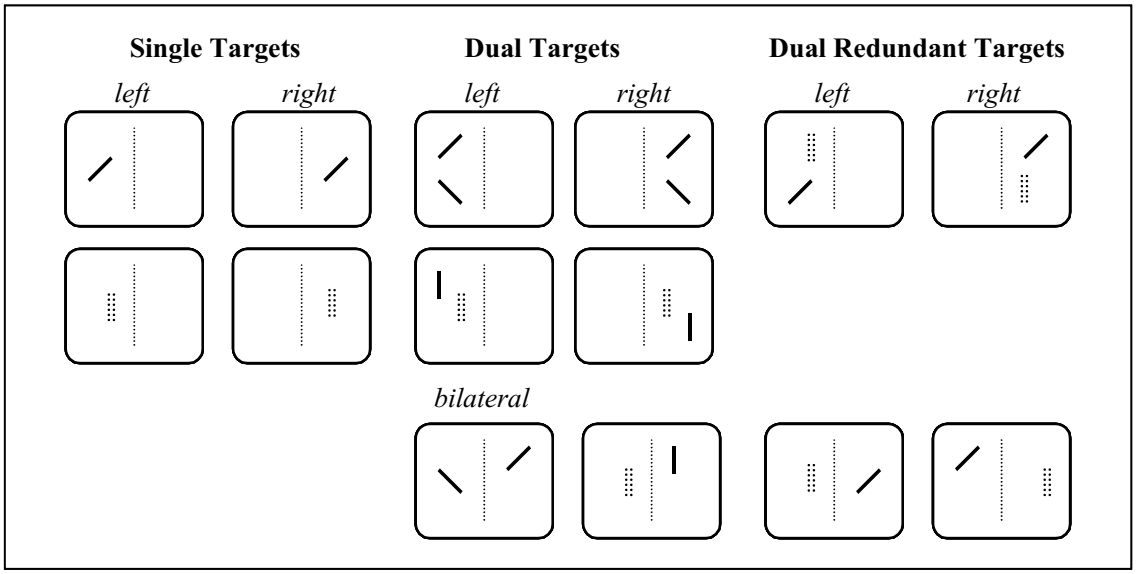

Fig. 3.2: Schematic illustration of target combinations and their position within half-fields of the display

3.2.4 Apparatus

Six of ten patients carried out the experiment in a room reserved for purposes of patient testing at the Universitätsklinikum Aachen. Four patients were tested at home due to the patient's restricted mobility. All participants were seated in front of a computer monitor at a distance of approximately 57 cm. Eye-screen distance was maintained throughout the experiment by the use of a chin rest. The computer was placed on a box of appropriate size so that the horizontal midline of the screen was on the level of the observer's eyes.

The room was dark except for a dim background light in order to allow for an optimal stimulus-to-background contrast and to avoid screen reflections. If patients

were tested at home, similar lighting conditions as those used in the clinic were aimed at. Stimuli were presented with a frame rate of 60 Hz on a 15" LCD color monitor controlled by a Pentium III Dell Laptop ('Latitude') computer.

All of the observers exhibited motor difficulties due to hemiparesis in their left hands (and arms). Therefore, all participants responded with two fingers of their right hand. Observers 1, 2 and 3 pressed the right or left button of a mouse with the middle or the index finger of their right hand, respectively, to indicate a response. All other participants used a SMI (SensoMotoric Instruments) input device pressing the left or right of two horizontally aligned buttons. This change in response tools was introduced due to difficulties reported by one of the first three patients of the experiment. Mouse buttons are easily triggered by applying a small force only and they were difficult to handle by the mainly elderly participants. An acoustic feedback signal generated by the computer's standard sound device was presented after each response to indicate to the observer that the response button had been pressed.

3.2.5 Design and Procedure

Each trial began with the presentation of a fixation cross (white on black background) in the center of the screen for 400 ms. The cross disappeared and a blank black screen was shown for 100 ms. The blank interval was followed by the appearance of the search display. The search array was terminated either after the observer pressed the (right or left) response button or, if no response was given, was erased

after a presentation duration of 2500 ms. Each response button press was accompanied by a 4000 Hz tone with a duration of 1000 ms. If no response was given within the maximum presentation duration a different tone (1000 Hz) was presented for 1000 ms as a feedback for observers.

Each trial began with the presentation of a fixation cross (white on black background) in the center of the screen for 400 ms. The cross disappeared and a blank black screen was shown for 100 ms. This was followed by the appearance of the search display. The presentation of the search array was terminated by the observer pressing either the right or left response button or was continued for a maximum duration of 2500 ms. A button press was accompanied by a 4000 Hz tone of 1000 ms duration. If no response was given within the maximum duration of display presentation a different tone (1000 Hz) was played for 1000 ms. Thus, the duration of individual trials varied depending on response times with a maximum duration of 3000 ms. The different target conditions were presented in randomized order within blocks comprising 60 trials each. At the end of each block, the (German) word 'Pause' appeared on the screen for 5000 ms followed by the instruction 'Weiter mit Tastendruck' instructing observers to continue the session by pressing any of the response buttons. This procedure allowed participants to extend the break individually when necessary.

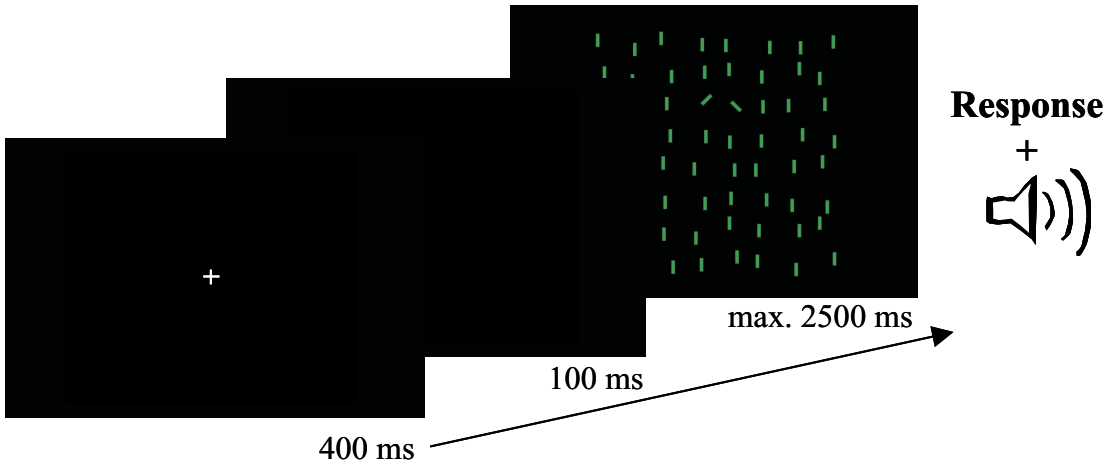

Fig. 3.3: Schematic illustration of the course of a typical trial in the search experiment. Responses were given with the index and middle finger of the right hand for target-absent and target-present trials, respectively.

3.3 Results

3.3.1 Patient group

For all experimental conditions of *display type* (absent, single, dual); *half-field* (left, right, both), and *target dimension* (orientation, colour, redundant), RTs faster than 200 ms and slower than 2000 ms were discarded as 'outliers' (overall 7.3% of all trials, ranging from minimum of 1.3% of trials excluded from analysis to maximum of 14.3 % for the ten observers). Also, erroneous trials (overall, 12.1 % of all trials) were not included in the analysis of RTs, rather these trials were analyzed separately. In the examination of the effects of the dimensional target identity of a previous trial N-1 on the performance in the current trial N (*inter-trial effects*), only sequences of two trials with correct responses were taken into account.

Accuracy

In a first step, error rates were subject to an ANOVA with the factors *display type* (single, dual), *half-field position* (left, right) and *target dimension* (orientation, colour). The ANOVA revealed a main effect of display type [$F(1,9) = 6.404; p = .032$] and a marginally significant interaction between half-field position and target dimension [$F(1,9) = 4.668; p = .059$]. The main effect of display type was due to a higher miss rate in single target trials relative to trials with dual targets. The interaction was based on the finding that within the left half-field of the display, the miss rates of orientation- and colour-defined targets were almost the same (10.8 %

and 12.2 %, respectively), while colour targets presented in the right half-field were missed more often than orientation (8.6% and 3.5%, respectively).

A second ANOVA including only dual target trials with the factors halffield position (left, right, left & right) and target dimension (orientation, colour, redundant) showed neither significant main effects for both factors ($[F(2,18) = 2.158; p = .144]$, $[F(2,18) = .233; p = .794]$, respectively) nor a statistically significant interaction ($[F(2,18) = .757; p = .560]$). The mean miss rate (in percent) for each experimental condition is shown in table 3.4.

Table 3.4: Mean percentage of misses for all conditions.

		HALFFIELD		
	DIMENSION	***left***	***right***	***left & right***
SINGLE	***orientation***	14,2	4,1	
	colour	17,7	13,9	
DUAL	***orientation***	7,5	3,1	3,0
	colour	6,8	3,4	6,8
	orientation & colour	6,3	2,5	3,2

'Within'–trial search performance

As a result of some restrictions to the design of the present search experiment not all the factors could be combined at all factor levels. For the single target condition (factor of display type) there were no dimensionally redundantly defined targets (factor of target dimension) and no half-field location involving targets in both the

'left & right' hemi-field. Therefore, separate analyses of variance were carried out for single target trials and dual target trials after an initial *overall ANOVA with a reduced design.*

Table 3.5: Mean RTs (in milliseconds) for all observers and all factor levels.

		HALFFIELD		
	DIMENSION	***left***	***right***	***left & right***
SINGLE	***orientation***	1072	932	
	colour	1002	893	
DUAL	***orientation***	1015	903	999
	colour	941	885	899
	orientation & colour	981	902	894

A first repeated-measures analysis of variance (ANOVA) was carried out with the factors: *display type* (single, dual), *half-field position* (left, right), and *target dimension* (orientation, colour). The ANOVA revealed significant main effects the factors display type [$F(1,9) = 11.7; p < .01$], half-field position [$F(1,9) = 9.43; p < .02$], target dimension [$F(1,9) = 6.07; p < .04$] as well as a significant interaction between the factors display type and half-field position [$F(1,9) = 5.53; p < .05$]. Post-hoc tests (paired t-tests) were applied to analyze the effects in detail. The results of these analyses are summarized in Figure 3.4.

The *main effect of display type* results from significantly faster RTs to dual targets

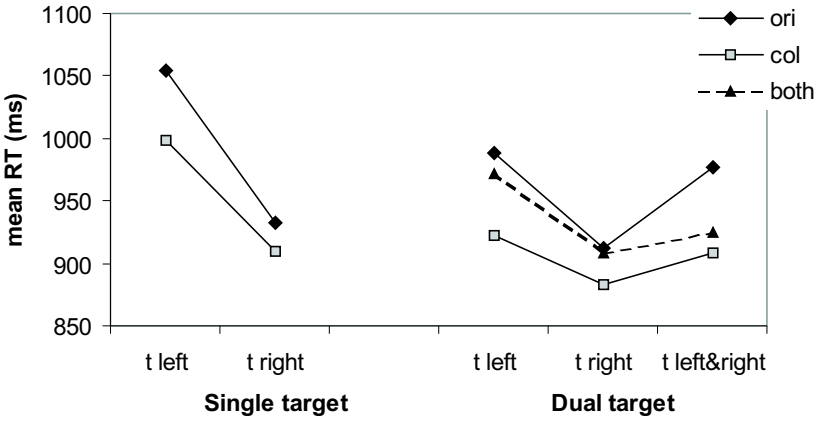

Fig. 3.4: Mean reaction times (RT) in milliseconds (ms) to single and dual orientation-, colour-, and redundantly defined targets located in the left or right half-field of the display.

(935 ms) relative to single target stimuli (975 ms) irrespective of their location in the display (left or right half-field) or dimension in which they were defined (orientation or colour). This finding is consistent with a 'numerical redundant target effect'.

The *main effect of half-field* was due to the fact that target stimuli were detected fastest when they were located in the right half-field of the search display (918 ms) and slowest when shown in the left half-field of the display (1012 ms). This left-right dichotomy is consistent with the literature on search performance in patients with visual hemi-neglect. Despite the rather subtle form of neglect revealed in clinical testing, target detection in the left part of the display is markedly slowed in the patients of the present study.

The main effect of target dimension was due to faster RTs to colour- (930 ms) relative to orientation-defined targets (979 ms). A similar tendency has been reported

by previous studies using similar stimulus dimensions (e.g. Pavlovskaya, 2002).

Further, there was also a significant *interaction* between the factors *display type* (single vs. dual target trials) and *half-field* (left vs. right). As illustrated in Figure 3.5, this effect resulted from RTs more pronouncedly expedited in dual target trials compared to single target trials if the target was presented within the left half-field relative to RTs to single and dual targets in the right half-field. That is, with RTs being much slower for left-sided targets, the facilitation of RTs for dual targets relative to single targets was greater in the left than in the right hemi-field (56 ms vs. 14 ms, respectively). To summarize, the numerical RT redundancy effect was more pronounced in the left compared to the right half-field.

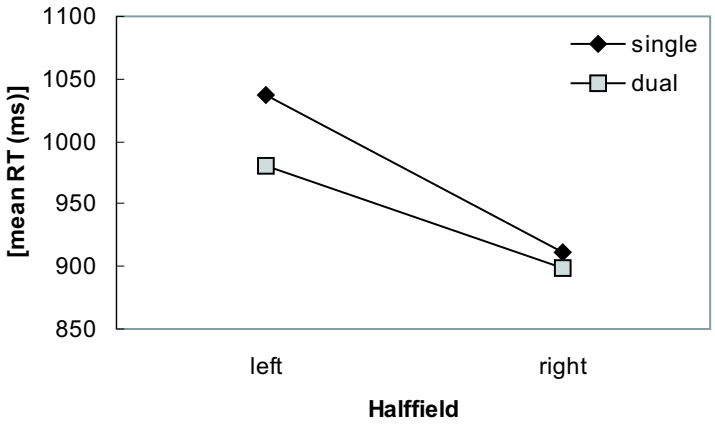

Fig. 3.5: Mean reaction times (RTs) in milliseconds (ms) to single and dual targets located in the left, right or both half-fields of the search display.

Subsequently, a separate *ANOVA including only dual target trials* was carried out. In contrast to single target trials, the two factors *target dimension* and *halffield position* had an additional level (redundantly defined in orientation *and* colour and left *and* right halffield presentation, respectively). Thus an ANOVA was conducted with *target dimension* (orientation, colour, orientation & colour) and *halffield* (left, right, left & right). The ANOVA revealed the two main effects to be statistically significant: target dimension [$F(2, 18) = 5.270; p = .015$] and halffield [$F(2, 18) = 4.361; p = .028$].

The *main effect of target dimension* was based on significant differences between orientation-defined dual targets (i.e., orientation & orientation) and colour-defined targets (i.e. colour & colour, [$t(9) = 2.479; p = .035$]) as well as dimensionally redundantly defined dual targets (i.e., colour & orientation targets, [$t(9) = 2.638; p = .027$]), with a mean difference 64 ms and 46 ms, respectively. The difference between RTs to colour targets and RTs to targets redundantly defined in both dimensions was not significant. The half-field effect was mainly due to a difference between RTs to left- vs. right-sided targets ([$t(9) = 2.196; p = .056$]; 979 ms vs. 896 ms, respectively). RTs to dual targets located each in one hemi-field of the display were not different from the two other conditions.

Effects of Redundancy

Two types of redundancy gains were calculated: (a) numerical and (b) dimensional redundancy gain. The former refers to the difference between RTs to dual targets

and single targets. The latter is revealed by comparing RTs to dual targets defined within one dimension (orientation *or* colour) and RTs to dual targets redundantly defined in two dimensions (orientation *and* colour). This was done separately for targets presented in the left, right, or in both halffields and for the different target dimensions (orientation and colour) and is described in detail in the following section.

Numerical redundancy: single-dimension vs. dual-dimension target trials

As reported earlier (see the result section above), observers' rate of detecting the presence of a target was a significantly affected by the number of target items presented in the search display in one trial. Overall, RTs were facilitated for dual target trials relative to single target trials (935 ms and 975 ms, respectively). The result of faster RTs to redundant target trials was more pronounced for targets presented in the left relative to the right half-field. In Table 3.6 mean numerical redundancy gains are listed separately for orientation- an colour-defined dual targets located in the right and left half-field of the display.

For example, the mean RT numerical redundancy gain for dual oriented targets in the left halffield resulted from the difference to the average of both single feature targets in the left halffield.

The mean numerical redundancy gains for left-sided dual targets were 22.4 ms, 95.5 ms and 55.8 ms for oriented, coloured and targets defined in both dimensions, respectively. In the right half-field, mean redundancy gains were 9.7 ms (orientation), 27.9 ms (colour), and 10.2 ms (orientation & colour).

An ANOVA was applied to numerical redundancy gains with the factors *target dimension* (orientation, colour, orientation & colour) and *half-field position* (left, right). The results confirmed higher numerical redundancy gains when targets were presented in the left half-field of the display [$F(1,9) = 9.957; p = .012$]. The influence of target dimension did not reach significance.

Dimensional redundancy: dual targets defined in one dimension vs. dual targets defined in different dimensions. The data from dual-target trials were also analyzed with regard to the dimensional identity of the targets. Effects of dimensional redundancy on RTs were expected if dual-target trials with both targets defined in the same dimension (colour & colour or, alternatively, orientation & orientation) were compared with dual target trials comprising two targets each defined in a different dimension (colour & orientation). The analysis was performed using Miller's (1982) race model inequality in a procedure developed by Krummenacher, Müller and Heller (2002a) to test for effects of dimensional redundancy. Mean RT redundancy gains were calculated separately for each half-field condition (left, right, and left & right) and for each observer.

The results are listed in Table 3.6. The presentation of dual (dimensionally) redundantly defined targets in the left or right halffield produced RT costs (rather than gains) relative to the average RT to dual targets defined in either orientation or colour (-3.2 ms (left) and -8.6 ms (right)). In contrast, there was a gain of 55.2 ms for dual redundantly defined targets relative to singly defined dual targets when

targets appeared in both hemifields of the display.

Table 3.6: Mean RTs and Error rates for single, dual and dual redundantly defined targets. Numerical and dimensional redundancy gains (Rgains) are listed in the two rightmost columns.

CONDITION	mean RT(ms)	overall mean RT(ms)	mean ER(%)	*numerical Rgain(ms)*	*dimensional Rgain(ms)*
Single target					
ori left	1072,1		16,8		
ori right	932,1		5,3		
orientation		*990,0*	*11,1*		
col left	1002,0		20,5		
col right	893,1		16,1		
colour		*943,4*	*18,3*		
Dual targets					
ori left	1014,6		12,1	22,4	
ori right	902,9		4,0	9,7	
ori both	998,7		6,2		
orientation		*969,8*	*7,4*	*16,0*	
col left	941,5		10,6	95,5	
col right	884,7		5,0	27,9	
col both	899,1		8,5		
colour		*904,6*	*8,0*	*61,7*	
Dual redundant targets					
ori/col left	981,2		7,8	55,8	-3,2
ori/col right	902,5		4,0	10,2	-8,6
ori/col both	893,7		5,5		55,2
ori/col		*924,1*	*5,7*	*33,0*	*14,5*

Dimensional redundancy gains were subject to an ANOVA with the factor *half-field*(left, right, left & right). The ANOVA revealed a main effect of half-field

$[F(2, 18) = 3.374; p = .057]$ based primarily on the difference between redundancy gains of targets in the right versus targets presented in both half-fields.

In sum, while for dual redundant targets presented in the left half-field reasonable redundancy gains were observed, targets in the right or in both half-fields produced only small gains or even RT costs. Furthermore, dimensional redundancy gains were observed only for dual redundantly defined targets presented in both half-fields of the display. In contrast, the presentation of a pair of redundantly defined targets in the left or right half-field did not speed RTs relative to two singly defined targets (oriented or colour-defined). There was even a small cost associated with dimensional redundancy.

Inter-trial analysis

To identify the influence of the characteristics of a trial (t *N-1*) on responses to a subsequent trial (t N), intertrial effects were analyzed considering *(1)* target dimension (change vs. no change), *(2)* display type (change vs. no change), *(3)* target half-field position in subsequent trials (change vs. no change) and *(4)* the potential interaction between change vs. no change of target dimension and half-field position. Further, intertrial transitions of target dimension and half-field were analyzed.

To test for intertrial influences of the number of targets shown in a display (single vs. dual) an ANOVA was carried out with the factors *display type* (single, dual) and *change of display type* (change vs. no change). This analysis revealed a main effect of display type $[F(1, 9) = 9.36; p < .01]$. As can be seen in Figure 3.6, the

main effect was due to the fact that dual targets were detected faster than single targets, even when preceded by a single target. Detection of single targets was not expedited when preceded by dual targets.

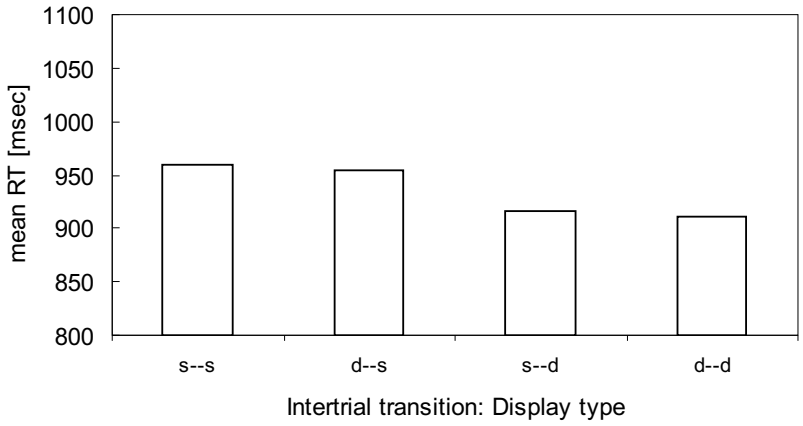

Fig. 3.6: Intertrial transition of display type from trial t*N-1* to trial t*N*: s-s (single target - single target), d-s (dual targets - single target), s-d (single target - dual targets, and d-d (dual targets - dual targets).

Subsequently, an ANOVA with the factors *intertrial transition: target dimension* (t *N-1* to t *N*: orientation-orientation, orientation-colour, colour-orientation, colour-colour) and *intertrial transition: half-field* (left-left, left-right, right-left, and right-right) was conducted. The ANOVA revealed a significant main effect for both factors, the interaction did not reach significance. The main effect of half-field $[F(3, 27) = 8.916; p < .01]$ was mainly based on differences between transitions within or towards the left half-field of the display and transitions within the right or towards the right half-field. RTs were slowest when the target position changed

from the right half-field in t *N-1* to the left half-field in t *N* (1043 ms). Detection was fastest when a target appeared in the right half-field that was preceded by a target in the left field (892 ms). The main effect of dimension transition [$F(3, 27) = 3.251; p < .05$] resulted from significantly slower RTs to orientation-defined targets preceded by a colour target relative to RTs to colour-defined targets preceded either by colour or orientation targets. Of all transitions, an orientation-defined target was detected slowest (1001 ms), whereas a colour target preceded by a similar target was detected fastest (936 ms). This is illustrated in Figure 3.7.

To address the possibility of an interaction between dimension change and the target's half-field position, a repeated measure analysis (ANOVA) was conducted with the factors *dimension change* (no change, change) and *half-field change* (no change, change). There was a main effect of dimension change [$F(l, 9) = 9.65; p < .01$] resulting from slower RTs to trials following a change of target dimension (978 ms) compared to trials in which no change had occurred (940 ms). That is, the dimension-specific change cost was 38 ms. The interaction between the two factors revealed a marginally significant effect [$F(l, 9) = 3.93; p < .07$]. The effect was based on a stronger dimension change effect (higher RT cost) when the dimension change was not associated with a change in the half-field location of the target (i.e. there was no half-field change). In contrast, the dimension change effect was smaller when it was associated with a half-field change.

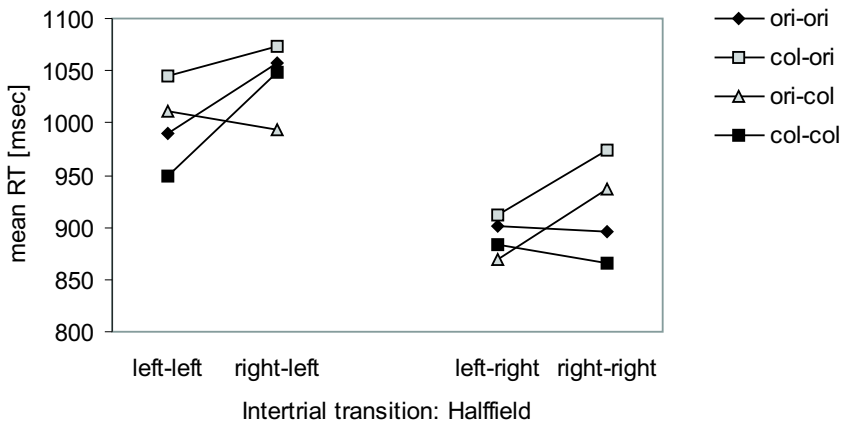

Fig. 3.7: Intertrial transition: half-field position versus target dimension.

3.3.2 Results: Age-matched controls

Data analysis was performed with the use of procedures similar to those in the experimental (patient) group. The overall mean error rate was 1.2%; 0.6% of all trials were not answered within the response interval of 200 ms to 2000 ms (outliers). Erroneous trials and 'outliers' were not included in the data analysis. Overall mean reaction time (RT) was 702.7 ms.

Within trial search performance

An ANOVA not including all factors (reduced design) was conducted with the factors *display type* (single, dual), *target dimension* (orientation, colour) and *half-field position* (left, right). There was a main effect of target dimension [$F(1,6) = 17.741; p = .006$] due to faster reaction times to colour targets (mean RT: 671 ms) relative to orientation-defined targets (mean RT: 683 ms). No other main effect or interaction reached significance.

Subsequently, single and dual target trials were subjected to separate ANOVAs. [1] An ANOVA including single trials only, with the factors *half-field* (left, right) and *target dimension* (orientation, colour) revealed a main effect of half-field [$F(1,6) = 5.960; p = .050$]. RTs to single targets located in the right half of the display were faster than RTs to left-side single targets (684 ms vs. 705 ms, respectively).

[2] No significant effects or interactions were found in an ANOVA including only dual target trials with the factors *half-field* (left, right, left & right) and *target*

dimension (orientation, colour, orientation & colour). However, there was a trend towards significance for the main effect of half-field [$F(2, 12) = 3.198; p = .077$] due to consistently faster RTs to targets located in the right (645 ms) or in both half-fields (633 ms) relative to left-side targets (661 ms). Mean RTs for both single and dual target trials are summarized in Figure 3.8.

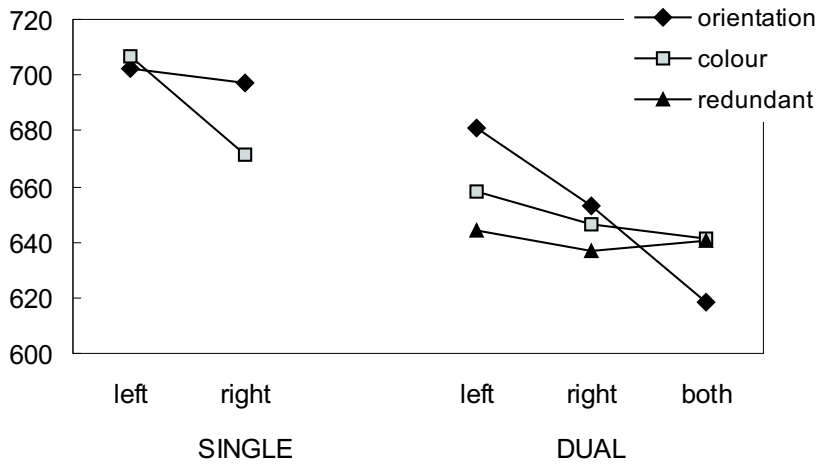

Fig. 3.8: Mean reaction times (RT) in milliseconds (ms) to single and dual orientation-, colour-, or redundantly defined targets located in the left, right or both half-fields of the display.

Effects of Redundancy

Redundancy gains were calculated following the same procedure applied to the data of the patient group.

Numerical redundancy: single vs. dual target trials. There was no significant effect of display type in an overall ANOVA described in the result section above. That is, there was no significant RT advantage for the detection of two relative to a single target in the display. However, the numerical gains are briefly described here and listed in Table 3.7.

The mean numerical redundancy gains for left-sided dual targets were 7.3 ms, 36.6 ms and 38.3 ms for oriented, coloured and targets defined in both dimensions, respectively. In the right half-field, mean redundancy gains were 8.2 ms (orientation), 13.8 ms (colour), and 48.6 ms (orientation & colour).

An ANOVA with the factors *target dimension* (orientation, colour, orientation & colour) and *half-field position* (left, right) revealed a main effect of target dimension $[F(2, 24) = 8.059; p = .002]$. This effect was due to significantly smaller redundancy gains for dual oriented targets relative to gains of both colour- or redundantly defined dual targets.

Dimensional redundancy: dual targets defined in one dimension vs. dual targets defined in different dimensions Mean dimensional redundancy gains, the difference between average RTs to dual targets defined in orientation *or* colour and RTs to redundantly defined dual targets, are also displayed in table 3.7. There was a mean gain of 21 ms for left-sided targets and 33.6 ms for targets presented in the right half-field. Bilateral presentation of redundant dual targets produced a mean RT cost of 20.3 ms.

A repeated-measures ANOVA with the factor *half-field position* (left, right, left & right) revealed a main effect of halffield based on a significant difference between the *gain* observed in the right half-field and *costs* associated with target presentation in both fields $[F(2, 24) = 5.039; p = .015]$.

Table 3.7: Mean RTs and redundancy measures over all age-matched control subjects

CONDITION	mean RT(ms)	overall mean RT(ms)	mean ER(%)	*numerical Rgain(ms)*	*dimensional Rgain(ms)*
Single target					
ori left	691,5		1,9		
ori right	676,3		0,5		
orientation		*683,8*	*1,2*		
col left	679,7		1,5		
col right	645,1		0,6		
colour		*662,3*	*1,0*		
Dual targets					
ori left	676,0		0,0	7,3	
ori right	661,8		0,4	8,2	
ori both	627,3		0,8		
orientation		*655,1*	*0,4*	*7,8*	
col left	637,1		0,4	36,6	
col right	622,0		0,0	13,8	
col both	624,2		0,0		
colour		*627,8*	*0,1*	*25,2*	
Dual redundant targets					
ori/col left	647,3		0,4	38,3	21,0
ori/col right	612,1		0,8	48,6	33,6
ori/col both	646,0		0,2		-20,3
ori/col		*635,2*	*0,4*	*43,5*	*11,4*

To summarize, in control group I (healthy elderly observers) there was no significant overall advantage in RTs for dual targets relative to single targets. That is, there was no significant numerical redundancy gain. Further analysis revealed an effect of target dimension on numerical gains with larger gains for colour- and redundantly defined targets relative to the gains for oriented targets. Dimensional redundancy gains were found to be different dependent on the targets' half-field position. When presented bilaterally, redundantly defined targets produced RT costs while gains were found for targets located in the left or right half of the display.

Intertrial analysis

To explore the influence of stimulus characteristics of targets in a trial t *N-1* on RTs to the subsequent trial an ANOVA with the factors *half-field change* (no change, change) and *dimension change* (no change, change) was conducted. Both factors showed main effects: half-field change $[F(1,6) = 9.571; p = .021]$ and dimension change $[F(1,6) = 8.737; p = .025]$. As illustrated in Figure 3.9, RTs were slowed when there was a change of the target's half-field position from trial t *N-1* to trial t *N* (mean difference change vs. no change: 26.4 ms). Similarly, increased RTs were found when there was a target dimension change in consecutive trials (mean difference change vs. no change: 29.6 ms).

Furthermore, to explore the effects of target position and target-defining di-

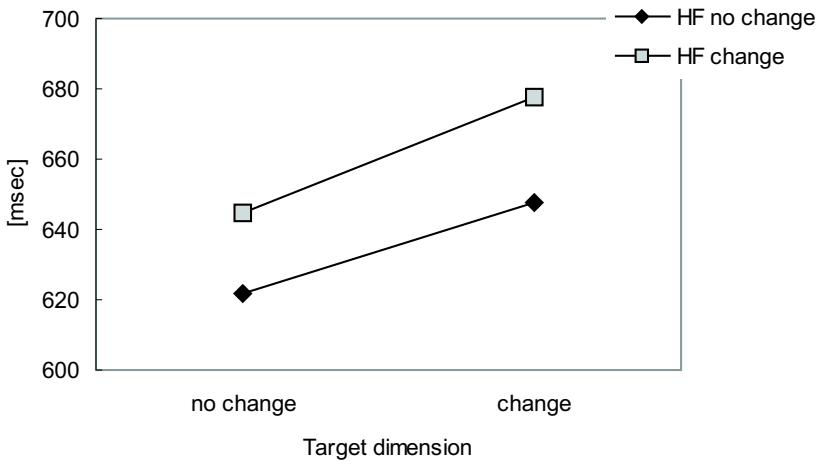

Fig. 3.9: Mean reaction times (RT) in milliseconds (ms) to trials after a change or no change of target dimension or half-field position of the target.

mension in consecutive trials in more detail, an ANOVA with the factors *intertrial transition: target dimension* (t*N-1* to t*N:* orientation-orientation, orientation-colour, colour-orientation, colour-colour) and *intertrial transition: half-field* (left-left, left-right, right-left and right-right) was conducted. The ANOVA revealed main effects of both factors to be significant: $[F(1,6) = 4.026; p = .023]$ and $[F(1,6) = 5.200; p = .009]$, respectively. The *main effect of dimensional intertrial transition* was mainly due to significant differences between colour-target trials preceded by a similar trial (621 ms) and (1) colour-target trials presented after a orientation-target trial (668 ms) and (2) an orientation-target trial preceded by a colour-defined target (655 ms). The *main effect of half-field transition* was based on a significant difference between a trial sequence of two left-sided targets (637 ms) and left-sided target trials preceded by a right-sided target (667 ms). Overall, RTs

to left sided target trials preceded by a right-sided target were slowest (667 ms) while RTs to right-sided target trials following a similar trial were fastest (632 ms). The relation between intertrial transitions of half-field and dimension are illustrated in Figure 3.10.

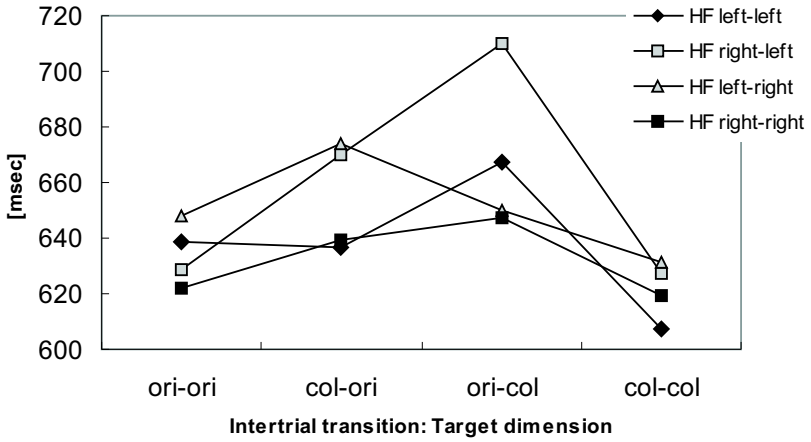

Fig. 3.10: Mean reaction times (RT) in milliseconds (ms) to intertrial transitions from trial *N-1* to trial *N* of target location (HF =half-field) and target dimension.

3.3.3 Results: Young controls

Observers in the *young control group* showed an overall error rate of 1.4%. An additionally 1.3% of all trials were not answered within a predefined response interval between 200 ms and 2000 ms after trial onset and consequently discarded as 'outliers'. Further data analysis was carried out similar to the procedure applied to the patient data reported above. First, an overall ANOVA with a reduced design was conducted. Subsequently, single and dual target trials were subject to separate ANOVAs.

Search performance

An ANOVA including single and dual target trials with the factors *display type* (single, dual), *target dimension* (orientation, colour) and *half-field* (left, right) revealed main effects of all three factors. $[F(1,9) = 9.028; p = .015]$, $[F(1,9) = 10.014; p = .011]$ and $[F(1,9) = 12.259; p = .001]$, respectively. None of the interactions were significant. Targets located in the right half-field were detected faster than left–sided targets (mean difference was 36 ms). The main effect of target dimension resulted from expedited RTs to colour-defined targets with a mean difference of 23 ms to orientation-defined targets. In addition to the main effects of half-field and dimension, there was a main effect of display type resulting from an RT advantage for dual targets compared to single targets (517 ms vs. 536 ms).

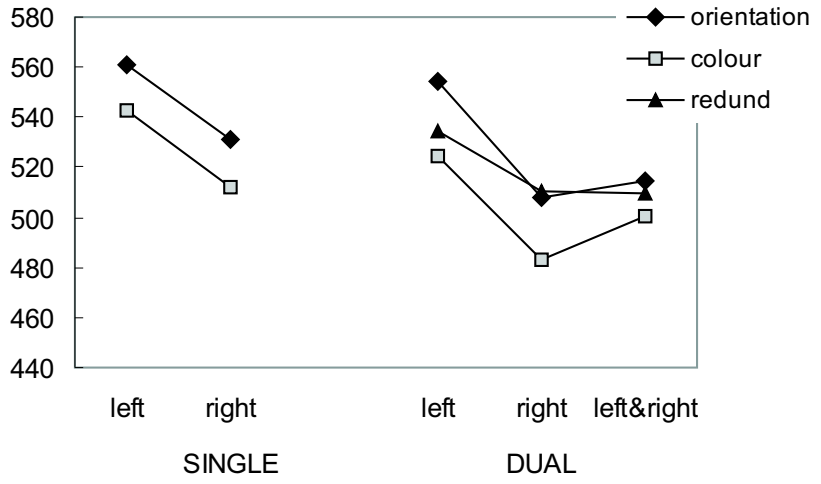

Fig. 3.11: Mean reaction times (RT) in milliseconds (ms) to single and dual orientation-, colour-, or redundantly defined targets located in the left, right or both half-fields of the display.

To examine reaction time effects dependent on half-field position and target dimension for *single target trials* an ANOVA was conducted including the factors *target dimension* (orientation, colour) and *half-field location* (left, right). There was a main effect of half-field $[F[1,9] = 35.025; p < .01]$, due to faster RTs to targets presented in the right half-field compared to targets located in the left half-field (521 ms vs. 552 ms, respectively). The difference between colour– and orientation–defined single targets (19 ms) did not reach significance $[F(1,9) = 3.725; p = .086]$.

Further, an ANOVA including only *dual target trials* with the factors *target dimension* (orientation, colour, both) and *half-field* (left, right, both) revealed main effects of both factors: $[F(2,18) = 3.609; p = .048]$ and $[F(2,18) = 12.098; p = .00]$, respectively.

The main effect of half-field resulted, similar to the effect observed with single target trials, from faster RTs to right-sided targets relative to targets in the left half-field. Detection of targets presented in both half-fields was also significantly faster than detection of left-side targets but not different from targets displayed in the right half-field: 501 ms (right), 508 ms (both) and 537 ms (left), respectively. Concerning the main effect of target dimension, colour targets (502 ms) were detected significantly faster than both orientation (525 ms) and redundantly defined targets (518 ms).

Effects of Redundancy

Numerical and dimensional redundancy gains were calculated similar to the procedure described for the patient and control group I (elderly healthy observers) above.

Numerical redundancy: single versus dual target trials Control group II showed a significant overall RT advantage for dual targets compared to single targets (517 ms vs. 536 ms). Mean redundancy gains, separately for each target dimension and half-field position, are shown in Table 3.8. When located in the left half-field, dual targets produced mean RT gains of -2.2 ms (orientation), 27.8 ms (colour) and 17.2 ms (orientation & colour). In the right half-field, numerical redundancy gains were 13.3 ms for oriented, 38.4 ms for coloured, and 11.3 ms for redundantly defined targets.

To test the influence of both the factors, dimension and half-field, mean RT

gains were subjected to an ANOVA. There was a main effect of target dimension [$F(2, 18) = 4.016; p = .036$]. The effect was mainly due to larger numerical redundancy gains for dual colour targets relative to dual orientation- or redundantly defined targets as revealed by posthoc tests.

Dimensional redundancy: dual targets defined in one dimension versus dual targets defined in different dimensions Mean dimensional redundancy gains are displayed in table 3.8: In the left half-field, dual redundantly defined targets had a mean RT advantage relative to the average RT of dual colour and orientation targets of 4.4 ms. When presented in the right half of the display or bilaterally, there were costs of -14.5 ms and -1.6 ms, respectively.

However, there was no significant effect of the targets' half-field position on dimensional redundancy gains [$F(2, 18) = 1.473; p = .256$].

Thus, in control group II, significant numerical redundancy gains were observed to be largest for colour defined dual targets independent of the half-field in which they were presented. There were small dimensional RT gains for targets presented in the left half-field. In contrast, right-sided or bilateral presentation of redundantly defined dual targets produced RT costs rather than benefits.

Table 3.8: *Mean RTs and redundancy measures over all young control subjects*

CONDITION	mean RT(ms)	overall mean RT(ms)	mean ER(%)	numerical *Rgain(ms)*	dimensional *Rgain(ms)*
Single target					
ori left	561,2		2,8		
ori right	531,4		1,4		
orientation		*546,1*	*2,0*		
col left	542,8		1,8		
col right	511,7		0,4		
colour		*527,1*	*1,1*		
Dual targets					
ori left	554,2		2,1	-2,2	
ori right	508,3		1,4	13,3	
ori both	514,5		0,5		
orientation		*525,7*	*1,4*	*5,5*	
col left	524,2		0,5	27,8	
col right	483,2		0,0	38,4	
col both	500,8		0,0		
colour		*502,9*	*0,2*	*33,1*	
Dual redundant targets					
ori/col left	534,8		0,5	17,2	4,4
ori/col right	510,2		0,5	11,3	-14,5
ori/col both	509,3		1,0		-1,6
ori/col		*518,0*	*0,7*	*14,3*	*-3,9*

Intertrial analysis

An ANOVA with the factors *intertrial transition: target dimension* (t *N-1* to t *N*: orientation-orientation, orientation-colour, colour-orientation, colour-colour) and *intertrial transition: half-field* (left-left, left-right, right-left and right-right) revealed main effects for both factors. The effect of half-field position ($[F(3, 27) = 3.206; p =$

.039]) across trials was mainly due to significant differences between the right-to-left and the right-to-right transition. The former transitions yielded the slowest and the latter produced the fastest RTs (555 ms and 510 ms, respectively). The effect of intertrial transition of the target dimension ($[F(3, 27) = 3.434; p = .031]$) resulted from significantly faster RTs to colour targets independent of the target-defining dimension in the preceding trial. This effect was observed in comparison to the condition of orientation-defined targets preceded by a colour target which yielded slowest RTs. However, the change versus no change of half-field position or target dimension across subsequent trials yielded no significant effects ($[F(1, 9) = .592; p = .462]$, and $[F(1, 9) = 1.335; p = .278]$, respectively).

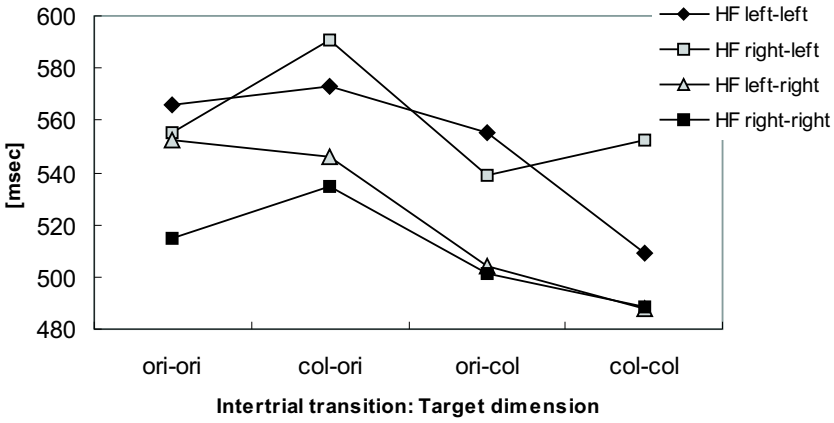

Fig. 3.12: Mean reaction times (RT) in milliseconds (ms) to intertrial transitions from trial *N-1* to trial N of target location (HF = half-field) and target dimension.

3.3.4 Comparison between groups

The three groups of observers, the patient group and two control groups (group I: healthy elderly observers; group II: young controls) showed significant differences concerning their overall mean RTs. Patients responded slowest (overall RT: 1003.8 ms) compared to observers of both (age-matched group and young) control groups, ($[t(9) = 8.358; p < .01]$ and $[t(6) = 3.158; p < .05]$, respectively). Mean RTs of age matched controls (control group I : 700.7 ms) were also slower than that of the group of young control subjects (529.6 ms; $[t(6) = -4.079; p < .01]$.

Search performance

To examine potential differences in search performance between the experimental group and the two control groups, an ANOVA with three within-subject factors *display type* (single, dual), *half-field* (left, right) and *target dimension* (orientation, colour) and one between-subjects factor *group* (patients, control group I and II) was conducted. The ANOVA revealed main effects for display type $[F(1, 30) = 38.924; p < .01]$, half-field $[F(1, 30) = 23.754; p < .01]$, and target dimension $[F(1, 30) = 20.239; p < .01]$. In addition, there was a significant two-way interaction between half-field and group $[F(2, 30) = 5.460; p < .01]$. The three-way interaction between display type, half-field, and subject group ($[F(2, 30) = 3.509; p < .05]$) was marginally significant.

The interaction between half-field and group resulted mainly from differences

between the patient and both control groups. The effect of half-field, that is significantly different RTs to targets in the left versus right half-field of the display, was larger in the patient group relative to both control groups I and II ($[t(21) = 3.137; p = .005]$, $[t(18) = 2.272; p = .036]$, respectively). In contrast, there was no difference between control group I and II ($[t(21) = 1.936; p = .066]$). That is, the half-field effect was stronger in patients (longer RTs in the left versus right half-field) relative to control subjects.

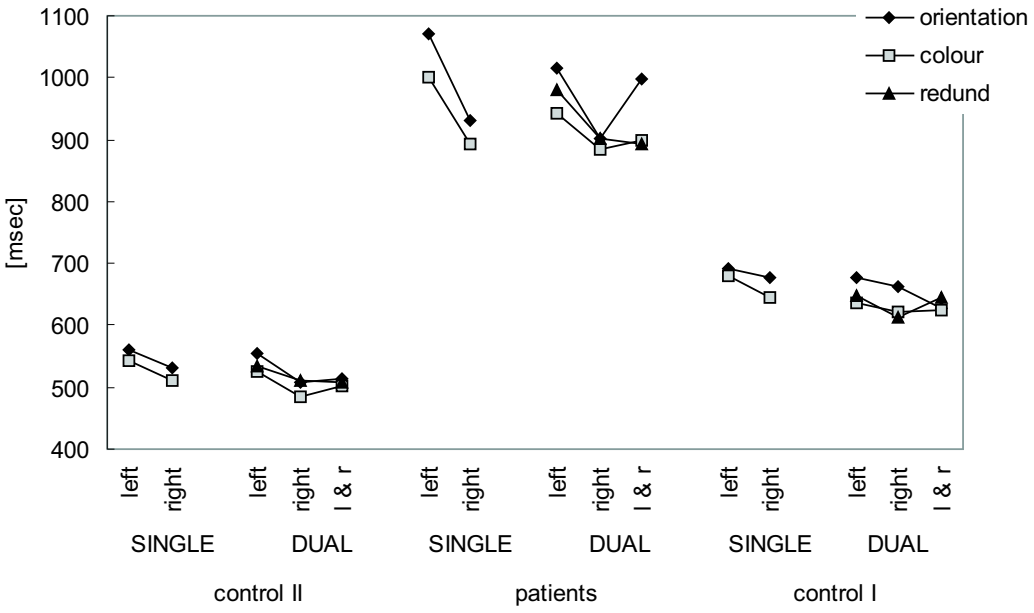

Fig. 3.13: Mean reaction times (RT) in milliseconds (ms) of neglect patients (patients), age-matched controls (control I) and young control subjects (control II). RTs are separately shown for oriented and colour-defined single targets presented in the left or right half-field and for dual targets either both defined within the orientation or colour dimension or each defined in a different dimension. Dual targets could be located both in the left or right hemifield or one in each half-field.

Effects of numerical and dimensional redundancy

Numerical redundancy. As illustrated in Figure 3.14, the three groups showed different results concerning numerical redundancy gains. An ANOVA with the factors *target dimension* (orientation, colour, orientation & colour), *half-field position* (left, right) and *group*(patients, control groups I and II as a between-subject factor) revealed the main effects of target dimension ($[F(2,4) = 10.610; p < .01]$) and half-field ($[F(1,2) = 4.195; p = .049]$), and the interaction between half-field and group ($[F(2,30) = 5.229; p = .011]$ to be significant. The patient group showed significantly larger numerical redundancy gains than control groups I and II for targets located in the left half-field, in particular for colour-defined targets ($[t(21) = 2.438; p = .022]$, $[t(18) = 1.904; p = .008]$, respectively). Furthermore, control group I exhibited a larger numerical gain than patients and control group II when dual redundantly defined targets were presented in the right half-field of the display ($[t(21) = -2.434; p = .024]$ and $[t(21) = 3.465; p = .002]$, respectively).

In sum, patients showed a larger RT advantage relative to both control groups, when dual, particularly colour-defined targets, were presented in the left half-field of the display. In contrast, control group I showed higher RT gains than the two other groups, when dual redundantly defined targets were presented in the right half-field.

Dimensional redundancy. There were also differences between groups concerning dimensional redundancy gains. An ANOVA of the gains with the factor *half-field position* (left, right, left & right) and *group* (patients, control groups I and

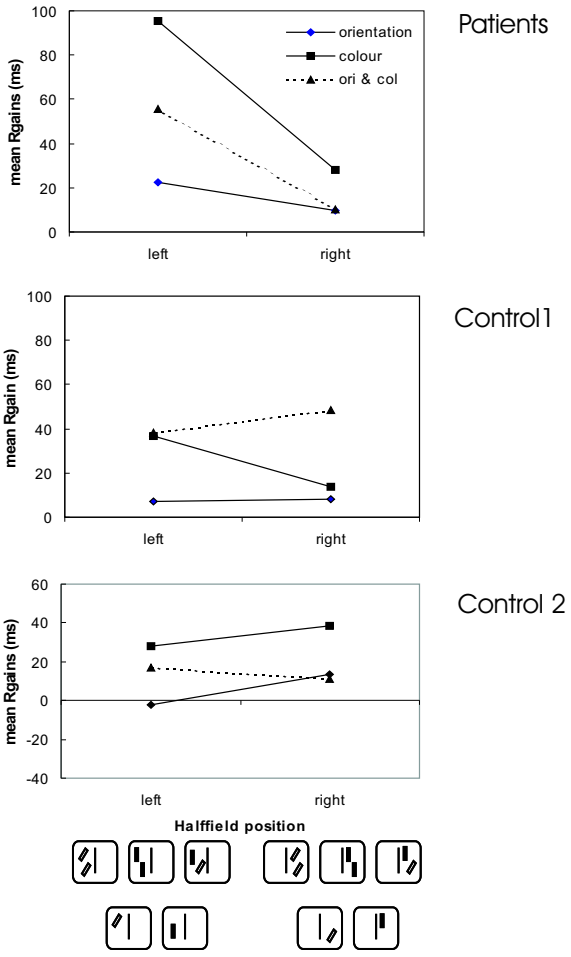

Fig. 3.14: Mean numerical redundancy gains for the patient group, control group I and II. Values are shown separately for half-field position (left, right) and target dimension (orientation, colour and redundantly defined targets: ori & col). Small boxes at the bottom of the graph show schematic illustrations of the conditions that were compared to calculate numerical redundancy gains.

II) as a between-subject factor showed an interaction between half-field and group ($[F(4, 60) = 5.496; p = .001]$). This effect was mainly due to significantly larger RT redundancy gains for dual redundantly defined targets presented in both half-fields in the patient group compared to both control groups ($[t(21) = 3.067; p = .006]$(control

I), $[t(18) = 2.291; p = .034]$(control II)). Further, control group I showed increased dimensional redundancy gains relative to patient and control group II for targets presented in the right half-field ($[t(21) = -2.806; p = .011]$ and $[t(21) = 5.198; p < .01]$, respectively). This is illustrated in Figure 3.15.

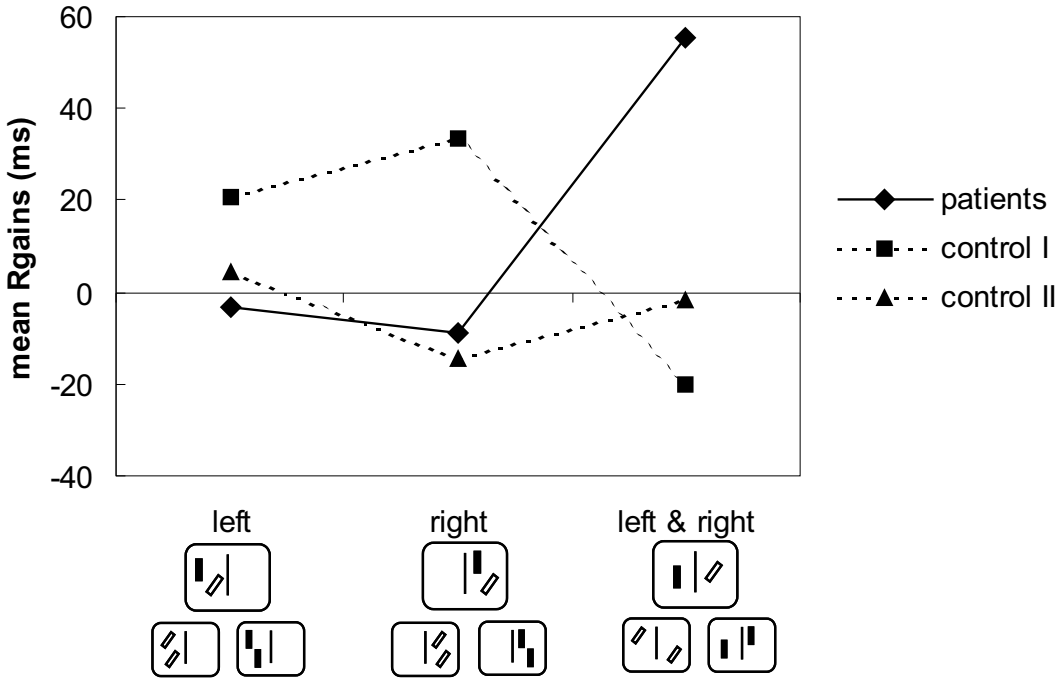

Fig. 3.15: Dimensional redundancy gains for the patient group, control group I and II. The gains are displayed separately for targets presented in the left, right or both half-field. Boxes below the graph illustrate the conditions that were compared to calculate mean dimensional redundancy gains: redundantly defined dual targets presented in the left, right or both half-fields versus the average of dual singly defined targets in the left, right or both half-fields.

Thus, while the patient group, similar to control group II, exhibited only small gains or even costs of RT when dual redundant targets were located in the left *or* right half-field, control group I (age-matched healthy observers) showed dimensional

redundancy gains in both conditions. In contrast, when targets were presented *bilaterally*, dimension-based redundancy gains were high in patients, whereas both control groups showed RT costs.

Intertrial effects

In order to compare change effects of half-field and target dimension in consecutive trials between groups, an ANOVA was conducted with the factors *half-field change* (change, no change), *dimension change* (change, no change) and *group* (patients, control group I and II) as between-subject factor. The result showed the two main effects of half-field and dimension change to be significant (([$F(1,2) = 7.173; p = .012$] and ([$F(1,2) = 37.055; p = .001$], respectively). Further, there was a significant three-way interaction of the factors half-field change, dimension change and group ([$F(2,30) = 4.934; p = .014$]. The interaction was due to a significant interaction between half-field change and dimension change in the patient group that was not observed in either control group. That is, in both control groups, dimensional change costs were not affected of whether a change of half-field position which was accompanied by a change in the half-field in which the target presented or not. The patient group however, showed higher dimensional change costs when target position changed within one half-field only or remained at the same position relative to a half-field change in consecutive trials (see also Figure 3.16). There was no difference between groups concerning the size of the dimensional change effect. A one-way ANOVA revealed no significant difference between dimensional change costs in the

patient group and both control groups ($F(2) = 1.106; p = .344$).

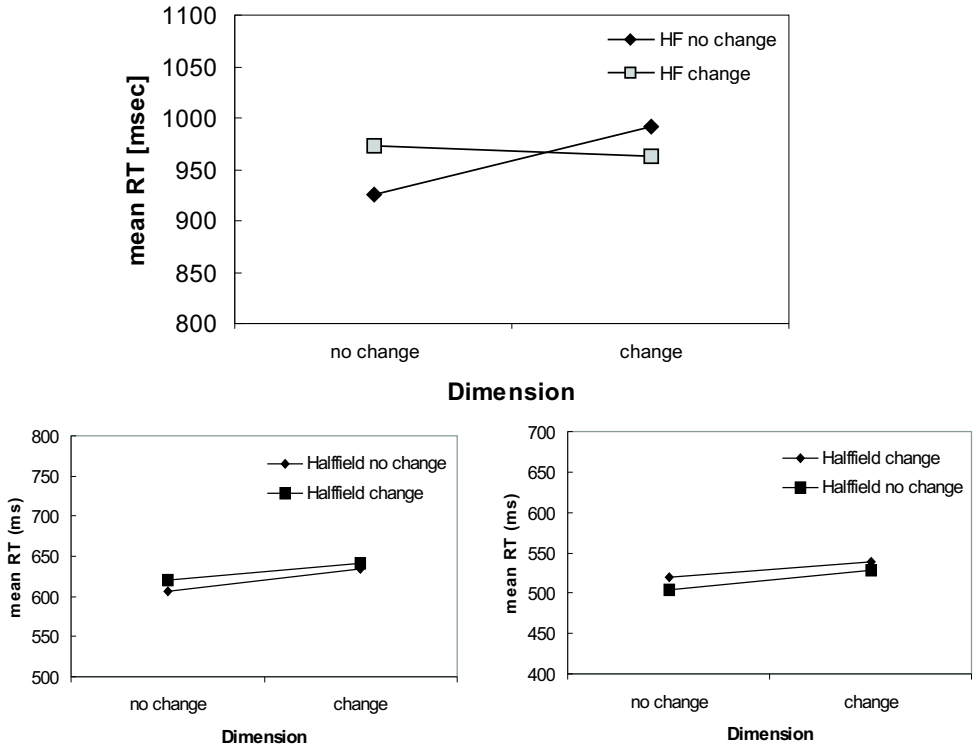

Fig. 3.16: Mean RTs to change vs. no change of target dimension and halffield position separately shown for the patient group (top panel) and control groups 1 (left bottom) and 2 (right bottom). A significant interaction between dimension and halffield change was only observed in the patient group (see result section for details).

A more detailed analysis of intertrial transitions of half-field position and target dimension from trial to trial also revealed differences between the three experimental groups. An ANOVA with the factors half-field transition (left–left, right–left, left–right, right–right), dimension transition (orientation–orientation, colour–orientation, orientation–colour, colour–colour) and group showed main effects for

both factors half-field ($[F(3, 90) = 20.003; p < .01]$) and dimension transition ($[F(3, 90) = 14.249; p < .01]$) to be significant. Further, a significant interaction between half-field transition and group ($[F(6, 90) = 4.894; p < .01]$was observed. The interaction is mainly based on differences between the patient group and control group I: Patients were slowest to detect left-sided targets when in the preceding trial the target was right-sided. In contrast, in control group I RTs were longest for a target in the right halffield if it was preceded by a left-side target.

3.4 Discussion

The aim of the present study was to investigate the performance of patients with unilateral neglect in visual search for single and dual targets defined in one (single and dual targets) or in different (dual targets) feature dimensions. Further, targets were either located in the left, the right, or in both half-fields of the search display. The effects of the following manipulations were of interest: *(1)* the influence of the number of search targets, the effect of target-defining dimensions and the half-field position within a given trial **(within trial performance)** and *(2)* the effects of changes in target dimension and target half-field position in consecutive trials **(inter-trial performance)**. Thus, it was asked whether patients with unilateral left neglect show enhanced performance when they are presented with redundant visual information (either numerically or dimensionally) and whether any potential performance improvement is dependent on half-field location of the target and/or dimensional intertrial history. Contrary to expectation, patients were well able to perform the search task. This preserved capability was observed despite the patients' impaired performance in clinical tests of neglect which implies (and is defined as) the inability to detect items in the contra-lesional hemispace. However, hardly any deficit can be characterized in an 'all or nothing' approach. In the present study, the patients' overall error rate was low, and there was no significant influence of the targets half-field position on accuracy. Although not explicitly tested, it is therefore plausible to assume that the patients consciously detected the majority of targets

presented in the left half-field of the display.

In summary, the main results observed were *(1)* a general slowing of overall response times of patients relative to both a group of age-matched controls and group of young students; *(2)* a slowing of RTs to targets presented in the left half-field of the display irrespective of their numerical or dimensional definition; *(3)* increased numerical redundancy gains for targets presented in the left half-field; *(4)* increased dimensional redundancy gains for bilaterally presented targets, and *(5)* a dimension-based intertrial effect that was modulated by whether the target's half-field position was changed or remained unchanged across consecutive trials. These findings will be discussed in detail in the following sections.

Speed of processing: prolonged overall RT. Independent of display and stimulus conditions, patients showed prolonged overall RTs in visual search for targets differing from distractors in one single feature. This slowing was observed if RTs were compared to RTs of young controls but also in comparison to age-matched controls. The overall slowing of response times might be due to a general reduction in processing speed often reported to be associated with brain damage (D'Erme et al., 1992; Halligan et al., 2003; Fink & Heide, 2004;). Particularly in periods immediately following brain injury, in the acute confusional state, alertness and global attentional functions are severely impaired (Mesulam, 1999). However, at the time of examination the patients participating in the present study were not in an acute stage and the conditions of all of them had considerably improved. Furthermore,

investigations into the electrophysiological correlates of early stages of processing found components of event-related potentials which are thought to be related to perceptual processes to be preserved in patients with attentional deficits (Vuilleumier et al., 2001; Verleger et al., 1996).

Therefore, reduced processing speed due to a brain lesion in general might not be sufficient to explain the marked RT differences to control subjects evident in the present study. Rather, in the recent research literature, non-spatial, non-lateralized deficits of attentional aspects such as alertness or sustained attention in neglect patients have been found to be relevant and to substantially contribute to slowed overall performance (e.g. Samuelsson et al., 1998; Husain & Rorden, 2003) .

Slowing of RTs to contralesional targets. The patient group showed a main effect of the target's half-field position on RTs, namely a marked slowing of target detection in the left part of the display. The effect was evident in all experimental conditions, that is, in single and dual target trials and independent of target dimension. This is a finding common to studies of visual search with neglect patients (e.g. Halligan & Marshall, 1993; Hildebrandt et al., 1999; Posner et al., 1984).

The present result of a significant effect of half-field in patients' feature search performance might also contribute to the debate of whether or not visual attention is involved in the type of visual search thought to be parallel in nature. Although display size was not manipulated in the present experiment, and therefore search slopes could not be analyzed with respect to potential effects of additional items,

one would expect similar search times in both half-fields when assuming unimpaired feature search.

This expectation is in contrast to studies reporting unaffected visual feature search performance in patients with neglect (Aglioti et al., 1997; Arguin et al., 1993; Esterman et al., 2000, Brook, Wong, and Robertson, 2005). However, the present finding is consistent with several other authors describing impaired performance in patients with neglect not only in serial (conjunction) search tasks but also in simple feature search (Riddoch and Humphreys, 1983; Eglin et al., 1989; Rapcsak et al., 1989; Pavlovskaya et al., 2002). In a recent paper, Behrmann et al. (2004) compared feature and conjunction search in a large sample of patients with neglect of various aetiologies and degrees of severity. The results showed a clear slowing of RTs with increasing display size in the feature search task that was not observed in controls. The authors listed a number of possible factors that might account for the discrepancy of the results of the different studies, such as hemispheric side of brain lesion and symptom severity. Patients with right-hemisphere damage exhibiting severe neglect performed worst. The authors further suggested that the dichotomy between pre-attentive feature and attentive conjunction search should be rejected and instead proposed a competition mechanism to determine the efficiency of attentional selection.

Alternatively, Brooks, Wong, and Robertson (2005) suggested that feature search in the neglected field can be executed in parallel. The finding of increased RTs would

only reflect that the features exceed the detection threshold later than features in the spared (unimpaired) field. In their study, detection thresholds for a target presented in uni- or bilateral displays of various set size were measured in a patient with unilateral neglect. Though left unilateral presentation times were longer for a level of 75% correct responses, there was no influence of the number of distractors surrounding the target. Thus, there was a preserved but slowed pop-out search in this patient.

As is known from the literature, neglect patients often show a disorganized search pattern with a marked preference to start their search on items displayed in the ipsilateral field and difficulties to disengage from this side of visual space even if instructed to do so (Eglin, Robertson, and Knight, 1991). Moreover, in large visual displays crowded with many items distributed across both half-fields (as it was the case in the present experiment), neglect patients show a greater impairments in terms of response time than control patients with brain lesions but without neglect. This observation led to the assumption that neglect behaviour has a strong extinction-like component, that is, neglect of contra-lesional stimulation may be much stronger if a second stimulus is simultaneously presented to the non-affected side of the visual field (e.g. Kinsbourne, 1987).

In agreement with this finding, patients' response times were slowed when dual targets were presented one in each half-field. Despite overall faster RTs to dual target trials compared to single target trials, bilateral dual targets were even slightly slowed

compared to the faster single target conditions.

Differential numerical and dimension-based redundancy gains. Enhanced performance due to 'enriched' stimulation has been shown also on a supra-modal processing level. Frassinetti et al. (2002) investigated cross-modal, audiovisual integration in patients with visual impairment due to a visuospatial attentional deficits (e.g. neglect). Patients were instructed to detect visual stimuli presented in isolation or in combination with auditory stimuli that could be spatially aligned or dis-aligned relative to the visual stimuli. The results showed an enhancement of visual detection performance of patients in the cross-modal condition (spatially aligned condition) compared to the (unimodal) visual condition.

Intertrial influence of dimension and half-field. Importantly, the neglect patients of the present study showed a clear effect of dimension-based changes across trials. Relative to the repetition of the target-defining dimension in consecutive trials (e.g. colour-colour), there were RT costs associated with the change in target dimension (e.g. colour-orientation). Thus, with respect to dimension-based effects, patients did not differ from healthy controls. However, only in the patient group, the dimension-based intertrial effect was modulated by the halffield (location) in which the target of consecutive trials were displayed. That is, when a change of the target dimension was accompanied by a change in the target's half-field position, dimensional change costs were markedly reduced.

These results are in part consistent with a recent study by Kristjansson, Vuilleumier, Malhotra, Husain and Driver (2005). These authors tested two neglect patients in order to determine whether priming of pop-out search by colour and/or location were evident in patients with unilateral neglect of the left visual half-field. Further, they tested whether, in the case that a priming effect was observed, the patients' search performance would improve and whether potential beneficial effects would be due only to targets presented in the intact right hemifield, or, alternatively, to targets displayed in the left and the right hemifield.

Based on an experimental task previously used by Maljkovic and Nakayama (1994, 1996, and 2002) patients were presented with three diamond-shaped objects located at upper, left and right vertices of a virtual triangular outline pointing upwards and located in the center of the visual field. The singleton pop-out target was defined by its different colour relative to the other two items; observers had to judge which of the diamond points was missing (top or bottom). To test for priming, the singleton's colour, location or both were repeated over trials. Similar to the results of the present study, Kristjansson et al. found (1) an overall slowing of RTs relative to control subjects, (2) increased RTs to left side targets, and (3) a main effect of both colour and position priming.

Interestingly, in Experiment 3 of Kristjansson et al.'s study, stimulus presentation time was reduced such that some of the left-sided targets escaped the observers' awareness. While colour priming was nevertheless observed, there was no priming

effect of the target location for targets which had not been consciously perceived. Thus, location priming was observed only when the 'prime' was consciously perceived and detected in the previous trial.

The present findings concerning the change vs. repetition of target location (i.e. halffield) it appeared that this was less dependent on change vs. no change of halffield but rather the direction of change. While a change from left to the right halffield resulted in slowed target detection in a given trial, RTs were expedited when the target location changed from the left to the right halffield or within the right halffield.

Duncan et al. (1999) suggested a link between general processing capacity and the attentional wheighting of stimulus attributes based on Bundesen's TVA (Bundesen, 1990; Bundesen, Habekost, & Kyllingsbaek, 2005). Although the concept of weighting differs in several aspects from the dimensional weighting mechanisms of the DWA, Duncan's account might serve as an interesting approach to explain the interaction of halffield change and dimension-based change effects found in the present study.

Implications for Neglect. Neglect is commonly defined as inattention to items or events in the contralateral hemi-space of the patient's lesion site that results in unawareness for stimulation in the contra-lateral hemi-field. This severe state is often transient with patients visual abilities recovering to marked degree, but in many patients more subtle deficits remain with disabling effects on patients' lives. Although

the patients of the present study were in chronic phases of neglect, they showed an overall reduced processing speed that was particularly marked for target items located in the half-field contra-lateral to their brain lesion. However, performance considerably improved when patients were provided with numerically redundant visual information (two instead of one target item). This finding is consistent with the RSE observed in healthy subjects. Interestingly, in the neglect patients, the redundancy gain, the reduction in (search) time from display onset to target detection, was largest in conditions of numerical redundant targets displayed in the contra-lesional half-field.

Bilateral presentation of redundant information also improved performance when this redundancy was not only numerical (single vs. dual targets) but also dimension-based. While similar targets (e.g. orientation-defined), if presented each in one half-field rather impeded than expedited detection times compared to one-sided presentation, bilateral targets defined in two different dimensions were beneficial. The knowledge of residual deficits in patients with chronic neglect and an understanding of the factors that improve the speed and accuracy of stimulus processing within the visual field of these patients might help to enforce the use of rehabilitation strategies not only immediately after the occurrence of a stroke but also at later points in time.

4 Visual feature search in left-frontopolar patients

4.1 Introduction

In functional magnetic resonance imaging experiments with non-brain-injured participants (Pollmann, Weidner, Müller & von Cramon, 2000 ; Weidner, Pollmann, Müller & von Cramon, 2002), left lateral frontopolar activation was found to be associated with trial-to-trial changes in the target-defining dimension in a visual singleton search task. Behavioral experiments using the same paradigm suggest that dimension changes (e.g., from a color-defined to a motion-defined target), but not feature changes *within* a dimension (e.g., from a red to a blue color-defined target), trigger a reallocation of attentional resources, or 'weight' (cf. Duncan & Humphreys, 1989) from the old to the new target dimension (Found & Müller, 1996; Müller, Heller & Ziegler, 1995). Potential target-defining dimensions (i.e.,

dimensions in which the target might differ from non-targets) are assigned weight in accordance with their instructed importance and their variability across trials. Target detection requires that the target-defining dimension is weighted sufficiently to amplify the saliency signal generated within this dimension above the detection threshold. Dimension changes incur a cost because attentional weight must be shifted from the old to the new dimension. This notion was recently confirmed by the observation that, in singleton feature search, visual input areas for color and motion processing show increased activation for cross-trial epochs of targets defined within the color and motion dimensions, respectively (Pollmann, Weidner, Müller, & von Cramon, in press). While Pollmann et al. (2000) have found left lateral frontopolar activation to be specifically associated with stimulus-driven dimension-changes in singleton feature search (where the target differs from the nontargets in a single feature), Weidner et al. (2002, Experiment 1) found top-down controlled dimension changes in singleton conjunction search (where the target differs from the nontargets in a conjunction of features) to be associated with increased activation in pregenual paracingulate cortex. In Experiment 2 of Weidner et al., the same participants who had taken part in Experiment 1 performed, within a single fMRI-session, the singleton feature search task in which stimulus-driven dimension changes were observed and the singleton conjunction search task in which dimension changes were top-down controlled. In confirmation of the previous data, a *double dissociation* was observed such that lateral frontopolar cortex showed a sig-

nal increase with stimulus-driven dimension changes, but not top-down-controlled dimension changes, whereas pregenual frontomedian cortex showed a signal increase with top-down controlled, but not stimulus-driven dimension changes. The authors postulated that left lateral frontopolar cortex is involved in the control of stimulus-driven and frontomedian cortex in top-down-controlled attentional weight allocation to visual dimensions (for details, see Pollmann, 2001, 2004). Functional activation, however, does not necessarily imply that these areas actively facilitate attention shifts between visual dimensions. Instead, frontopolar activation may reflect some process, such as monitoring or change detection, that accompanies dimension changes without directly contributing to visual dimension weighting. However, if left frontopolar cortex supports a process which is necessary for the reallocation of attentional resources from the old to the new dimension when the target-defining dimension changes in singleton feature search, a lesion in this area should give rise to increased dimension change costs. Involvement of left lateral frontopolar cortex in stimulus-driven attention changes in an efficient visual search task such as the one used in our fMRI studies was initially unexpected, because this area is typically thought to be involved in complex tasks that require the integration of multiple cognitive processes (for a recent review, see Ramnani & Owen, 2004). Furthermore, frontopolar activation is not routinely observed in studies of visual attention shifts. Shifts of visuo-spatial attention have not usually led to frontopolar activation (e.g., Corbetta et al., 1998; Gitelman, Nobre, Parrish, LaBar, Kim, Meyer,

and Mesulam, 1999; Pollmann, & Morrillo, 2003; Vandenberghe, Gitelman, Parrish, & Mesulam, 2001; Yantis, Schwarzbach, Serences, Carlson, Steinmetz, Pekar, and Courtney, 2002). Left frontopolar activation was observed, however, to be increased in trials with invalid, compared with valid, exogenous (peripheral) cues in a spatial cueing paradigm (Lepsien & Pollmann, 2002). Likewise, frontopolar activation was not consistently observed in studies of featural attention changes (Liu, Slotnick, Serences, and Yantis, 2003). Büchel et al. (1998) found a left lateral frontopolar activation related to attention to motion (see their Figure 1), but did not further comment on it in the text, presumably because it failed to exceed their significance level. For endogenous motion cueing, an anterior cingulate activation was reported (Luks & Simpson, 2004), near the location of our pregenual ACC-activation for top-down controlled visual dimension changes (Weidner et al., 2002). Many studies of featural attention selectively imaged posterior brain areas (Beauchamp, Cox, & DeYoe, 1997; Culham et al., 1998), which limits the database relating to prefrontal contributions to featural (or dimensional) attention. Thus, no clear picture emerges as to the role of anterior prefrontal areas in the allocation of attention to features or dimensions. Given this, the present study was designed to investigate whether left lateral frontopolar cortex contributes actively to attention shifts between visual dimensions, or whether the frontopolar activation reflects some process that accompanies visual dimension changes without actively facilitating attention shifts. To answer this question, the performance of patients with left lateral frontopolar

lesions was examined in visual singleton search. If left frontopolar cortex facilitates the shift of attentional resources from the old to the new dimension when the target-defining dimension changes in singleton feature search, a lesion in this area should slow down this reallocation of resources, leading to increased search times on trials on which the target-defining dimension changes relative to that in the preceding trial, compared to trials on which the target-defining dimension remains the same. A group of patients with left frontopolar lesions was tested in a cross-dimensional singleton feature search paradigm. Based on our fMRI findings, it was predicted that lesions of left lateral frontopolar cortex, but not frontomedian lesions, would lead to increased dimension change costs in singleton feature search. These costs were predicted to be specific to changes between visual dimension, that is, they were not expected to be observed for changes of feature values within a repeated visual dimension.

4.2 Methods

Patients. Former patients of the Day Clinic of Cognitive Neurology of the University of Leipzig were tested. Written informed consent was obtained following the guidelines of the Max-Planck-Institute for Human Cognitive and Brain Sciences, Leipzig. The former patients and the normal control participants were paid for their participation. A description of the patient sample is given in Tables 4.1 and 4.2. Individual lesions were manually segmented on the transverse slice of the MR

images. All images were spatially coregistered to correct for position, orientation, image dimension, and head size to generate a lesion density map of the lateral and the medial lesion group.

The *lateral frontopolar group* consisted of four patients who had lesions that overlapped with or bordered the lateral frontopolar activation focus, at the lateral bank of the intermediate sulcus, in a previous fMRI-experiment with normal participants (Weidner et al., 2002, Experiment 2). The lesions which bordered the activation maximum disconnected this area from the lateral-posterior parts of prefrontal cortex.

The *frontomedian group* consisted of seven patients who had lesions which overlapped with the frontomedian activation focus.

Within left anterior prefrontal cortex, there was a clear demarcation between areas in which the percentage of lesions in the lateral group was higher than in the medial group and vice versa. This demarcation can be described by a line running approximately in parallel to the limb of the forceps minor from the anterior horn of the ventricle to the frontolateral convexity. The activation focus obtained for stimulus-driven dimension changes in non brain-damaged participants lay in the area that was dominantly affected by lesions in the lateral frontopolar group. In contrast, the activation focus observed with top-down controlled dimension changes lay within the area dominantly affected by lesions in the frontomedian group. Lesions in right anterior prefrontal cortex were dominantly observed in the frontomedian group.

Table 4.1: *Clinical and demographic characteristics of patients with lateral frontopolar lesions. AcoA = Arteria communicans anterior, FMC = frontomedian Cortex, CC = Corpus callosum, TBI = traumatic brain injury.*

ID	GENDER	ETIOLOGY	LESION SITES	ACCESSORY LESIONS
Lateral frontopolar group				
197	**F**	AcoA aneurysm (ruptured): perioperative and postoperative (vasospastic) lesions	Left lateral frontal and lateral orbitofrontal (lateral orbital and posterior orbital gyrus lesioned).FMC intact	left anterior basal ganglia (caudate nucleus, putamen, internal capsule), CC
342	**M**	traffic accident: severe blunt TBI	Bilateral frontal contusion: frontal pole and aFMC. Focus on left lateral frontal pole. (Gyrus rectus, medial and anterior orbital gyrus bilaterally, right lateral and posterior orbital gyrus)	bilateral anterior temporal contusion
467	**F**	AcoA aneurysm (ruptured): perioperative and postoperative (vasospastic) lesions	Left lateral frontal and lateral orbitofrontal (left, anterior, lateral, and posterior orbital gyrus, posterior part of medial orbital gyrus) . Left subcallosal FMC. Right FMC and medial orbitofrontal (right Gyrus rectus and medial orbital gyrus).	bilateral septal region, CC
589	**m**	fall: severe open TBI.	Bilateral orbitofrontal and basal aFMC; (Left anterior gyrus rectus, medial and anterior orbital gyrus. Right Gyrus rectus and medial orbital gyrus).	Traumatic hemorrhages left caudate nucleus and left minor forceps. Left lateral precentral region. CC

This, however, was due to a selection criterion, in that left lateral frontopolar lesions were selected, in keeping with left lateral frontopolar activation data previously found with normal participants.

Stimuli & Procedure. Displays contained either 5x5, 6x6, or 7x7 items. The latter displays had extended 14° x 14° of visual angle. Displays consisted of green vertical bars, each sized 0.2° x 0.8°. In 50% of the trials, one of the green bars was replaced by a target. There were four different targets, two, red or blue vertical

Table 4.2: *Clinical and demographic characteristics of patients with frontomedian lesions. AcoA = Arteria communicans anterior, FMC = frontomedian Cortex, CC = Corpus callosum, TBI = traumatic brain injury.*

ID	GENDER	ETIOLOGY	LESION SITES	ACCESSORY LESIONS
Frontomedian group				
150	**M**	traffic accident: severe blunt TBI	Bilateral frontopolar und anterior orbitofrontal. Bilateral aFMC. (Gyrus rectus, medial orbital, and anterior orbital gyrus bilaterally lesioned).	Minor contusion right inferior frontal and anterior temporal. Traumatic microbleed left lower midbrain and left posterior thalamus.
188	**M**	severe open TBI caused by a hit with a heavy object.	Bilateral frontopolar, right orbitofrontal. (anterior parts of Gyrus rectus and medial orbital gyrus bilaterally).	Minor right temporopolar lesion. Initially subarchnoid and peridural hemorrhage posterior fossa and left occipital convexity.
203	**F**	Olfactory meningeoma with large perifocal edema.	Bilateral medial orbitofrontal and aFMC. Medial frontal pole. (anterior parts of gyrus rectus and medial orbital gyrus bilaterally lesioned)	none
291	**M**	traffic accident: severe blunt TBI	Contusion left lateral frontal and frontopolar region. Bilateral medial orbitofrontal. (left anterior Gyrus rectus, anterior medial orbital gyrus lesioned; left anterior, lateral, and posterior orbital gyri. right anterior gyrus rectus and anterior medial orbital gyrus).	Diffuse axonal injury; anterior and lateral temporal contusions.
300	**M**	traffic accident: severe blunt TBI (1980)	Bilateral frontal and orbitofrontal contusions. Frontal pole and aFMC bilaterally. (Gyrus rectus, medial and lateral orbital gyri bilaterally lesioned).	Left inferior frontal gyrus.
480	**M**	traffic accident: severe blunt TBI	Bilateral orbitofrontal contusions. **(**Gyrus rectus, anterior parts of medial orbital gyrus lesioned)	Traumatic microbleeds frontolateral white matter and anterior insula bilaterally and splenium of CC. Bilateral anterior temporal contsions. Minor right frontolateral lesion (inferior frontal Gyrus).
520		fall: blunt TBI	bilateral frontal hemorrhagic contusions. Medial and lateral orbitofrontal lesion bilaterally**.** left basal aFMC and right basal FMC and both frontal poles lesioned.	Minor right anterior temporal contusion

bars, defined by their color, and the other two, green bars tilted 45° to the left or the right, defined by their orientation. Targets and distractors were isoluminant ($4.3cd/m^2$), presented on a black background ($0.5cd/m^2$). Targets were presented equiprobable at all locations within the display matrix, with the exception of the marginal positions. The experiment was run in a dimly lit room. Participants viewed the displays at a distance of 100 cm. Displays were presented for maximally

5 seconds or until a response was given. Participants responded with a forced-choice key press to target presence (right index finger) or target absence (left index finger). After an inter-trial interval of 1500 ms, the next display was presented. Blocks of 48 trials were separated by breaks, the duration of which could be chosen by the participant (minimum 5 seconds). The experiment consisted of 13 blocks. The first, practice, block of 24 trials contained all possible target types and display sizes. The data of this block were discarded. The remaining 12 blocks consisted of 6 cross-dimension search blocks with a total of 528 trials, which contained both color- and orientation-defined targets. Of the remaining six within-dimension search blocks of 480 trials in total, three contained only color-defined targets and three only orientation-defined targets. Within blocks, the different trial types were presented in pseudo-randomized order. The sequence of blocks was varied such that the same condition was not repeated in immediately successive blocks.

4.3 Results

Behavioural Data. Based on our previous imaging studies, expected increased stimulus-driven dimension change costs were expected in patients with left lateral frontopolar lesions, in contrast to patients with frontomedian lesions. According to our hypothesis that left lateral frontopolar cortex is specifically involved in visual dimension changes, further it was expected that changes between target-defining features within a dimension would not lead to enhanced costs in the same patients.

Accordingly, a repeated measures analysis of variance (ANOVA) was carried out on the change costs with *type of change* (dimension change versus feature change) as within-subjects factor and *lesion location* (lateral versus medial frontopolar lesions) as between-subjects factor. The ANOVA yielded significant main effects for lesion location ($F(1,9) = 20.37; p < 0.05$) and change ($F(1,9) = 60.86, ; p < 0.05$), and a significant interaction ($F(1,9) = 21.68; p < 0.05$). Patients with lateral frontopolar lesions exhibited higher dimension change costs than the patients with frontomedian lesions. Both groups displayed higher dimension change costs than feature change costs. The interaction reflected a differential increase in dimension change costs in the lateral frontopolar patients. These results are illustrated in Figure 4.1.

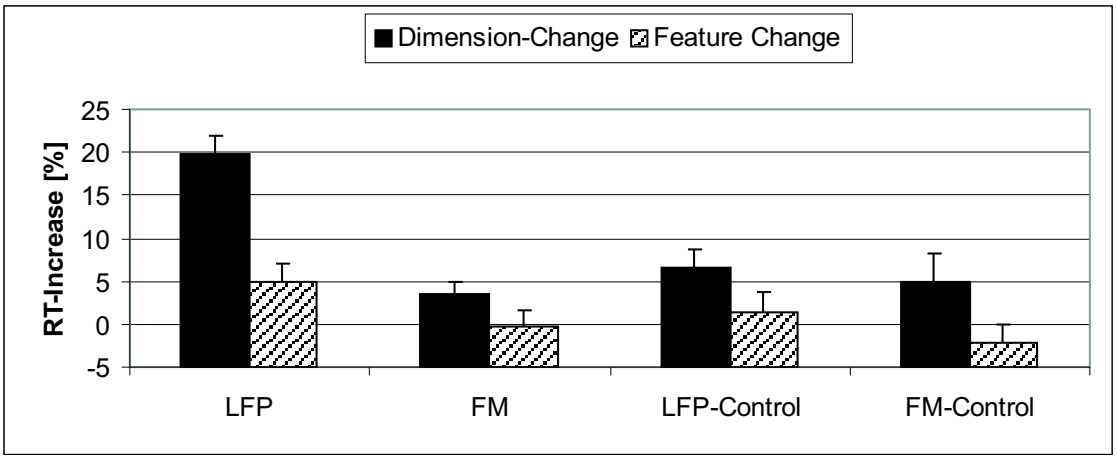

Fig. 4.1: Normalized change costs on reaction times in the singleton feature search experiment as a function of change type and group. LFP: left frontopolar patients, FM: frontomedian patients.

Higher dimension change costs in the LFP compared to the FM patients may theoretically come about by decreased dimension change cost in the latter, instead

of increased dimension change costs in the former patients. To rule out this explanation, the search times of both patient groups was compared with the search times obtained for matched non brain-lesioned control groups. Compared to their normal controls, LFP patients displayed higher change costs overall, and specifically increased dimension change costs. An ANOVA with *change type* (dimension change versus feature change) as within-subjects factor and *group* (LFP patients, LFP controls) as between-subjects factor yielded significant main effects for change ($F(1,6) = 7.61; p < 0.05$) and group ($F(1,6) = 27.9; p < 0.05$), and a significant interaction ($F(1,6) = 6.53; p < 0.05$). In contrast, FM patients did not differ from their normal controls in overall change costs ($F(1,12) = .05; p > 0.05$). Dimension changes led to higher costs than feature changes ($F(1,12) = 55.7; p < 0.05$). Dimension change costs were comparable in both groups (4% increase in the patients, 5% in the controls). Relative to feature change costs, dimension change costs were actually higher in the control group, leading to a significant change type x group interaction ($F(1,12) = 5.57 : p < 0.05$).

Only few errors were made, both in the patient and control groups (Table 4.3). As Levene's test for equality of variances did not indicate any significant violations of this assumption, two-tailed t-tests for equal variances were calculated. The two patient groups did not differ significantly in either total errors ($t(9) = 0.71; p < .05$) or misses ($t(9) = 0.08; p > .05$), but the LFP patients made more false alarms ($t(9) = 2.27; p < 0.05$). The LFP patients displayed a higher percentage of total

errors compared to their control group ($t(6) = 2.86; p < .05$), though neither the miss nor the false-alarm rate comparisons were significant ($t(6) = 1.43; p > .05$), and ($t(6) = 2.00; p > .05$), respectively. The FM patients did not differ from their control group in either total errors ($t(12) = 0.19; p > .05$), misses ($t(12) = 0.34; p > .05$), or false alarms ($t(12) = 0.51; p > .05$). Finally, both control groups did not differ significantly in total errors ($t(9) = 1.82; p > .05$), misses ($t(9) = 1.40; p > .05$), or false alarms ($t(9) = 0.71; p > .05$).

Table 4.3: *Error rates (in percent) for the patient and control groups.*

		Patient group:			
		LFP	*FM*	*LFP-Control*	*FM-Control*
Type of error:	*total*	2,1	1,4	0,2	1,2
	misses	2,5	2,3	0,2	1,9
	false alarms	1,6	0,4	0,3	0,6

4.4 Discussion

Based on previous fMRI-experiments with non-brain-injured participants (Pollmann et al., 2000; Weidner et al., 2002), it was hypothesized that left lateral frontopolar cortex would be involved in shifts of attention between visual dimensions. Here, this hypothesis was tested by examining dimension change costs in a visual singleton feature search task in patients with frontopolar lesions. Increased dimension change costs were found in patients with left lateral frontopolar lesions, compared

with patients with frontomedian lesions as well as with non-brain-injured controls. This pattern thus converges with the dimension-change-related lateral frontopolar increase of the fMRI signal in non-brain-injured participants and supports the hypothesis that left lateral frontopolar cortex is genuinely involved in stimulus-driven visual dimension weighting. Most accounts of frontopolar function are based on tasks making complex cognitive demands. Accordingly, they postulate frontopolar contributions to high-level cognitive processing, such as 'cognitive branching', the combining of working memory retention with dual-task processing (Koechlin et al., 1999, 2000), the use of self-generated information (Christoff, Ream, Geddes, & Gabrieli, 2003), or the integration of multiple higher cognitive processes (for a recent review, see Ramnani & Owen, 2004). At first sight, all of these accounts fail to explain the finding of frontopolar dimension change-related activation in our singleton feature search paradigm, which is neither demanding on working memory (see Müller, Krummenacher, & Heller, 2004) nor on executive functions. However, there are parallels between these accounts and the present paradigm. Dimension changes in singleton feature search require changes (although attentional changes rather than task changes) and they require an interaction of attention with memory (although not working memory), as it will be now discussed.

4.4.1 Lateral frontopolar cortex and change-related behavior.

Instead, it is proposed that left lateral frontopolar cortex supports changes of attention when the need to shift attention is not explicitly indicated by specific stimulus attributes (e.g. an arrow pointing to the target location) or task instructions. Dimension-change-related activation in left lateral frontopolar cortex in singleton feature search has been demonstrated (Pollmann et al., 2000; Weidner et al., 2002). The selective increase of dimension change costs in the LFP patients in the current study supports the notion that this structure facilitates the allocation of attentional resources from the old to the new target-defining dimension. However, frontopolar cortex appears to support attention changes only under specific conditions. Anterior prefrontal cortex was not usually related to shifts of (visuo-spatial and featural) attention in previous imaging studies. One characteristic of cross-dimensional singleton search that sets it apart from most previous studies of attention shifts is the uncertainty about the target-defining dimension on a given trial. In standard visual search, participants are instructed to search for a specific target (e.g., a red X). When a change occurs, participants are typically informed in advance. This is different in singleton search. Here, participants have to respond to an odd-one out stimulus, but they do not know how the singleton will differ from the distractors. In particular, the uncertainty about which visual dimension will contain the unique target-defining feature gives rise to reaction time costs in detecting the singleton (see

Müller et al., 1995; Found & Müller, 1996, and Müller et al., 2004, who reasoned that singleton feature detection in cross-dimensional search requires at least implicit determination of the target-defining dimension). Anterior prefrontal activation has been observed in other change paradigms which share a component of uncertainty, such as the ambiguous target-defining dimensions in the Wisconsin Card Sorting Test (WCST, Grant & Berg, 1948; Nagahama et al., 2001; Rogers et al., 2000), and ambiguous word primes in cued recall (Henson, Shallice, Josephs, & Dolan, 2002). Taken together, this evidence may suggest that anterior prefrontal cortex is involved in the active search for relevant information under conditions of uncertainty.

4.4.2 Lateral frontopolar cortex and episodic memory.

Detection of task-relevant changes (e.g., a change in the target-defining dimension) requires the comparison of stimulus attributes (such as the color and movement direction of the singleton) between the current and the previous trial. Frontopolar cortex is reliably activated during this kind of episodic memory retrieval (Christoff & Gabrieli, 2000; Rugg & Wilding, 2000). Furthermore, activation strength in frontopolar cortex correlates with the amount of proactive interference (Henson et al., 2002), which may also indicate that frontopolar cortex is involved in change detection. A comparison between previous and current stimulus characteristics may be especially important in tasks that permit automatic processing, in order to maintain the ability to respond optimally to changes in the environment. Such a comparison

depends on what has been termed 'source memory', that is, memory under what circumstances a particular item was encoded. Recently, left frontopolar cortex, though more lateral and inferior than the activations found in our studies, was reported to support source memory selectively (Dobbins, Foley, Schacter, & Wagner, 2002). More posterior left inferior frontal areas, in contrast, showed activations related to both source and item memory. Left lateral frontopolar activation was also observed in tasks requiring the recollection of contextual information, specifically, in which task a particular item was previously encountered. In contrast, no frontopolar activation was found for the recollection of the list membership of repeated items, underlining the specificity of the frontopolar involvement in the recollection of task-related details (Simons et al., 2005). These findings fit well with the concept of task-related change detection in left lateral frontopolar cortex, which, in turn, leads to a reallocation of attentional resources in order to adapt to a change in task demands. The data presented here fit into this framework if task-related information is not narrowly seen as related to switching operations between tasks, but also to changes of attentional allocation for the optimal performance within the same task, in our case singleton feature search.

To conclude, a specific increase in dimension change costs were observed in a singleton feature search task in patients with left lateral anterior prefrontal lesions, compared both with patients with anterior frontomedian lesions and controls without brain lesions. This finding agrees with dimension change-related activation in

previous event-related fMRI studies with normal subjects and supports the proposal that left lateral frontopolar cortex is involved in the reallocation of attention from the old to the new target-defining dimension in visual singleton feature search. The specific role of this brain area in the reallocation of attention may be episodic change detection, which enables the organism to reallocate attentional resources according to changing task demands. This specific hypothesis, however, needs to be investigated in further research.

5 General Discussion

The thesis presented here was mainly concerned with exploring further the role of dimension-based processing in visual feature search. In particular, the influence of spatial aspects of search displays on search performance, i.e. changes in target positions within and across half-fields, and effects of dimensional change were examined in both healthy observers and patients with visual-spatial deficits (visual neglect). In addition, it was investigated whether the beneficial effect of presenting numerical and/or dimensional redundant target information on search performance is similar in healthy observers and neglect patients. Further, the role of the left lateral fronto-polar cortex in the control of dimension-based changes in visual search was examined in patients with damage to this structure previously found to be specifically activated in association with changes of target-defining dimensions.

Top-down influence on dimension-specific effects in feature search: the role of expectation

In Chapter 2 two types of visual search tasks were compared with respect to dimension–based intertrial effects and their susceptibility to spatial aspects of the display: simple feature search expected to be executed without focused spatial attention, and compound search tasks combining search for a feature target and discrimination of a response-relevant (additional) feature of the target item within one trial. Firstly, in search for pop-out targets of varying dimensional definitions across trials, greater distances between targets of subsequent trials resulted in slower RTs. Whether the change of the target's position involved a half-field change or not, however, did not affect RTs. The change of the target-defining dimension in subsequent trials resulted in RT costs. This dimension-specific change effect was neither modulated by the distance of the target positions in consecutive trials nor by changes of the half-field.

Traditional accounts of efficient detection of pop-out targets assume automatic processing mechanisms independent of limited-capacity, attentional, resources, and, thus, do not predict any effects of the target's spatial characteristic within a display (e.g. Treisman & Gelade, 1980; Wolfe, 1992). The effect of distance between target positions in subsequent trials in simple feature search is consistent with claims made in recent theoretical accounts of pop-out search arguing against a strict dichotomy of parallel (feature) and serial (compound) search. While feature detection might pro-

ceed rapidly, the spatial position of the target is encoded and might be used to guide attention preferentially to the area where the target was encountered previously.

The compound task, combining target detection and discrimination also revealed dimension-specific intertrial effects. Similar to the feature search task, dimension change costs did not interact with target distance or a half-field change of target position. This result is at variance with work by Kumada (2001) and Theeuves (2004) who failed to find dimensional effects in compound tasks. In contrast, Olivers and Humphreys (2003) found clear evidence for intertrial effects in the search for a compound target.

In the compound task, observers first had to find a pop-out target, defined in one of two possible dimensions which provided the information required to allocate the attentional weight. In a subsequent trial the dimensional definition of the target either remained constant or changed to the other feature dimension. Within the same trial, observers also had to judge the position of a gap in the target item, with gaps located in the upper half of the item requiring a right-hand and those in the lower half a left-hand response. Similar to the dimensional definition of the target, the position of the gap either remained constant or changed across trials. Thus, when a trial started, observers first needed to find out whether the target dimension had changed or not, and, subsequently, dependent on gap position, discovered which response hand to use. That is, dimensional definition and response-related information of the target were independent of each other.

However, the results showed a significant interaction between dimension change and response hand change. A change in the target-defining dimension across trials reduced the RT costs observed in connection with a change of the response hand. The hand change cost was only evident if the target dimension remained constant across two consecutive trials.

This finding might be explained by the concept of 'combined expectancies' (Kingstone, 1992). Combined expectancies refers to the assumption, that, if the observer, in a given trial, finds the target to be defined on the same dimension as in the previous trial, he/she might implicitly expect the same to be true for the response hand. Due to this anticipation, response times will be expedited if the response hand remains unchanged. In contrast, if the dimension remains constant, yet the response hand changes (against the observer's expectation) there will be RT costs. However, a change in the target dimension relative to the previous trial, encountered at an earlier stage of processing within a given trial might, in addition to deleting the dimension-based intertrial memory, extinguish the intertrial expectancies concerning the response hand as well.

In both (the feature search and the compound) tasks, the observed effects of displacement of the target location in the display across consecutive trials were not completely linear. Contrary to expectation, RTs were not fastest if targets appeared at exactly the same location in consecutive trials. Rather, targets at positions adjacent to the target location in previous trials were detected fastest. This result

might be due to an inhibitory process referred to as 'inhibition of return' (IOR) thought to reflect a mechanism that prevents the focus of attention from being re-oriented back to a previously attended location, thus supporting orienting of the attentional focus towards novel locations (and/or objects/events) (Klein, 2000). IOR has typically been investigated using different types of cues (symbolic: arrows; direct: flash) indicating potential target locations rather than in search paradigms. However, if one assumes the first target in a sequence of trials to serve as cue, the similarity in the course of events becomes evident.

Taken together, there are priming effects of the target position even in a search for targets assumed to be detected in parallel across the search field. The effects of position appeared in addition to dimension-specific intertrial effects, however, the two types of effect did not interact with each other. This indicates that spatial and non-spatial attentional mechanisms might work together in order to render search more effective. However, they operate independent of each other.

Preserved dimension-based processing in patients with neglect

Disturbed visual search is one characteristic manifestation of visual neglect. Neglect patients tend to fail to detect contralesional targets in some search tasks and there have been controversial findings as to the issue of whether or not simple feature search might escape the deficits typically found in neglect. In a visual search task for

pop-out targets within and across the two half-fields of the search display, patients with left visual neglect showed overall slowed RTs compared to healthy controls and a specific increase in RTs for targets located in the left half of the display. This result is in accord with previous studies reporting impaired feature search in patients with neglect (e.g. Pavlovskaya et al., 2002; Behrmann et al., 2004). It also supports proposals that even feature search, typically assumed to be performed pre-attentively, requires the allocation of some amount of attentional resources (Joseph, Chun, & Nakayama, 1997) .

However, despite the deficits observed in neglect patients performing visual search tasks, there are residual visual functions that survive the lesion. There has been a wealth of work showing that the presence, colour, shape, and even the identity or category of neglected or extinguished objects may still be unconsciously extracted by intact brain structures in the patients' visual system (e.g. Berti, 2003; Driver & Vuilleumier, 2001, for reviews).

In line with this observation, patients in the present study showed intertrial effects for the target defining dimension. A change of target-defining dimension was found to impede performance, i.e. to increase RTs, compared to a two-trial sequence with targets defined in the same dimension. Thus, neglect patients showed 'normal' dimensional change effects. This finding is in accordance with the findings of Kristjansson et al. (2005) who found priming-of-popout for visual search, by repeated target location or colour in two neglect patients. Interestingly, in the study by Krist-

jansson et al., colour priming was found regardless of whether a preceding target in the left hemi-field had escaped the patients' awareness. In contrast, location priming required awareness of the preceding left target.

In the present experiment, in contrast to healthy controls, dimension-based processing did interact with a change of the target's half-field position across trials. The interaction was based on a stronger dimension change effect (higher RT cost), if the dimension change was not accompanied with a change of the target's half-field location. In contrast, the dimension change effect was smaller when it was associated with a half-field change. This seems to indicate that the dimension change and target location change, in patients, work in an interdependent fashion.

Furthermore, there were other aspects of the display that proved to be beneficial to the patients' performance. Numerical redundancy, that is, the presentation of two instead of only one search target in the display, expedited reaction times. Interestingly, this benefit was more pronounced for targets presented in the left, impaired, half-field. This increased RT redundancy gain is evident if RTs are compared with RT gains to (numerical) dual targets presented both in the right half-field and bilaterally.

Evidence from the first two experiments (Chapter 2) indicates a conjoint, yet independent influence of spatial and non-spatial attentional factors in visual search. The results of the patients suffering from visual-spatial neglect indicate preserved non-spatial, dimension-based processing, whereas at the same time, spatial aspects

of attention are severely impaired.

Another interesting approach was recently presented by Ricci & Chatterjee (2004). They investigated the effects of stimulus characteristics and response modalities on the sensory discriminability within the contra-lesional hemi-field of two patients with visual extinction. Using signal detection measures (sensitivity d' and response criterion c), they were able to describe the observers' response behaviour in greater detail. For example, one of their patients exhibited more marked extinction in a task with higher attentional load. Signal detection analysis revealed that this change in awareness of the contra-lesional stimulus was not due to a decrease in sensory discriminability but to a change of the patient's response criterion. Future experiments based on investigations into the effects underlying attentional influences (i.e. sensitivity vs. criterion effects; Müller & Rabbitt, 1989), and on the recent study described above, should use signal detection theory to separate sensitivity and criterion effects in singleton search within and across dimensions.

Furthermore, a marked difference in performance in visual search was found between neglect patients and healthy age-matched controls. Even though most patients showed only mild signs of neglect in standard clinical testing, their performance implied an overall reduced processing speed as well as a clear asymmetry with impaired left-side performance. Future studies should clarify the clinical relevance of these more subtle deficits also in later stages of recovery from brain damage.

In addition, search behaviour of the group of healthy elderly participants appeared

to be significantly different from that of both the patient group and a group of young students. A general slowing of response times (relative to the student group) as well as a different pattern of effects of numerical and dimensional redundancy were observed. These differences were not central subject of the present study and therefor not analyzed in detail. However, in future studies, it might be worthwhile to investigate age-related differences in search behaviour as older adults frequently report difficulties with activities that rely on visual search skills, e.g. problems with distracting objects and events, crowded visual scenes, or insufficient time to locate relevant objects (e.g. in technical devices). The present results are in agreement with earlier studies indicating preserved feature search performance in older participants (Foster, Behrmann, and Stuss, 1995; Oken, Kishiyama, and Kaye, 1994) , yet they also hint to more subtle deficits in addition to the overall slowing relative to the student group (see also Owsley, Burton-Danner, and Jackson, 2000; Zacks & Zacks, 1993).

Neuropsychological evidence supporting LFPC function in change-related behaviour

In Chapter 4, two groups of brain damaged patients and healthy observers performed a visual feature search task with the target defining dimension changing unpredictably from trial to trial. Patients with lesions of the left lateral frontopolar cortex (LFPC) showed a specific increase in dimension change costs. That is, when

the target-defining dimension changed from the preceding to the current trial, target detection was particularly slow compared both to patients with anterior frontomedian lesions and controls without brain lesions.

In a series of experiments investigating the functional neuroanatomy of visual dimension changes with fMRI, Pollmann and colleagues (Pollmann et al., 2000; Weidner et al., 2002) identified an extended fronto-posterior network of activations associated with a change of visual target-defining dimensions. In addition to multiple posterior visual brain areas, several prefrontal activations were observed, specifically in the left frontopolar cortex and the anterior frontomedian cortex at the anterior border of the pregeniculate anterior cingulate cortex. Both frontal activations were associated specifically with dimension changes. However, only the frontopolar cortex showed clear phasic increases of activation at the time of a dimension change. Frontomedian activation was more tonic in nature and was only found when comparing blocks of trials with variable target dimension to those with targets consistently defined in the same dimension.

RT costs following a change of target dimensions from trial to trial are assumed to be based on a time consuming shift of attentional weight from the previous to the current target-defining dimension (Müller et al., 1995). Change-related activations in the LFPC were therefore interpreted as processes controlling the ongoing re-allocation of attentional resources. One potential problem with this interpretation is that activation found in fMRI does not necessarily prove that a given structure is

functionally involved in the performance of a certain task. However, neuropsychological studies with patients suffering from lesions of a particular brain structure can provide direct evidence for or against a region of interest being the neural substrate.

Thus, the results obtained in the present study, investigating patients with circumscribed lesions of the LFPC, support the proposal that left lateral frontopolar cortex is involved in the reallocation of attention from the old to the new target-defining dimension in visual singleton feature search since it agrees with dimension change-related activation observed in previous event-related fMRI studies with normal subjects.

Moreover, frontal brain structures have been previously reported to play a role in change-related processes. For example, Owen et al. (1993) found patients with frontal lobe damage severely impaired when tested with the Wisconsin Card Sorting Test (WCST, Grant & Berg, 1948). This test requires subjects to sort cards according to colour, shape or the number of items on the card. The sorting rule is frequently changed and patients have to initiate a shift to a different sorting dimension accordingly. Patients with frontal lobe damage were worse than controls in their ability to shift from a previously relevant sorting category to a new one.

As reported in Chapter 3, patients with neglect were impaired in processing dimensionally defined visual pop-out targets. Their overall processing speed was severely reduced and detection of targets presented in the left half of the display was markedly delayed compared to controls. However, dimension-change related

reaction time costs, hypothesized to result from costly shifts of attentional weight when the target-defining dimension changes in subsequent trials indicate preserved processes of dimensional weighting. Despite otherwise impaired visual processing, the patient's dimensional change cost were not different from those of controls. Thus, while patients with lesions primarily located in parietal areas and suffering from visual neglect exhibited normal dimensional switching costs in comparison to healthy controls, target detection was selectively slowed in a group of patients with left lateral fronto-polar lesions when the target-defining dimension changed. Both brain regions are part of the fronto-parietal network found to be activated in dimension-based feature search, however serving different functions. In line with the functional specialization of anterior versus posterior parts of the network proposed by Pollmann and colleagues (Pollmann et al., 2000; Pollmann, Weidner, Müller, and von Cramon, in press), LFPC patients showed impaired change-related processing, while neglect patients showed a more space-related deficit of target processing yet preserved processing of dimensional changes.

It might be of interest to analyze, in further studies, the patients lesion sites in order to exactly separate 'pure' parietal patients and patients with additional damage to frontal structures. However, for now the data seems to provide support for the differential role of frontal and parietal structures in dimension-based visual attention.

6 Zusammenfassung

Ein Objekt, das sich von seiner Umgebung in nur einer wichtigen Eigenschaft unterscheidet, wird in der Regel bevorzugt wahrgenommen.

Dies wurde experimentell belegt mit Hilfe des Paradigmas der Visuellen Suche, in dem den Probanden ein Suchfeld (Display) bestehend aus einer variablen Anzahl von Elementen dargeboten wird. Ihre Aufgabe ist es, die An- bzw. Abwesenheit eines Zielreizes ('Target') unter Störreizen ('Distraktoren') zu entdecken und dies so schnell wie möglich per Tastendruck anzugeben. Jedes der im Display gezeigten Elemente (Stimuli) lässt sich in der Regel als eine Kombination aus basalen Merkmalen (z.B. rot, gross, senkrecht) beschreiben. Diese Merkmale können wiederum Dimensionen zugeordnet werden: z.B. Farbe, Größe oder Orientierung.

Grundsätzlich wurden zwei Arten der Suche beobachtet: die Suchzeiten der Probanden für Displays mit einem Zielreiz aber unterschiedlicher Anzahl von Distraktoren stiegen entweder mit zunehmender Größe an oder sie blieben für jede Displaygröße annähernd gleich. Ein Anstieg wurde als Evidenz für einen sukzessiven, jedes Item

des Display betrachtenden Suchvorgang gewertet (*serielle Suche*). Bei gleichbleibenden Suchzeiten trotz zunehmender Displaygrösse ging man davon aus, dass alle Elemente im Display simultan abgesucht wurden (*parallele Suche*).

Zielreize, die sich in einem einzelnen, salienten Merkmal von den Distraktoren unterscheiden, können ohne Anstrengung, scheinbar automatisch entdeckt werden. Dieser subjektiv als 'Heraussspringen' des Targets empfundene Prozess wird auch als 'pop-out Effekt' bezeichnet. Der Effekt tritt auch dann auf, wenn die Eigenschaften des Zielreizes dem Beobachter zuvor nicht bekannt sind.

Einflussreiche Erklärungsansätze wie die Merkmalsintegrationstheorie von Treisman (Treisman & Gelade, 1980; Treisman, 1988a) oder Wolfe's Guided Search Model (Wolfe, 1994a) postulierten, dass die Entdeckung von 'pop-out' Targets prä-attentiv, d.h. ohne die Beteiligung gerichteter, kapazitätslimitierter Aufmerksamkeit stattfinden. Somit wurde angenommen, dass Mechanismen der visuellen Wahrnehmung, die diesem Phänomen zugrunde liegen, räumlich-parallel und automatisch ablaufen und durch attentionale Prozesse nicht beeinflussbar sind.

Müller und Kollegen (Müller et al., 1995; Found & Müller, 1996; Müller et al., 2003) konnten in einer Reihen von Arbeiten jedoch zeigen, dass die Suche und Entdeckung von Zielreizen, die einen pop-out Effekt unterstützen, Beschränkungen unterliegen, die sich aus der dimensionalen Zugehörigkeit der zielreizdefinierenden Merkmale ergeben. Im Dimensions-gewichtungsansatz der Visuellen Suche (Müller et al., 1995) wurde postuliert, dass die Effizienz der Suche nach dimen-

sional definierten Zielreizen durch einen Gewichtungsprozess beeinflusst wird: Attentionales Gewicht wird der Zielreizdimension des aktuellen Targets zugewiesen. Ist der Zielreiz über Durchgänge hinweg in der gleichen Dimension definiert, wird ihm viel Gewicht zugeteilt und seine Endeckung somit beschleunigt. Wechselt die zielreizdefiniernde Merkmalsdimension jedoch unvorhersagbar in aufeinanderfolgenden Durchgängen, ist dies mit einer zeitintensiven Verschiebung der attentionalen Gewichtung verbunden, und die Targetentdeckung wird verzögert.

Weitere Arbeiten zu dimensions-basierten Effekten in der pop-out Suche erbrachten ausserdem Evidenz für die Annahme, dass Signale aus verschiedenen Dimensionen parallel und co-active in der visuellen Informationsverarbeitungshierarchie transportiert werden. So konnten Krummenacher und Kollegen (Krummenacher et al., 2001, 2002a, 2002b) zeigen, dass redundant definierte Zielreize, d.h. Targets, die nicht nur in einer einzelnen (z.B. Farbe), sondern in zwei oder mehr Merkmalsdimensionen (z.B. Farbe und Orientierung) definiert sind, schneller entdeckt werden können, als einfach definierte Zielreize. Diese Reaktionszeitgewinne (Redundanzgewinne) beruhten nicht auf einem einfachen numerischen Vorteil, wobei die beschleunigte Entdeckung eines von zwei Zielreizen wahrscheinlicher ist, als die eines einzelnen Zielreizes, sondern wurde durch ein verstärktes Signal der zweifach repräsentierten Dimensions hervorgerufen. Krummenacher und Kollegen erbrachten Evidenz für die Annahme, dass die von ihnen beobachteten dimensionalen Redundanzgewinne durch parallel, coactive Vermittlung zweier Signale aus einer Merk-

malsdimension auf die zentrale Salienzkarte entstanden, da die Gewinne die von Miller (1982) vorgeschlagene Wettlaufsungleichung (race model inequalitiy) verletzten. In der vorliegenden Arbeit wurden diese Effekte hinsichtlich ihres Vorkommens bei Patienten mit Neglect.

Im Mittelpunkt der vorliegenden Arbeit stand die Untersuchung der Auwirkungen der dimensionalen Definition von pop-out Zielreizen auf deren Entdeckungsgeschwindigkeit innerhalb eines gegebenen sowie des darauffolgenden Durchgangs. Zudem wurde gefragt, inwieweit diese dimensionalen Effekte durch die räumliche Position des Zielreizes innnerhalb des Suchfeldes und/oder visuell-räumliche attentionale Defizite von Probanden moduliert werden können.

Kapitel 1 In **Kapitel 1** werden zwei Experimente zur visuellen pop-out Suche berichtet. Ziel war es, die potentielle Interaktion von Wechseleffekten der zielreizdefinierenden Dimension mit der relative Position des Targets im Suchfeld zu untersuchen. Dabei war auch von Interesse, ob eine Überschreitung von Halbfeldgrenzen (d.h. Wechsel der Targetposition innerhalb eines Halbfeldes bzw. zwischen Halbfeldern in aufeinanderfolgenden Durchgängen) einen Einfluss auf die Endeckungsgeschwindigkeit hat.

In *Experiment 1* suchten Probanden in einem Feld von gleichen Distraktorelementen (grün, vertikal) nach Zielreizen, die entweder in der Farbdimension (rot) oder durch ihre Orientierung (45° nach rechts geneigt) definiert waren. In aufeinanderfolgenden Durchgängen konnte die Targetposition wechseln, so dass im aktuellen

Durchgang der Zielreiz an der gleichen Stelle oder an einer anderen Position relativ zum vorhergehenden Trial erschien. Die Entfernung zwischen beiden Position war kontrolliert (gleiche Position oder Distanz 1 bis 4). Zudem konnte der Wechsel der Targetposition *innerhalb* eines Halbfeldes des Displays stattfinden oder aber *zwischen* beiden Halbfeldern. Zusätzlich variierte die die Dimension des targetdefinierenden Merkmals unvorhersagbar von Durchgang zu Durchgang. Hauptinteresse galt der potentiellen Interaktion der Dimensionswechseleffekt mit einem Wechsel der Targetposition über variable Distanzen innerhalb oder zwischen den beiden Halbfeldern des Suchdisplays.

Die Ergebnisse zeigten, dass die räumliche Position der Zielreize nur geringen Einfluss auf die Entdeckungsgeschwindigkeit dimensional definierter pop-out Targets hatte. Zielreize in der linken Displayhälte wurden schneller entdeckt als rechts positionierte Targets, ebenso Zielreize, die näher zur Mitte des Displays dargeboten wurden relativ zu peripher präsentierten Zielreizen. In aufeinander folgenden Durchgängen, wurden Targets mit geringer Distanz zur Position des vorhergehenden Ziereizes schneller berichtet. Ein Wechsel bzw. die Konstanz des Halbfeldes hatte keinen Einfluss auf die Entdeckungsgeschwindigkeit. Die ebenfalls beobachteten dimensions-basierten Wechseleffekte (d.h. Reaktionszeitkosten beim Wechsel der zielreizdefinierenden Dimension (Müller et al., 1995; Found & Müller, 1996) blieben von den räumlichen Eigenschaften der Zielreize unberührt.

In *Experiment 2* wurden die Suchbedingungen erschwert, um zu prüfen, ob die

in Experiment 1 gefunden Effekte durch erhöhte attentionale Anforderungen beeinflussbar sind oder nicht. Dies wurde erreicht, indem die Probanden zusätzlich zu einer visuellen Suche nach einem dimensional definierten Zielreiz (andere Farbe oder Orientierung im Vergleich zu Distraktoren) auch dessen Identität berichten mussten. Jedes der rechteckigen Elemente besaß ausser seiner dimensionalen Definition (Farbe, Orientierung) eine weitere Eigenschaft (Einschnitt am oberen oder unteren Ende). Um die Position des Einschnitts für einen Zielreiz zu berichten, muss zuerst eine Suche nach einem andersfarbigen bzw. abweichend orientierten Element ausgeführt (Pop-out Suche: parallel) und in einem zweiten Schritt die Position des Einschnitts unterschieden werden (Diskrimination). Für diese sogenannte *'compound' Aufgabe* wird die Beteiligung räumlicher Aufmerksamkeit angnommen, da anders als bei einer reinen pop-out Suche, Aufmerksamkeit auf den Zielreiz ausgerichtet werden muss, um die Diskrimination leisten zu können.

Vereinbar mit Studien aus der Literatur (Müller et al., 1995) wurden dimensionale Wechseleffekte beobachtet. Ein Wechsel der Zielreizdimension ging mit Reaktionszeitkosten einher. Zudem ergab sich eine Interaktion des Dimensionswechseleffektes mit den Wechsel der Antworthand von Trial zu Trial: Trat der Wechsel der Antworthand zugleich mit einem Wechsel der Zielreizdimension auf, so ergaben sich nur geringe Dimensionswechselkosten. Blieb die Antworthand in zwei aufeinanderfolgenden Trials die gleiche, ergaben sich Dimensionswechselkosten in der erwarteten Höhe.

Dieses Ergebnis wurde angelehnt an eine 'Hierarchische Verarbeitungshypothese' ('hierarchical processing hypothesis') von Kingstone et al. interpretiert. Diese postuliert, dass ein Proband primär von einer Konstanz der Zielreizdimension sowie der zu verwendenden Antworthand ausgeht. Wechselte nun die Dimension von einem Durchgang zum folgenden wurde diese Annahme nicht bestätigt. Diese 'enttäuschte Erwartung' wurde dann auf die Annahme einer konstanten Antworthand übertragen (da diese im aktuellen Trials zeitlich nach dem Dimensionswechsel relevant wurde). Somit entstanden keine Reaktionszeitkosten.

Ausserdem war, anders als in der einfachen Suchaufgabe, ein Wechsel des Halbfeldes in aufeinanderfolgenden Trials mit erhöhten Reaktionszeiten verbunden. Dieser Effekt wurde mit zunehmender Distanz verstärkt.

Insgesamt zeigte sich, dass in einer pop-out Suchaufgabe dimensionale Wechseleffekte von räumlichen Eigenschaften des Zielreizes unberührt blieben. In einer 'compound' Aufgabe wurden ebenfalls (wenn auch quantitativ redudzierte) dimensionale Wechseleffekte beobachtet. Diese zeigten eine Interaktion mit dem Wechsel bzw. Nicht-Wechsel der Antworthand in aufeinanderfolgenden Durchgängen.

Kapitel 2 In **Kapitel 2** wird eine Untersuchung zur dimensions-basierten Visuellen Suche bei Patienten mit visuell-räumlichem Neglect berichtet.

In einer visuellen Suchaufgabe wurden Displays mit einem oder zwei (dualen) Zielreizen unter homogenen Distraktoren präsentiert. Einfache Zielreize waren entweder durch ihre Farbe oder Orientierung definiert. Duale Zielreize unterschieden

sich von den Distaktoren entweder beide durch Farbe oder Orientierung oder aber eines der beiden Targets war durch Farbe, das andere durch Orientierung definiert. So ergaben sich Effekte numerischer Redundanz aus dem Vergleich der Entdeckunggeschwindigkeiten einfacher versus dualer Ziereize. Dimensionale Redundadanzeffekte zeigten sich bei der Gegenüberstellung dualer Zielreize, die innerhalb einer Merkmalsdimension definiert waren (Farbe *oder* Orientierung) und dualen Targtes, die sich in beiden Dimensionen von den Distraktoren unterschieden (Farbe *und* Orientierung). Zudem wurden einfache Zielreize im rechten oder linken Halbfeld, duale Zielreize entweder beide im rechten, beide im linken oder je ein Target im rechten und linken Halbfeld des Displays gezeigt.

Ziel war es, zu prüfen, ob Leistungsgewinne, basierend auf numerisch oder dimensional redundanter Information, die bereits bei gesunden Probanden beobachtet wurden, auch bei Neglectpatienten trotz attentionaler Defizite auftreten.

Im Vergleich mit einer altersangepassten sowie einer studentischen Vergleichsgruppe zeigten sich (1) eine allgemeine verlängerte Reaktionsgeschwindigkeit, (2) eine verzögerte Endeckung von Zielreizen im linken Halbfeld unabhängig von deren Anzahl oder dimensionaler Definition, (3) erhöhte numerische Redundanzgewinne, wenn Zielreiz(e) im linken Halbfeldern präseniert wurde(n), (4) erhöhte dimensionale Redundanzgewinne, wenn duale Targets in beiden Halbfeldern dargeboten wurden und (5) dimensionale Wechseleffekte in aufeinanderfolgenden Durchgängen, die von der Halbfeldposition des Zielreizes beeinflusst wurden.

Kapitel 3 In **Kapitel 3** wird eine Untersuchung berichtet, in der eine weitere Patientengruppe eine visuelle Merkmalssuche nach pop-out Zielreizen ausführte. Vorangegangene Studien mit Verwendung von ereigniskorrelierter funktioneller Magnetresonanztomographie (fMRT) hatten gezeigt, dass eine spezifische Aktivierung des linken lateralen fronto-polaren Kortex (LFP) mit einem Wechsel der Merkmalsdimension des Zielreizes assoziiert war. Um die These zu prüfen, wonach der LFP eine dimension-basierte Aufmerksamkeitsverschiebung aktiv unterstützt, wurden Patienten mit einer Verletzung des LFP mit einer einfachen Merkmalssuchaufgabe untersucht. Die zielreizdefinierende Dimension variierte unvorhersagbar von Durchgang zu Durchgang. Im Vergleich mit Patienten, deren Läsion fronto-median lokalisiert war und gesunden Kontrollprobanden zeigte die Versuchsgruppe deutlich verlangsamte Reaktionszeiten nach einem Wechsel der Zielreizdimension. D.h. die dimensionalen Wechselkosten waren deutlich erhöht.

7 Appendix

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7.2 Curriculum Vitae

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7.3 Selbstständigkeitserklärung

Hiermit bestätige ich, dass ich die vorliegende Arbeit selbstständig angefertigt habe. Ich versichere, dass ich ausschliesslich die angegebenen Quellen und Hilfen in Anspruch genommen habe.

München, den 10.10.2005

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