The influence of the level of alertness on spatial and non-spatial components of visual attention in healthy subjects and neglect patients

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Chapter 1: Introduction

It is widely accepted that attention is a multi-dimensional cognitive ability which consists of separable components supported by overlapping, but independent, neural networks (Desimone & Duncan, 1995; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Fernandez-Duque & Posner, 1997; Posner & Boies, 1971). Current theoretical conceptions bridging the behavioral and neuroanatomical levels of analysis such as the 'Theory of Visual Attention' (TVA; Bundesen, 1990, 1998a) or the 'attentional-networks' model (Fan, McCandliss, Sommer, Raz, & Posner, 2002) consider both spatially lateralized and non-lateralized components of visual attention to be critical determinants of attentional performance. A currently widely debated question concerns whether and, if yes, how these different components interact (e.g., Robertson, Mattingley, Rorden, & Driver, 1998; Robertson, Tegner, Tham, Lo, & Nimmo-Smith, 1995; Thimm, Fink, Kust, Karbe, & Sturm, 2006). One important line of research on this issue has focused on how varying levels of alertness influence spatial and non-spatial components of visual attention (Fimm, Willmes, & Spijkers, 2006; George, Dobler, Nicholls, & Manly, 2005; Manly, Dobler, Dodds, & George, 2005).

The present Ph.D. thesis is designed to bring deeper insight into answering this question by investigating the influence of varying levels of alertness on spatial and non-spatial components of visual attention in healthy subjects and neglect patients. The methodological background of the thesis is based on Bundesen´s TVA (Bundesen, 1990; 1998a; see below). The strength of TVA is that it allows the effects of stimulus and task variations on spatially lateralized and non-lateralized components of visual attention to be assessed in parallel within the same subjects. Combined with experimental-psychological methods this approach promises to

provide a clearer picture of the way in which attentional components interact within the normal brain, and about the pathological mechanisms underlying attentional disorders such as neglect. Before describing the basic concept of alertness in more detail, I first turn to a description of the theoretical and mathematical background of the TVA model .

1.1 The Theoretical Framework of Bundesen´s Theory of Visual Attention (TVA)

TVA is a formal computational theory assuming latent, independent parameters to underlie the observable attentional performance. Whereas many theories of visual attention separate the two processes of visual recognition/identification and attentional selection (e.g., Broadbent, 1958; Deutsch & Deutsch, 1963), TVA instantiates the two processes in a unified mechanism implemented as a race model of both selection and recognition. Thus, based on TVA, when an object in the visual field is recognized it is also selected at the same time and vice versa.

TVA was developed out of a choice-model (Bundesen, Pedersen, & Larsen, 1984; Bundesen, Shibuya, & Larsen, 1985) and the Fixed-capacity Independent Race Model (FIRM; Bundesen, 1987; Shibuya & Bundesen, 1988). Because the choice-model and the FIRM are integrated parts of TVA and can be derived mathematically from it, they will not be discussed further here.

1.1.1 Basic Assumptions

In TVA, both visual recognition/identification and attentional selection of objects in the visual field consist in making *perceptual categorizations*. A perceptual categorization has the form 'object x has feature i', or equivalently, 'object x belongs to category i'. Here, object x is a perceptual unit in the visual field, feature i is a perceptual feature (e.g., a certain color, shape, movement, or spatial position), and category i is a perceptual category (the class of all

objects that have feature i). Examples of perceptual categories are the class of red objects (a color category), the class of letters of type A (a shape category), and the class of objects in the right visual field (a location category).

According to Bundesen (1990; 1998a), an object x is selected (encoded into a capacity-limited VSTM), as soon as one or another perceptual categorization of that object is encoded into VSTM. When the perceptual categorization is encoded into VSTM, object x is said a) to be selected, and b) to be recognized (identified) as a member of category i. Hence, in TVA, attentional selection of a visual categorization of object x consists of encoding the categorization of object x into VSTM. An important claim of TVA is that objects in the visual field are processed in parallel. Objects that are selected, and hence, may be reported from a briefly exposed visual display are those elements for which the encoding is completed before the sensory representation of the stimulus array has decayed and before VSTM has filled up with other objects. The value of objects in the store is limited by the maximum storage capacity K, and thus, K is one of the basic parameters in TVA. The value of parameter K is typically about three to four objects (Bundesen et al., 1984; Bundesen et al., 1985; Luck & Vogel, 1997; Sperling, 1960, 1967). Any (target) object entering the store is correctly reported with a probability θ (typically close to 100%)[1], regardless of the fate of the other objects in the visual field. The total number of objects entering the store, K, is independent of the number of objects in the visual field (Bundesen et al., 1984; Bundesen et al., 1985).

Because VSTM capacity is limited to K different objects, objects in the stimulus array compete to be selected/encoded into VSTM (especially if their number exceeds the VSTM capacity). It is assumed by the TVA model, that each object in the visual field is assigned a

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[1] The number of targets reported from a given display equals the number of targets encoded into VSTM (Bundesen, 1990; Kyllingsbaek, 2006).

certain *attentional weight* (an *impact*). Until VSTM has been filled up with *K* objects, the probability θ that any not-yet-selected object is the next one to be encoded into VSTM equals the weight of that object divided by the sum of the weights of all objects not yet selected/encoded.

It is important to note, that the VSTM store is not limited in terms of the number of categorizations from objects already encoded into the store. Space in VSTM is available for a new categorization of object *x* if a) object *x* is already represented in the store (with one or another categorization), or b) less than *K* objects are represented in the store. Hence, categorizations from objects already represented by other categorizations may freely enter VSTM even though it is filled up with the maximum number of *K* objects. Thus, VSTM is mainly limited with respect to the number of objects of which categorizations may be stored, *not* with respect to the number of categorizations of the objects represented in the store. This assumption is in accordance with a study of Luck and Vogel (1997) who were able to show that the capacity of the VSTM must be understood in terms of integrated objects (= number of features/categorizations that can be linked together in a single object representation) rather than individual features/categorizations.

However, if VSTM is filled up with *K* objects and *x* is *not* among these objects, there is no room for a categorization of object *x*, and thus, the sampled categorization of object *x* is lost.

1.1.2 Stages of Processing

In TVA the processing of a stimulus display is understood as a two stage process, comprised of a) an initial match of the visual percept with visual long-term memory (VLTM) representations, which does not imply recognition, followed by b) a selection/recognition race for representation in VSTM.

During the first stage of visual processing, a parallel matching between each object in the visual field and representations in VLTM (*template x* = specification of the sensory characteristics of object *x*) takes place. This matching process consists of comparing the presented object *x* against a number of alternative templates, one for each member of the stimulus set. The template for object *x* is associated with a perceptual category *x* subsuming object *x* but no other objects of the stimulus array. This process is capacity unlimited in the sense that the time the matching takes is independent of the number of objects in the visual field. The result of the matching process, and thus, of comparing object *x* against template *x*, is the computation of so-called eta-values ('evidence values'), $\eta(x,i)$. Each eta-value measures a certain degree of match between a given object *x* and a long-term memory representation (category *i*). Hence, eta is a measure of the *strength of the sensory evidence* that object *x* is a target (i.e., satisfies the selection criterion) rather than a distractor. In other words, eta is the strength of evidence that object *x* belongs to category *i*. Eta-values are affected by factors of visibility (e.g. contrast) of the visual objects as well as the degree of match between the objects and the VLTM representations (e.g., Bundesen, Kyllingsbaek, Houmann, & Jensen, 1997).

However, independent of the outcome of the matching process, the subject is more or less pre-disposed (by task requirements) to assign object *x* to category *i*, and the strength of this category-related perceptual decision bias is denoted by β_x (Bundesen, 1987, 1993, 1998b). Beta acts as a weight on the outcome of the matching process.

Then, during the second stage of processing (*the race*), objects are encoded into the VSTM store by a process with limited capacity. A fixed amount of processing capacity (*C*; elements per second) is distributed among the objects in the visual field and finally the encoding race between objects takes place. The total processing capacity of *C* distributed across objects is directly proportional to the *attentional weights* (w_0 or w_1) of the objects, which are based on the strength of the sensory evidence that the object is a target ('object *x* belongs to

category i). The amount of processing capacity that is allocated to an object determines how fast the object can be encoded into VSTM. The objects actually selected (i.e. stored in VSTM) are those objects whose encoding processes is complete before the stimulus presentation terminates and before VSTM has been filled up. In general, targets should receive higher weights, and therefore more processing capacity than distractors. This is in accordance with a study of Shibuya and Bundesen (1988) showing, that the probability that a given target is correctly reported is reduced by competing objects in the visual field., and that the performance loss caused by a competing distractor (low weight) is less than the reduction caused by a competing target (high weight). This result suggests that allocation of processing capacity (processing resources) is selective, so that, the available processing capacity captured by a distractor is less than the capacity allocated to a target.

These two stages of processing are formalized in TVA by several equations, which are described in the following sections.

1.1.3 Single Stimulus Identification

In race models of single-stimulus recognition, alternative perceptual categorizations are processed in parallel, and the subject selects the categorization that first completes processing. For example, object x is displayed for t-ms and is immediately followed by a mask. In TVA, the time taken to encode a perceptual categorization of object x into VSTM is exponentially distributed, and the time available for encoding equals the stimulus duration in excess of the minimum effective exposure duration t_0 (for an example see Figure 1, and, Bundesen & Harms, 1999).
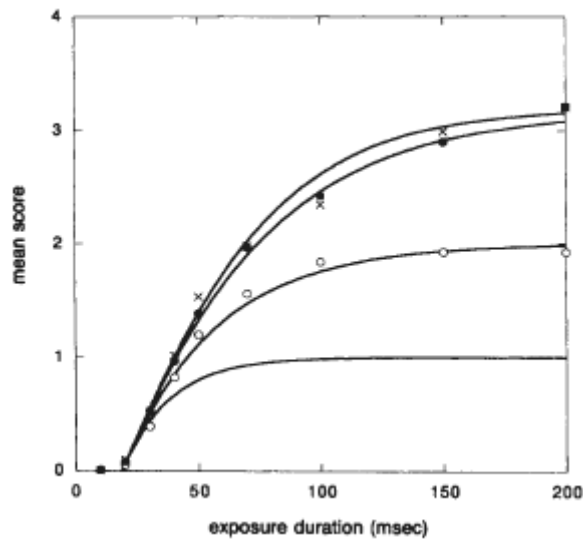
Figure 1. Mean score (number of targets correctly reported) as a function of exposure duration (eight different exposure durations) in the whole-report condition in the study of Shibuya and Bundesen (1988). Number of targets, $n(T)$, was two (open cycles), four (closed cycles) or six (crosses). Solid lines represent best fitting predictions from TVA. A predicted curve for $n(T) = 1$ is also shown (from Duncan et al., 1999).

The probability P_x for encoding a certain categorization of object x into VSTM, and thus the probability that object x will be correctly reported as a function of exposure duration t, equals the equation (Bundesen & Harms, 1999):

$$P_x = 1 - \exp^{-v_x(t-t_0)}$$

where t_0 (the *minimal effective exposure duration*) reflects the onset of array processing, below which information uptake from the display is assumed to be zero, and the equation presupposes that $t \geq t_0$. Typical estimates for t_0 in young healthy subjects are around 20 ms (Bundesen & Harms, 1999; Kyllingsbaek, 2006). The difference $(t-t_0)$ is the *effective exposure duration* of the stimulus display. If the stimulus is presented unmasked, an additional effective exposure duration of μ-ms should be added to $(t-t_0)$ (e.g., Bundesen, 1990; Kyl-

lingsbaek, 2006). The processing rate parameter v_x can be described as the 'speed' at which object x races toward VSTM at $t = t_0$, v_x is the slope of the function relating the report probability P_x to the exposure duration t (for an example see, Figure 1). For each object in the visual field the probability that it completes processing in the available time is, therefore, determined by its v-value.

When x is the only object in the visual field, v_x equals the *basic sensory effectiveness* of object x, s_x (Bundesen, 1990, 1998a; Duncan et al., 1999). For any given object, data on single object recognition can hence be used to measure basic sensory effectiveness s_x. The sensory effectiveness of an object depends on such factors as stimulus discriminability, contrast and retinal eccentricity. The product of s_x and $(t-t_0)$ is called the *accumulated sensory effectiveness* (A_x) of object x at time t: $A_x = s_x(t - t_0)$.

Note, that the studies of the present thesis provide estimates for A_x without providing separate estimates for s_x and t_0. In such a case, A_x may be taken as an indirect measure of sensory effectiveness if the effective exposure duration is kept constant (Duncan et al., 1999).

1.1.4 Selection from Multi-element Displays

As stated above, TVA is based on the principle that all possible categorizations (ascribing features to objects) compete for encoding into VSTM, before VSTM is filled up, and this competition is called a *race*. This principle is known as 'biased competition' (e.g., Desimone & Duncan, 1995). Individual objects in the visual field start the race at the same moment in time ($t = 0$), and therefore, are assumed to be processed in parallel. Attentional selection is made of those objects that first finish processing (the winners of the race). Thus, selection of targets (objects to be selected) instead of distractors (objects to be ignored) is based on faster processing of targets than processing of distractors. Hence, clearing of VSTM effectively starts a race among all objects in the visual field to become encoded into VSTM, and each

possible categorization is supported by the sensory evidence that object x belongs to category i. However, the competition between objects is *biased* by attentional weights and perceptual biases. The way sensory evidence, attentional weights, and perceptual biases interact is specified in two equations: the rate and the weight equation of TVA – which will be introduced in the following sections.

1.1.4.1 Equation 1: Rate Equation (Hazard Function)

The conditional probability (= hazard function) that the processing of a particular perceptual categorization is finished at time t (given that processing is not finished before time t) is called the v-value of the perceptual categorization. This rate $v(x, i)$ at which a particular visual categorization, 'x belongs to i', is encoded into VSTM (= speed at which a perceptual categorization 'object x belongs to category i' is processed) is given by Equation 1 of TVA:

$$v(x,i) = \eta(x,i)\beta_i \frac{w_x}{\sum_{z \in S} w_z} \text{ (Equation 1),}$$

where $\eta(x, i)$ is the strength of the sensory evidence that object x satisfies the selection criterion (= strength of the sensory evidence that object x is a target rather than a distractor), β_i is the (category-related) perceptual decision bias associated with category i, S is the set of all objects in the visual field, and w_x and w_z are attentional weights for objects x and z respectively. v is called the *basic processing rate* (processing speed) at which a perceptual categorization is processed (encoded into VSTM).

As stated above (see also Shibuya & Bundesen, 1988), compared to single-element arrays, the basic processing rate of an object in a multi-element display is decreased. Specifically eta-

and beta-values are multiplied with the relative attentional weight of object x (i.e. the weight

of object x, w_x, divided by the sum of weights across all objects in the visual field, S): $\dfrac{w_x}{\sum\limits_{z \in S} w_z}$.

Thus, the probability (processing rate) that any categorization from a given object x will

enter VSTM is influenced by the ratio of the attentional weight of x and the sum of attentional

weights of all objects in the visual field. By definition, weight ratios for the different objects

in the visual field always sum up to 1.

Taken together, in TVA selection/recognition depends on the outcome of the race between

possible perceptual categorizations. The rate at which a possible categorization of the form

'object x belongs to category i' is made (encoded into VSTM) increases with a) the strength

of the sensory evidence that supports the categorization, b) the subject's bias for assigning

stimuli to category i, and c) the (relative) attentional weight of object x. When only a single

object x is presented in the visual field, all attentional weight is focused on object x

$$\left(\frac{w_x}{\sum\limits_{z \in S} w_z} = \frac{w_x}{w_x} = 1 \right),$$ and so the v-value equals $\eta(x,\, i)\beta_i$.

1.1.4.2 Equation 2: Weight Equation

Given by Equation 1, before the race for selection and recognition takes place attentional

weights have to be computed for each object in the visual field. According to TVA

(Bundesen, 1990, 1998a; Kyllingsbaek, 2006), attentional weights are derived from *percep-*

tual processing priorities. Every perceptual category is assumed to have a certain processing

priority (*pertinence value*). The pertinence value π_j associated with a category is a measure of

the current importance of attending to objects that belong to that category. For example, if the

task requires the selection of *red* objects, pertinence for *red* should be high. The weight for an object *x* in the visual field is given by Equation 2 of TVA:

$$w_x = \sum_{j \in R} \eta(x, j)\pi_j \quad \text{(Equation 2)},$$

where *R* is the set of all perceptual categories, $\eta(x, j)$ is the strength of sensory evidence that object *x* belongs to category *j* and π_j is the pertinence value (pi-value) of category *j*. By Equation 2, the attentional weight of object *x* is a weighted sum of pertinence values, where each pertinence value is weighted by the degree of sensory evidence that object *x* actually is a member of category *j*. Hence, the current selection criterion is represented by the distribution of pertinence values (Equation 2) over perceptual categories, and thus, can be used for ma-nipulating attentional weights.

Taken together, the attentional weight of an object depends on the perceptual features of the object $\eta(x, j)$, and the current importance of feature *j*, π_j. As soon as attentional weights are computed the selection race takes place. So, the more an object appears to have a currently important feature the higher its attentional weight (and thus, the higher its processing rate) in the upcoming race for selection/recognition.

1.1.4.3 Limited Processing Capacity *C*

In TVA, processing capacity (speed) *C* is defined as the sum of *v*-values across all percep-tual categorizations of all objects in the visual field: $C = \sum_{x \in S} \sum_{i \in R} v(x, i)$. Parameter *C* is a measure of the total rate of information uptake (= identification rate in objects per second), and can be understood as the total processing capacity distributed across the objects in the visual field (Duncan et al., 1999).

However, *C* is not only an attentional but also a sensory parameter (Duncan et al., 1999), and so, is highly dependent on the sensory properties and general discriminability of the stimuli/objects.

1.1.5 Short Summary of TVA Basics

This paragraph shall provide a short summary of the sections described above. TVA is a unified theory of recognition and selection and is a quantification of the following ideas. Each object in the stimulus display is associated with two distinct parameters. *Sensory Effectiveness* reflects how well an object is processed when presented alone, and it depends on factors such as contrast, luminance, and so forth. In a display containing multiple objects the *Attentional Weight* parameter is important. Objects in such multi-element displays compete to be selected (encoded into VSTM), and the attentional weight reflects how strongly any given object competes. Attentional weights depend on several factors, most importantly, an object gains weight to the extent that it matches a top-down description of currently relevant input (task-relevant weighting). Hence, targets are assigned higher weights than distractors, and are thus processed preferentially. In terms of TVA, competition between objects is the implementation of limited processing capacity, and attentional weights determine how this limited processing capacity is distributed across the objects in the visual field.

1.1.6 Mechanisms of Selection

To determine the rate of processing of each categorization of an object, the eta-values are combined with two types of 'subjective (top-down)' values, *pertinence* and *bias* (see 1.1.4, and Bundesen, 1990; Bundesen, 1998a; Kyllingsbaek, 2006). Basically, Equations 1 and 2 of TVA describe two mechanisms for selection (see, Broadbent, 1970; Broadbent, 1971): a

mechanism for selection of objects based on pertinence (filtering), and a mechanism for selection of categories based on bias (pigeonholing).

<u>1.1.6.1 Filtering</u>

The filtering mechanism is represented by attentional weights, which are derived from pertinence values π_j and sensory evidence (see Equation 2). For example, if red objects have to be selected, then the pertinence of *red* should be high. Equation 2 implies that if the processing priority (the *pi*-value) of red is increased, then the attentional weight of an object x gets an increment which is directly proportional to the strength of the sensory evidence that the object is red. Or in other words, when *red* has a high pertinence red objects get high attentional weights. Thus, the processing of red objects is speeded up in relation to the processing of other objects so that the red ones get a higher probability of winning the processing race and of becoming encoded into VSTM. The effect of *filtering* therefore is, to increase attentional weights of objects that belong to category i rather than to increase attentional weights of other objects and, accordingly, to favor selection of objects belonging to category i by speeding up processing of such objects at the expense of any other objects (see Equation 1).

Taken together, by varying pertinence values of certain categories the filtering mechanism increases the likelihood that objects that belong to a certain category (e.g. red objects) are selected. A change in the pertinence value of a perceptual category causes a change in the distribution of attentional weights over objects in the visual field (see Equation 2), and a change in the relative attentional weight of an object x changes the v-value for any categorization of object x (see Equation 1).

1.1.6.2 Pigeonholing

The pigeonholing mechanism is represented by perceptual decision bias parameters β_i. Pertinence values determine which objects are selected (*filtering*), but perceptual decision-bias parameters determine how the objects are categorized (*pigeonholing*). If particular types of categorizations are desired, decision bias parameters of the relevant categories are set high. Hence, according to Equation 1, the desired types of categories are likely to be made (to be represented in VSTM). It is important to note, that pigeonholing is a pure categorical bias mechanism, complementary to filtering. For example, if one wants to categorize objects with respect to color, one can prepare oneself for categorizing objects in the visual field with respect to color by giving higher values to perceptual bias parameters associated with color categories than to other perceptual bias parameters. By adjusting the beta-values participants are able to directly control the probability of specific categorization without favoring categorizations from a particular object x. Equation 1 implies that if the perceptual bias parameter (the β-value) for a particular category is increased, the tendency to classify objects into that category gets stronger: the v-values for perceptual categorizations of objects as members of the category are increased, but other v-values are not affected.

To sum it up, filtering changes the probability that object x is selected, without affecting the conditional probability that category i is selected given that object x is selected. Conversely, pigeonholing changes the probability that a particular category i is selected, without affecting the conditional probability that object x is selected given that category i is selected.

1.1.6.3 Combining Filtering and Pigeonholing

Equation 1 of TVA describes the combined effect of filtering and pigeonholing. For example, let us assume that the task (in a partial-report paradigm) is to report the identity of every red letter in a mixed array of red and green letters (out of a set of ten possible letters of

the alphabet). According to TVA, a plausible strategy for doing this is to select red rather than green objects, and thus, set the pertinence value of the perceptual category *red* high, and keep other pertinence values low. The effect is to speed up the processing for all types of categorizations of red objects - relative to rates of processing for categorizations of green objects. To perceive the identity of the red letters rather than other attributes of the objects, ten perceptual-decision bias parameters are set high, one for each letter type, and other perceptual-decision bias parameters are kept low. The effect is to speed up the processing of categorizations with respect to letter type, relative to rates of processing for categorizations with respect to other attributes.

The combined effect of the adjustments of pertinence and decision-bias parameters is to speed up the processing for categorizations of a red object with respect to letter types, in relation to any other categorization.

1.1.7 A Neural Theory of Visual Attention (NTVA)

The 'Neural Theory of Visual Attention' (NTVA; Bundesen, Habekost, & Kyllingsbaek, 2005b) is a further development of the above described TVA and provides a close link between attentional functions at the behavioral and the neural level. Basically, NTVA is a neural interpretation of TVA´s Equations 1 and 2.

Equation 1 of TVA describes the combined effect of filtering and pigeonholing on the total activation of the population of neurons representing a particular categorization ('object x has feature i'). Hence, the total rate of processing of a categorization $v(x,i)$ is directly proportional to both the number of neurons in the inferior temporal cortex (Bundesen, 1998b; Bundesen et al., 2005b) representing the categorization (which is controlled by filtering) and the level of activation in the individual neurons representing the categorization (which is controlled by pigeonholing). In some more detail, filtering affects the number of neurons in

which an object is represented. The number of neurons increases with the behavioral importance π of an object. Thus, the probability that a neuron represents a particular object x within its classical RF equals the attentional weight of that object x divided by the sum of attentional weights across all objects z in the RF (see, Equation 1). Pigeonholing (β-value) on the other hand, is a multiplicative up or down scaling of the level of activation in neurons coding for particular categorizations/features.

In correspondence with the computational definitions of TVA, the total processing capacity C is represented by the firing rate of the entire population of neurons in inferior temporal cortex.

More important for the studies of the present thesis is the assumption, that the beta- and pi-values (and thus attentional weights) are computed in the frontal and in the posterior parietal cortex (Bundesen, 1998b; Bundesen et al., 2005b; Schneider, 1995). The parameter settings of beta and pi are transmitted via projections to the visual system. Of course, computation of attentional weights occurs before processing recourses (neurons) are distributed among objects in accordance with their weights. When several objects are present within the classical RF of a neuron a) the *effective* RF of the neuron is contracted around only one of the objects, and b) the probability that the RF contracts around a particular object equals the attentional weight of the object divided by the sum of the attentional weights of all the objects in the classical RF. Thus, only a fraction of the population is allocated to processing of object x, and the expected size of this fraction equals $\dfrac{w_x}{\sum\limits_{z \in S} w_z}$.

Taken together, according to NTVA, the object selection of a neuron occurs by dynamic remapping of the cell's receptive field (RF) such that the effective RF contracts around a selected object.

1.1.8 Applications of TVA

Two relevant applications of the TVA model, also used in the studies of the present thesis, are the whole- and the partial-report paradigms, which are described in the following sections.

1.1.8.1 Whole-Report Paradigm

As mentioned above, in TVA, the general efficiency of the visual processing system is reflected in the parameters *visual perceptual processing speed C* (number of visual elements processed per second) and *VSTM storage capacity K* (number of elements maintained in parallel). Both parameters are assessed using a whole-report task, in which subjects are briefly presented with multiple stimuli at varying exposure durations (ranging from near-threshold t_0 to near-ceiling performance) from which they have to identify (name) as many as possible. The score (number of correctly reported items) is measured as a function of exposure duration (Duncan et al., 1999; Habekost & Bundesen, 2003; Shibuya & Bundesen, 1988). The probability of identifying a given object *x* is modeled by an exponential growth function. The slope of this function at $t = t_0$ indicates the total rate of information uptake in objects per second (perceptual processing speed *C*), and its asymptote the maximum number of objects that can be represented at a time in VSTM (VSTM storage capacity, *K*). These parameters have shown to be reliable indicators of individual differences in normal controls, as well as distinguishing reliably between patient groups such as Huntington patients (Finke, Bublak, Dose, Muller, & Schneider, 2006; Finke et al., 2007), neglect patients (Duncan et al., 1999), or patients with various right hemisphere lesions (Habekost & Rostrup, 2007; Peers et al., 2005).

In sum, given a sufficient number of observations at different exposure durations the parameters t_0, *C* and *K* can be estimated from whole-report data.

1.1.8.2 Partial-Report Paradigm

In the present Ph.D. thesis, a TVA based partial-report task was used, in which subjects have to identify as many briefly presented target objects (letters) as possible, which are belonging to a pre-specified target-category (with respect to color), and thus fit a particular selection criterion, while ignoring distractors (non-targets; green letters). Targets and distractors are appearing in the same (unilateral condition) or in opposite (bilateral condition) hemi-fields. The focus is on differences between accuracy for a single target and for the same target accompanied by other objects either targets or distractors on the same or the opposite side. In general, this partial report task is able to measure how the total processing capacity is distributed across objects in the visual field, which requires a consideration of attentional weights (Duncan, Humphreys, & Ward, 1997). Hence, from the probability of target identification, attentional weights are derived for targets (w_T), and for distractors (w_D), separate for each visual hemi-field (w_{left} and w_{right}). Objects with high attentional weights are processed relatively well, but interfere strongly with other objects, whereas objects with low attentional weights are processed poorly, and interfere weakly with others. Two types of weighting are typically investigated: the task-related weighting (top-down control) of objects and the spatial weighting of objects in different parts of the visual field (spatial distribution of attentional weighting; e.g. the weight of objects in the left versus the right hemi-field). Top-down control is related to the selection of task relevant objects, and is reflected by parameter α, defined as the ratio w_D/w_T, averaged across hemi-fields. Ideally, targets should have high weights and be processed well – while distractors should have low weights and be processed poorly. In a case of effective top-down control (low α-values) attentional weights would be properly allocated by task relevance. If so, the ratio between distractor and target weights w_D/w_T expressed by α, would be less than 1, with lower α-values indicating more efficient top-down control. Thus, targets would be attended and distractors would be ignored. Impaired control functions, by

contrast, would give rise to equally weighted target and distractor processing, increasing α to approach 1. In such a case, attentional weights would be independent of task context.

Additionally, averaging across targets and distractors, separate weights can be estimated also for the left (w_{left}) and for the right hemi-field (w_{right}). In TVA, the absolute attentional weighting has no meaning, only relative intra-individual values can be compared. Therefore, a laterality index is computed from the raw data of the w estimates: the 'index of spatial distribution of attentional weighting' (w_λ). Parameter w_λ is defined as the ratio of attentional weighting across the two hemi-fields: $w_{\text{left}} / (w_{\text{left}} + w_{\text{right}})$. Parameter w_λ is related to performance losses in multi-element displays and thus, to differences in single and multi-element performance. Hence, a value of $w_\lambda = 0.5$ indicates a balanced distribution of weights, values of $w_\lambda > 0.5$ indicate a leftward, and values of $w_\lambda < 0.5$ a rightward spatial bias.

If attentional weights are biased towards one hemi-field, performance in the bilateral (compared to the unilateral) target condition will suffer more for the target presented in the hemi-field with relatively low attentional weight, compared to the target in the hemi-field with high weight. One could argue, that in the bilateral stimulus conditions, performance for left and right side stimuli could differ due to reduced sensory effectiveness in one side. However, this factor was controlled for by data from the unilateral target-only conditions, which are assumed to basic sensory efficiency in target discrimination at a given exposure duration. In unilateral displays, this basic efficiency is assumed to be *independent* of the spatial attentional weighting across the two hemi-fields. Remaining side differences in the bilateral condition should therefore be attributed to different attentional weighting. Thus, w_λ represents a pure estimate of spatial attentional bias (controlled for sensory factors).

When unilateral displays are used, estimates of $t0$, C, K and α can be obtained separately in each visual field, whereas w_λ by definition relates to bilateral displays. In experiments that use only one exposure duration (as the present partial report study) the processing rate C can-

not be inferred from the data. Instead the (*accumulated) sensory effectiveness*, *A*, separately in each visual field, of the display can be estimated. Parameter *A* is assumed to reflect the total processing rate for each hemi-field rather than how capacity is divided between the different objects of a display. The estimation of *A* is related to accuracy on a single element presented alone rather than to performance losses in multi-element displays. As with attentional weighting, a laterality value A_λ above 0.5 reflects a lateralization of sensory effectiveness to the left, a value below 0.5 a lateralization to the right visual hemi-field.

1.2 The Theory of Visual Attention and the Concept of Alertness

Spatial (spatial distribution of attentional weighting; top-down control) and non-spatial (visual perceptual processing speed; VSTM storage capacity) components of visual selective attention rely on the dynamic adaptiveness of the brain, enhancing neural responses within multiple cerebral systems. One important line of research to this regard is the examination of the influence of modulations of the level of alertness on these spatially lateralized and spatially non-lateralized attentional components. However, until now it remained unclear how and when different attentional components are modulated by varying levels of alertness. It is proposed by this thesis that an important step to resolve these questions can be made based on the TVA model which integrates separable spatial and non-spatial components of attention within a formal framework, and allows the effects of specific task variations on these components to be assessed independently and in parallel within the same subjects.

The following studies are therefore designed to examine interactions between the level of alertness, as a basic component of visual attention (Posner & Boies, 1971; Posner & Petersen, 1990; Posner & Raichle, 1994), and spatial and non-spatial components of visual attention within the formalized framework provided by TVA. To better understand the term of 'alert-

ness' the following section shall provide an introduction for the behavioral and the neural concepts of alertness.

1.3 The Concept of Alertness

1.3.1 Basic Definition

According to the classical view of attention a distinction between phasic and intrinsic aspects of alertness has to be made (e.g., Posner & Boies, 1971; Posner & Petersen, 1990; Sturm et al., 1999; Sturm & Willmes, 2001; van Zomeren & Brouwer, 1994). Intrinsic (non-phasic) alertness refers to the internal control of the level of arousal (in the absence of an external cue) enabling an organism to respond to sensory stimuli - in a sense of a general level of response readiness (Posner & Petersen, 1990; Sturm et al., 1999; Sturm & Willmes, 2001). A typical task for the assessment of intrinsic alertness is a simple reaction time (RT) task. Some authors have defined even this short periods of endogenously maintaining vigilant responding as sustained attention (Robertson et al., 1998). Moreover, it is generally assumed that the level of alertness may be phasically influenced by 'alerting stimuli' that induce a preparatory state of the cognitive system by means of a change in neural state (Heilman, Watson, & Valenstein, 2003; Posner & Petersen, 1990). Thus, phasic alertness may be subscribed as the ability to increase response readiness. For example, several studies have shown that stimulus detection and discrimination can be enhanced by 'alerting' or 'warning signals' which inform subjects that a target stimulus is imminent (Posner, 1978). Although alerting signals usually provide no or little information as to where or when a target will occur, the 'alerting effect' confers a behavioral advantage – for example, in terms of RT performance – over conditions without warning signals (Coull, Nobre, & Frith, 2001; Posner, 1978; Posner & Petersen, 1990). Thus, the level of alertness may be hypothesized to enhance visual processing speed, a spatially

non-lateralized component of attention which, in turn, is reflected in expedited RT performance and an enhanced ability for detecting and discriminating stimuli.

1.3.2 Neural Correlates

Based on neuroimaging evidence, the intrinsic alertness system is assumed to be supported by a widely distributed, predominantly right-hemispheric cerebral network involving the frontal lobe, the inferior and superior parietal lobe, as well as thalamic and brain stem regions (Coull, Frackowiak, & Frith, 1998; Kinomura, Larsson, Gulyas, & Roland, 1996; Robertson et al., 1998; Sturm et al., 1999; Sturm et al., 2006; Sturm & Willmes, 2001). Thus, intrinsic alertness primarily depends on a right fronto-parieto-tjalamic network. The arousal model of Heilman et al. (2003), as well as Posner and Petersen (1990) suggest that noradrenergic pathways provide the basis for maintaining intrinsic alertness, and that they act most strongly on the spatial attention systems centered in the parietal lobe (Posner & Petersen, 1990; Sturm & Willmes, 2001).

However, only few studies explored the neural networks underlying phasic alertness and their results are somewhat inconsistent. For example, Thiel, Zilles, and Fink (2004) mainly found higher activity in extrastriate regions when trials with visual warning-cues were compared to uncued trials. They speculated that the results may reflect enhanced sensory processing due to top down influences from higher order frontal and parietal areas. Several studies showed a somewhat more extended activation pattern underlying phasic alertness compared to intrinsic alertness conditions (see e.g., Sturm & Willmes, 2001). Weis et al. (2000) found additional activations to the intrinsic alertness condition in the thalamus of the right hemisphere and in parts of the frontal gyrus and the parietal lobe of the left hemisphere (for left lateralized fronto-parietal activation see also, Coull et al., 2001). Another study investigating warning-cue induced alertness reports left-sided superior parietal and right-sided ventral prefrontal

activity (Konrad et al., 2005), while Fan et al. (2005), as well as Thiel and Fink (2007) revealed the most extensive phasic alerting-related activation in the right temporo-parietal junction. Sturm and Willmes (2001) interpreted the more extended activation of the right-hemisphere under phasic alerting conditions to be the result of an extrinsic (externally initiated) activation by the warning stimulus. According to the authors, the additional left frontal and parietal activation should be considered to be an indication of elementary attention selectivity, caused by the need to select between warning and target stimulus - since under the phasic alertness condition responses to the warning stimulus have to be inhibited in an active way. One of the areas, activated during intrinsic and phasic alertness, the right parietal cortex, is also known to play a central role in spatial-attention functions (e.g., Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Corbetta & Shulman, 2002) – pointing to the existence of direct (neural) links between spatial attention and (intrinsic and phasic) alertness.

Regardless whether phasic and intrinsic alertness are similar or different neural processes, they are both essential for fast and efficient responding to stimuli in the environment and may impact on spatial as well as non-spatial components of visual attention. The link between alertness and (behavioral performance) aspects of spatial and non-spatial components of attention are introduced, investigated, and discussed in Chapters 3 and 4. First of all a short overview of the studies presented in Chapter 3 and 4 is given in the 'Synopsis' in Chapter 2.

Chapter 2: Synopsis

This thesis is an examination of the relationship between varying levels of intrinsic and phasic alertness on spatially lateralized and spatially non-lateralized components of visual attention in healthy subjects (Chapter 3) and neglect patients (Chapter 4). The primary aims were to pinpoint 1) which attentional components are directly related to different states of alertness and 2) to observe in which time range these alertness-dependent changes occur. By using TVA based partial- and whole-report paradigms these studies allowed spatial and non-spatial attentional components to be assessed independently and separately within the same subjects. Thus, it was possible to disentangle the influence of intrinsic and phasic aspects of alertness on different attentional components.

Study 1 (Chapter 3) investigated the influence of the level of *phasic* alertness on spatial (i.e., the spatial distribution of attentional weighting w_λ) and non-spatial components of visual attention (i.e., visual perceptual processing speed C and VSTM storage capacity K) in a group of healthy subjects. By using different cue-target SOAs the study was also designed to observe the time course of these changes. Two TVA based whole-report paradigms combined with a non-spatial, visually presented alerting-cue were used. The non-spatial alerting-cue was designed to phasically increase the level of alertness of the subjects without spatially cueing them to one or the other hemi-field. The global pattern of effects revealed in the three experiments of study 1 can be summarized as follows: There were 1) a fast evolving and short-lasting modulation of perceptual processing speed by the alerting-cue (Experiment 1) and 2) a longer-lasting effect of the alerting-cue on spatial attentional weighting (inducing a stable pseudo-neglect; Experiment 2). Both of these alerting-cue effects can be attributed to an 'ex-

ogenous', cue-induced state of alertness. Furthermore, there was 3) a rightward re-distribution of spatial attentional weighting in the absence of an alerting-cue (Experiments 2). Finally, 4) a slow evolving but longer-lasting effect of compensatory processes enhancing processing speed irrespective of the cue condition (Experiment 1), a re-instantiation of a leftward spatial bias (Experiment 2), and a leftward enhancement of sensory effectiveness (Experiment 2) in the no-cue condition, likely associated with an 'endogenously' induced state of alertness (as confirmed in Experiment 3) were shown.

Study 2 (Chapter 3) was designed to investigate the influence of *intrinsic* alertness on the spatial distribution of attentional weighting (w_λ) and top-down control (α), and to ascertain whether the vulnerability for a rightward re-distribution of attentional weights in a state of low intrinsic alertness is determined by the participants´ ability to maintain an appropriate alertness state. By applying a visual vigilance task it was possible to reduce the participants´ level of alertness over time-on-task. In order to independently assess the two parameters spatial distribution of attentional weighting and top-down control, a partial report task was used. Results revealed a significant leftward bias of spatial weighting under conditions of normal alertness reflecting the well-known (slight) pseudo-neglect in normal subjects. After the monotonous vigilance task, which led to a state of low intrinsic alertness, a significant rightward bias was found. However, the parameter top down control seemed to be independent of the changes in the level of alertness. Correlations indicated that those subjects who had subjectively rated their decrease of alertness to be more pronounced were also those with the larger rightward lateralization at a state of low alertness. Moreover, correlations indicated that those subjects who responded more slowly already at a level of normal alertness were more vulnerable for decreases in the level of intrinsic alertness and showed a significantly larger change of the spatial distribution of attentional weighting to the right visual hemi-field when their alertness decreased.

The study presented in Chapter 4 observed the influence of *phasically-induced alertness* on the spatial distribution of attentional weighting (w_λ) and sensory effectiveness (*A*)/processing speed (*C*) in patients with visual hemi-neglect. The primary aim of the study therefore was to disentangle the influence of cue-induced phasic alertness on spatially lateralized and non-lateralized components of visual attention in patients with (pronounced) spatial-attentional asymmetries. Furthermore, by using three different cue-target SOAs the time course of changes was assessed. Results showed a fast evolving and short-lasting, 'phasic' modulation of spatial attentional weighting, and a longer-lasting effect of the alerting-cue on sensory effectiveness/processing speed. Thus, it can be assumed that higher levels of alertness overcome the typical neglect symptoms such as a rightward lateralization and unilateral extinction stressing the relevance of alertness in disturbed attentional competition, and thus, spatial attentional asymmetries.

Conclusion: The results of Chapters 3 and 4 demonstrated a significant influence of the level of intrinsic and phasic alertness on spatial and non-spatial components of visual attention in healthy subjects and neglect patients. This demonstration was only possible by using methods that permit the different attentional components and their time courses to be assessed independently, within the same subjects. At the same time, these results suggest that 'alertness', rather than being synonymous with a capacity parameter such as processing speed, might be more appropriately considered as a basic attentional factor influencing various components of attention in parallel, however each with a distinct time course.

Chapter 3: The Influence of the Level of Alertness in Healthy Subjects

3.1 Introduction

Behaviorally, a link between the level of alertness and spatial components of attention has first been supported by data from patients suffering from a combination of a spatial-attentional asymmetry with a reduced level of (intrinsic) alertness. One prominent example are patients with visual hemi-neglect who show a pathological ipsilesional spatial bias of attention almost exclusively following right-parietal lesions (Bisiach & Vallar, 1988; Heilman et al., 2003; Karnath, Himmelbach, & Kuker, 2003; Mort et al., 2003; Vallar & Perani, 1986). The degree of this rightward spatial bias is especially severe in neglect patients with profoundly lowered intrinsic alertness (Bartolomeo & Chokron, 2002; Heilman et al., 2003; von Cramon & Kerkhoff, 1993). Further evidence of a functional relationship between the level of alertness and spatial attention stems from the observations that the rightward bias in neglect patients can be temporarily reduced following alertness training (Robertson et al., 1998; Robertson et al., 1995; Thimm et al., 2006). For example, Robertson et al. (1998) demonstrated that an increase of the alertness level induced by an alerting tone can significantly alleviate the neglect symptoms.

Interestingly, patients with Attention Deficit Hyperactivity Disorder (ADHD) show a comparable combination of spatial and non-spatial attentional deficits. Clinically, ADHD patients are known to suffer predominantly from deficits in maintaining an appropriate level of alertness (Antrop, Roeyers, Van Oost, & Buysse, 2000; George et al., 2005; Tucha et al., 2006). Consequently, the dominant pharmacological approach to the treatment of ADHD symptoms consists of medication with stimulants, which influence the intrinsic alertness state

of the patient (Nigg, Swanson, & Hinshaw, 1997; Sheppard, Bradshaw, Mattingley, & Lee, 1999; Tucha et al., 2006). Recently, ADHD patients have been reported to favor the right visual hemi-field, similar to visual hemi-neglect patients (Carter, Krener, Chaderjian, Northcutt, & Wolfe, 1995; Dobler et al., 2005; George et al., 2005; Nigg et al., 1997; Sheppard et al., 1999). Interestingly, there is also evidence that the degree of this spatial-attentional bias exhibited by ADHD patients may be modulated by the intrinsic alertness level (Dobler et al., 2005). The bias has been reported to increase with time-on-task effects inducing a lowered intrinsic alertness level (George et al., 2005), and to disappear after successful stimulant medication (Sheppard et al., 1999; Tucha et al., 2006). Recently, there have also been indications that effects of the (intrinsic) alertness level on spatial attention, although more subtle than in patients with spatial bias, are also evident in healthy normal subjects. Normal subjects tend to exhibit a slight leftward spatial bias, referred to as 'pseudoneglect' (Bowers & Heilman, 1980); for example, they place the cross mark slightly to the left of the true midpoint in a line bisection task (for a review, see Jewell & McCourt, 2000). Bellgrove et al. (2004) found a positive relationship between the participants´ level of alertness and the degree of spatial lateralization. They were able to demonstrate that the leftward 'pseudoneglect' bias was significantly reduced in a group of healthy participants who performed poorly on a (non-spatial) alertness attention task relative to participants exhibiting better task performance. After total sleep deprivation, normal subjects show reduced behavioral performance, for example, prolonged response latencies in simple RT tasks (Dinges & Kribbs, 1997; Gillberg & Akerstedt, 1998). Reduced performance is associated with decreased levels of global cerebral glucose metabolism, with the most pronounced decrease of local activation in the alertness-related cortico-thalamic network (Thomas et al., 2000) including the thalamus, (Kinomura et al., 1996), the prefrontal cortex, and the posterior parietal lobe. In sleep-deprived subjects, Manly et al. (2005) found a significantly stronger rightward spatial lateralization in a landmark task

compared to controls with a normal alertness state (see also Dufour, Touzalin, & Candas, 2007). Moreover, a rightward shift of spatial attention was observed over the course of the testing session (time-on-task effect). And Fimm et al. (2006) reported a disproportionate slowing of responses to stimuli presented on the left side of fixation for subjects in a state of maximally lowered alertness. Therefore, it has been proposed (e.g., Bellgrove et al., 2004; Fimm et al., 2006; Manly et al., 2005) that a reduction in the level of alertness might suffice to induce a rightward bias in visuo-spatial attention even in subjects with a healthy attention system, who normally show a slight bias towards the left.

In summary, there is converging neuroimaging, neuropsychological, and psychophysi-ological evidence (see also topic 1.3.2) that the level of phasic and intrinsic alertness not only affects non-spatial attention functions such as processing speed (as reflected in RT perform-ance), but that it also exerts significant influence on spatial attention functions, reflected in a modulation of the spatial bias. In particular, higher levels of alertness give rise to an en-hancement of processing speed, whereas lower levels lead to an increase in RTs as well as a weaker leftward, or even stronger rightward lateralization of visuo-spatial attention.

3.2 Study 1: The Influence of Increased Phasic Alertness on Visual Attention

3.2.1 Abstract

The aim of the present study was to investigate whether spatial and non-spatial compo-nents of visual attention, independent of any motor components, are affected by changes in the level of the participant's phasic alertness. If so, it should be assessed whether such effects on mechanisms underlying selective attention occur independently of each other. A no-cue/alerting-cue paradigm with six different cue-target stimulus onset asynchronies (SOA) in two differing whole-report paradigms based on Bundesen´s (1990) 'Theory of Visual Atten-tion' was used. The paradigm allows for spatially lateralized and non-lateralized components

of selective attention to be assessed independently of each other. Our results indicate that the level of alertness affects both the spatial distribution of attentional weighting and processing speed, but not visual short term memory storage capacity. SOA-based analyses suggest that the effect on processing speed occurs prior to the effect on the spatial distribution of attentional weighting. It can be concluded that the level of alertness affects both spatial and non-spatial component mechanisms of visual selective attention and that this two effects of the level of alertness develop independently of each other.

3.2.2 Introduction and Scope

Although there seems to be converging evidence for a strong relationship between the level of alertness and attentional performance the majority of the studies reviewed above (see 1.3.2 and 3.1) have assessed the influence of intrinsic and phasic alertness on spatial and non-spatial components of attention using tasks that required speeded motor responses as dependent variable (Fan et al., 2005; Fan et al., 2002; Fernandez-Duque & Posner, 1997; Fimm et al., 2006; Thimm et al., 2006; Thomas et al., 2000; Tucha et al., 2006). Thus, it cannot be ruled out that the relationships between the level of phasic or intrinsic alertness and the spatial and non-spatial components of visual attention described in those studies are, at least in part, influenced by alertness-dependent changes in motor performance (e.g., modulation of the processes underlying the preparation and/or execution of the motor response). Consequently, it remains unclear exactly which of the spatially lateralized and non-lateralized components of attention are influenced by the level of alertness independently of any motor 'confounds', and whether the (non-confounded) effects on the various components of attention are indeed independent of each other. On this background, the present study was designed to examine the time courses of the various components of visual attention by using a Posner-like no-cue/alerting-cue paradigm (Posner, 1980) - dependent on different cue-to-target SOAs (stimu-

lus onset asynchronies). In general, trials in which an alerting-cue precedes the target are thought to index phasic alertness, while trials without a warning signal (no-cue condition) index non-phasic, intrinsic alertness (e.g., Coull & Frith, 1998; Posner, 1978; Sturm et al., 1999). Thus, it should be able to assess whether the level of phasic alertness exerts a simultaneous, 'global' effect on all components, or whether these display a pattern of independent effects occurring at different SOAs.

To address these questions, the present study used a TVA-based approach to examine the effects of an alertness manipulation (alerting-cue vs. no-cue conditions) in two whole-report tasks on the three distinct TVA parameters assumed to reflect the key components underlying performance in selective attention tasks: perceptual processing speed C, VSTM storage capacity K, and the spatial distribution of attentional weighting w_λ. These parameters were determined using the same stimulus material (letters) and response requirements (verbal, non-speeded report). Performance was assessed in terms of the level of accuracy achieved at pre-defined, brief exposure durations (rather than in terms of response speed), effectively ruling out confounding of the results by stimulus material and motor-response related factors.

Furthermore, acording to TVA, one explanation of a rightward spatial bias found under low-alertness conditions (e.g. Bellgrove et al., 2004; George et al., 2005; Manly et al., 2005) is that attentional weights are reduced on the left compared to the right hemi-field, unbalancing the competition between left and right sided targets. However, it is also possible that basic sensory effectiveness is reduced on the left hemi-field, unbalancing sensory processing between hemi-fields (see Equation 2, Bundesen, 1990). In neglect patients, Duncan (1999) observed in a TVA based partial-report task – besides the expected rightward spatial bias – a significant impairment of relative sensory effectiveness in the left visual hemi-field. Thus, target letters presented alone were identified less well in the left field. This results indicate the possibility that alertness might also effect sensory effectiveness on one hemi-field. Hence, to

clarify this question (analogously to the definition of w_λ), a laterality index for sensory effectiveness (A_λ) was computed.

3.2.3 General Method

To examine the influence of phasic and intrinsic alertness on the above described TVA parameters, the present study compared an alerting-cue condition (indexing phasic alertness) versus a no-cue condition (indexing non-phasic alertness). In the alerting-cue condition, observers were provided with a warning signal. At the start of a trial, an outline frame flashed briefly around the whole (potential) display array which was non-informative as to the location of the upcoming target letters. Thus, while alerting the observers to the imminent appearance of the target array, this warning signal was designed to induce a spatially diffuse distribution of attentional weighting across the (potential) stimulus display (i.e., it could not be used to systematically orient spatial attention to the stimulus locations). The non-informativeness of the alerting-cue with regard to the target location is likely to have discouraged subjects from making eye movements. In any case, since the stimulus exposure durations were relatively short, eye movements were unlikely to affect performance systematically. However, to avoid suboptimal fixation in the beginning, central fixations at start of each trial were controlled by the experimenter. Subjects were encouraged to hold central fixation over the entire trial period.

Observers, Apparatus and Stimuli, Design and Procedure

All subjects had normal or corrected-to-normal vision and none of them suffered from color blindness or any psychiatric or neurological impairment. All subjects were naïve as to the purpose of the experiment and received either course credits or monetary payment (€ 8 per

hour) for their participation. Written informed consent according to the Declaration of Helsinki II was obtained from all participants.

The PC-controlled experiment was conducted in a dimly lit, sound-proof cubicle. Stimuli were presented on a 17" monitor (1024×768 pixel screen resolution, 70 Hz refresh rate). Subjects viewed the monitor from a distance of 50 cm, controlled by the aid of a head- and chin-rest. Participants were first instructed to fixate a white fixation cross (0.3° × 0.3°) presented for 600 ms in the centre of the screen, on a black background. The cross was followed by a blank screen presented for 500 ms. Then, either a white outline square (5° × 5°) appeared on the screen for 50 ms (alerting-cue condition) or the screen remained blank for the same length of time (no-cue condition; see Figure 2). Alerting-cue and no-cue trials were presented in random order within the same block. After a variable cue-target stimulus onset asynchrony (SOA, randomly of 80, 100, 200, 300, 450, or 650 ms), red letters (0.5° high × 0.4° wide) were presented as targets for a pre-set exposure duration determined in a pre-test part of the experiment. The letters for a given trial display were chosen randomly from the set (ABEFHJKLMNPRSTWXYZ), with a particular letter appearing only once at a time. By using six different and randomized cue-target SOAs ranging from less than 100 milliseconds to over half a second, the warning stimulus was expected to primarily induce a more general alerting/arousing effect, rather than supporting any specific temporal expectations about the onset of the stimulus array.

The participants' task was to verbally report the letters they had recognized with certainty. The target letters could be named in any, arbitrary order, and there was no emphasis on reporting speed. The experimenter entered the reported letter(s) using the computer keyboard and initiated the next trial after the observers had indicated that they were ready. The trial started after an intertrial interval of 1000 ms.

3.2.4 Experiment 1

3.2.4.1 Method

The aim of Experiment 1 was to investigate the influence of the level of alertness on the two non-spatial parameters of selective attention: visual perceptual processing speed C and VSTM storage capacity K.

Participants: 11 right-handed healthy volunteers (M_{age} = 24.2, SD_{age} = 3.3; range: 21–30 years; 2 male, 9 female) participated in Experiment 1.

Procedure: Figure 2 shows the sequence of frames presented on a no-cue (top panel) and an alerting-cue (bottom panel) trial in Experiment 1. Five equidistant red target letters (each 0.5° high × 0.4° wide) were presented in a vertical column, 2.5° of visual angle either to the left or to the right of the fixation cross. The participants had to report as many letters as possible. Stimulus arrays were presented for three different exposure durations, and were then either masked or not masked. The masks consisted of letter-sized squares (of 0.5°) filled with a '+' and an '×' and presented for 500 ms at each letter location. Due to 'iconic memory' buffering, the effective exposure durations are usually prolonged by several hundred milliseconds in unmasked as compared to masked conditions (Sperling, 1960)[2]. Thus, by factorially combining the three exposure durations with the two masking conditions, six different 'effective' exposure durations were produced. These were expected to generate a broad range of performance, tracking the early and the late parts of the functions relating response accuracy to effective exposure duration.

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[2] In TVA this additional effective exposure duration is named μ (Bundesen, 1990, 1998; Duncan et al., 1999)
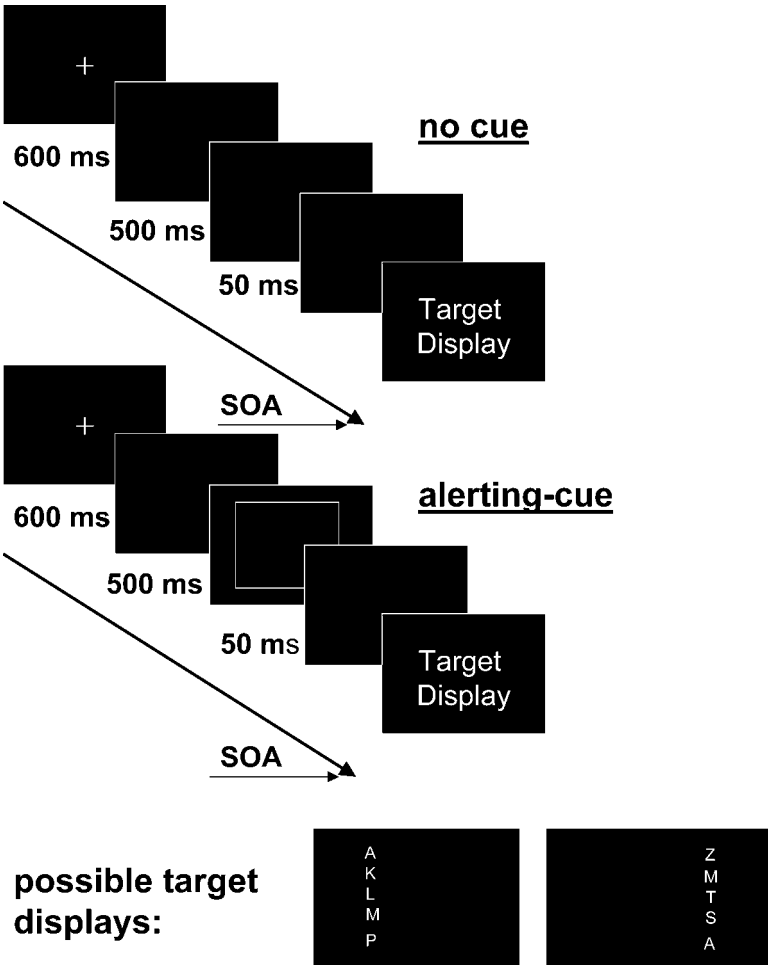
Figure 2. Sequence of frames presented on a given trial for the two cueing conditions in Experiment 1. Top panel: no-cue, bottom panel: alerting-cue. Two (unmasked) target displays with target letters in the left and the right hemi-field (left- and right-hand panel), respectively, are also shown.

Experimental design: In two previous studies that used a similar paradigm (Finke et al., 2006; Finke et al., 2005), highly reliable estimates of the parameters *C* and *K* were obtained on the basis of 16 trials per target condition. On this basis, in the present experiment, each subject completed 8 blocks of 288 trials each (2 cueing conditions x 6 SOAs x 2 hemi-fields x 2 masking conditions x 3 exposure durations x 16 trials per target condition), altogether 2304 trials per subject. Trials were randomly assigned to the eight blocks. Subjects performed three

blocks each in sessions 1 and 2 (about 1.5 hours per session), and two blocks in session 3 (about 1 hour), with 5-minute breaks between blocks. The order of the sessions was counter-balanced across the subjects. Each subject performed the three sessions at the same time of day and within (a maximum of) two weeks. Before each block, the subjects were given writ-ten and verbal instructions.

Target exposure durations: The first session started with the pre-test phase in which three target exposure durations were determined for each subject that were then introduced in the experimental phase. The pre-test consisted of 48 masked trials (4 trials for each SOA and hemi-field) with a fixed exposure duration of 86 ms, to assess whether the subject reported, on average, 1 letter (20%) per trial correctly. If this standard was achieved, exposure durations of 43, 86 and 157 ms introduced in the experimental phases. If pre-test performance was below the 20% standard, exposure durations of 86, 157, and 300 ms were used instead. Thus, in the main test 6 participants had exposure durations of 43, 86 and 157 ms, and 5 participants had exposure durations of 86, 157, and 300 ms.

3.2.4.2 Results and Discussion

Response Accuracy

Figure 3 illustrates the qualitative pattern of performance for a representative subject at the 80-ms SOA: the observed numbers of letters reported correctly [Mean(obs)] as a function of the 'effective exposure duration t' (see definition below), separately for the no-cue and the alerting-cue condition. Because of the results of the parameter estimation (see section below), only the most relevant SOA condition, 80 ms, is illustrated. Along with the observed data points, the best – maximum likelihood (e.g., Ross, 2000) – fits to the data based on the TVA parameter estimates are presented for the two cueing conditions.
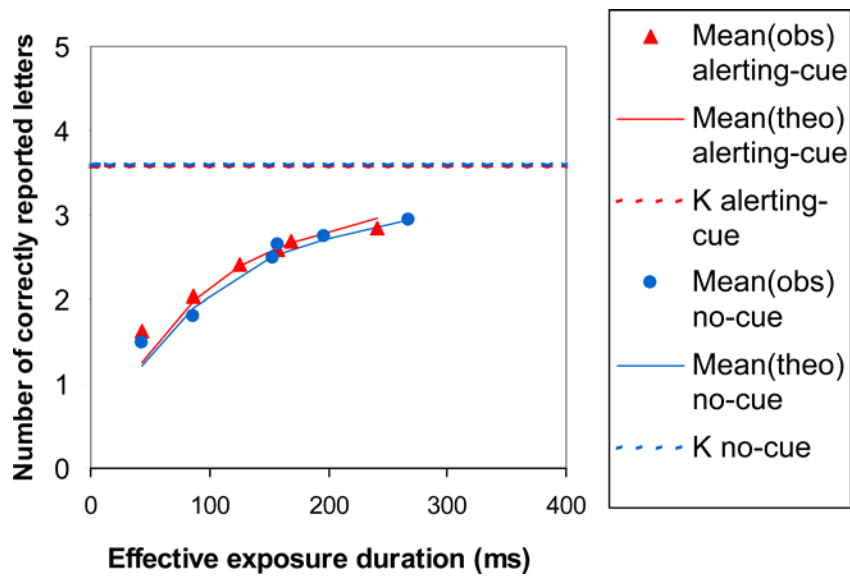
Figure 3. Whole-report performance for a representative participant at 80 ms SOA, separately for the two cueing conditions (no-cue, alerting-cue). The mean number of correctly reported letters is shown as a function of effective exposure duration. Mean (obs) = observed number of letters reported correctly; Mean (theo) = predicted number of letters reported correctly; C = visual perceptual processing speed; K = VSTM storage capacity.

According to TVA, in masked conditions the effective exposure duration of the stimulus display is the difference $t–t_0$, with t being the display presentation time and t_0 denoting the estimated *minimal effective exposure duration*, below which information uptake from the display is assumed to be zero. In unmasked stimulus conditions, an effective exposure duration of μ ms was added to $t–t_0$. TVA assumes that t_0 and μ for a given subject are constant across experimental conditions (e.g., Bundesen, 1990). The resulting six effective exposure durations (for each cueing-condition) were expected to generate a broad range of performance, tracking the early and the late parts of the accuracy-exposure duration function (for more details see 1.1.4).

In TVA, a central consideration is the time taken to complete identification of any display element (= processing speed C). For each element, these times are exponentially distributed (Bundesen, 1990, 1998; Duncan et al., 1999). The identification probability for an object is modeled by an exponential growth function, with the growth parameter (slope of the function relating the total number of elements reported to the exposure duration t) reflecting the rate at which the presented stimuli can be processed (processing speed C), and the asymptote indicating the maximum number of objects that can be represented in parallel (storage capacity K).

As can be seen from Figure 3, in both cueing-conditions, the theoretically predicted functions [Mean(theo)] exhibit a steep initial rise, in line with previously published studies (e.g. Duncan et al., 1999; Finke et al., 2005). However, closer inspection reveals the mean scores to show a somewhat more marked increase in the alerting-cue compared to the no-cue condition, indicating a higher processing speed C in the former condition. As exposure duration increases to a few hundred ms, both curves become flatter and approach an asymptote at a similar level of 3.5–4 reported letters. Accordingly, the two lines indicating the subject's predicted VSTM storage capacity K in the two conditions are at nearly the same height.

As can be seen, there is a close correspondence between the theoretically predicted and the observed mean scores in both conditions. The observed and the predicted mean scores showed a reasonable correspondence. Across all subjects, the average Pearson product-moment correlation between the observed values and the TVA best data fits across all SOAs was .84 ($SD = .02$) in the no-cue condition and .85 ($SD = .03$) in the alerting-cue condition.

Parameter Estimates

Processing Efficiency. In TVA, the efficiency of processing is defined by two parameters: visual perceptual processing speed C and VSTM storage capacity K (Bundesen, 1990, 1998; Bundesen et al., 2005). The following section describes the SOA-dependent time-course of

these parameters for the two cueing conditions. Parameter C was estimated (by TVA model fitting) as the average of the summed processing rate values v for the objects presented to the left and the right of fixation, respectively. With reference to Figure 3, parameter C is the slope of the function relating the number of elements reported to t – that is, effectively, it is a measure of the identification rate in elements/second (Duncan et al., 1999). And parameter K reflects, in effect, the maximum number of letters reported on any single trial at any exposure duration.

Visual Perceptual Processing Speed (C). Figure 4 illustrates the time course of the parameter visual perceptual processing speed C for the no-cue and the alerting-cue condition.

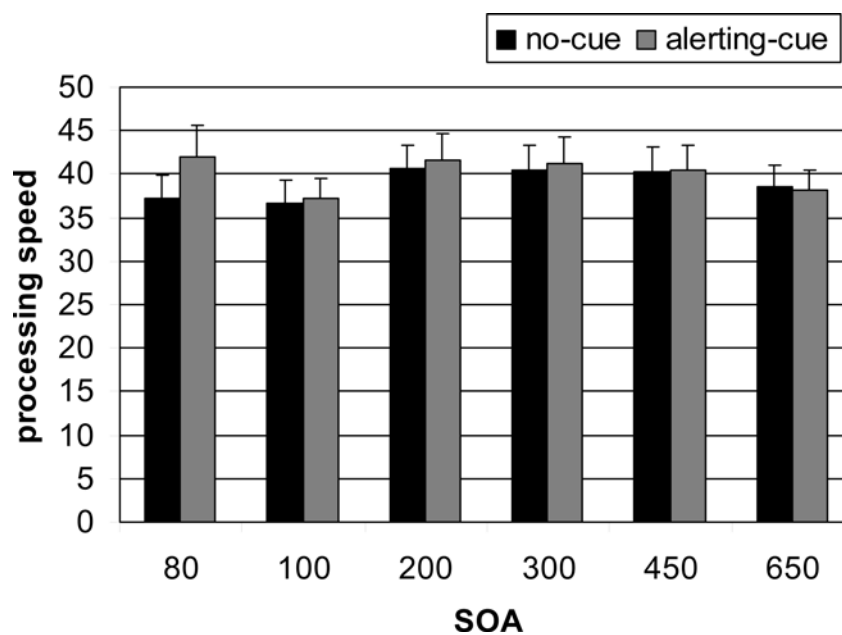**Figure 4.** Parameter C (visual perceptual processing speed = numbers of elements processed per second) as a function of SOA, separately for the no-cue and the alerting-cue condition in Experiment 1. The error bars show the standard errors.

The results described qualitatively above were confirmed by a repeated-measures ANOVA of the processing speed C with the factors of Cue (no-cue, alerting-cue) and SOA

(80, 100, 200, 300, 450, 650 ms). The analysis revealed a marginally significant main effect of Cue [$F(1,10) = 4.17$; $p = .07$], a significant main effect of SOA [$F(5, 6) = 57.12$; $p < .001$; $\eta^2 = .97$], and a significant (Cue × SOA) interaction [$F(5, 6) = 7.28$; $p < .05$; $\eta^2 = .85$]. Visual perceptual processing speed was significantly faster in the alerting-cue compared to the no-cue condition at the 80-ms SOA [$t(10) = -2.41$; $p < .05$], but not at the longer SOAs (all $ps > .25$). Moreover, in the alerting-cue condition, the processing speed decreased between the 80- and the 100-ms SOA [$t(10) = 2.26$; $p < .05$]. In both cueing conditions, processing speed significantly increased from the 100- to the 200-ms SOA [no-cue: $t(10) = -4.09$; $p < .01$; alerting-cue: $t(10) = 3.39$; $p < .01$], reaching its highest level at around the 300-ms SOA, followed by some decline towards the 650-ms SOA.

The significantly enhanced processing speed parameter in the alerting-cue, as compared to the no-cue, condition at the shortest time interval of 80-ms SOA demonstrates that the alerting stimulus used in Experiment 1 has a positive effect on subjects' processing efficiency. However, with longer SOAs, this processing speed advantage following an alerting-cue was no longer existent.

However, since the TVA-based approach used in the present study provides estimates of processing efficiency that are independent of motor-response speed, the present finding is the first to demonstrate that alerting stimuli not only affect the time it takes to respond to the extracted and encoded target information, as suggested by Posner (1978), but also directly influence the extraction/encoding of this very information. In the light of the present results, previous reports of a decrease in RTs following an alerting stimulus (e.g., Fan et al., 2005; Posner & Boies, 1971; Posner & Petersen, 1990; van Zomeren & Brouwer, 1994) cannot be exclusively attributed to a heightened readiness to respond to a target stimulus; instead, the present result provide evidence for an increase in visual perceptual processing speed.

In the 'Neural Theory of visual Attention' (NTVA; Bundesen et al., 2005), an extension as well as an interpretation of TVA at the level of neurons or neuronal assemblies, perceptual categorizations of objects are assumed to be based on activations (v values) in the set of neurons that represent the object. The speed at which a visual object x is categorized is determined by the number of cortical neurons representing object x on the one hand and by the level of activation of the individual neurons representing object x on the other (for a more detailed description of NTVA, see 1.1.7). In these terms, an NTVA-based interpretation of our finding of a temporary acceleration of processing speed therefore would be that, for a short period following after the presentation of an alerting-cue, either a larger set of neurons was allocated to the five target letters presented and/or these neurons were activated to a higher level.

The finding that (apart from the initial boost in the alerting-cue condition) visual perceptual processing speed was highest at around the 300-ms SOA is likely to reflect a temporal-range effect that is: participants tend to (endogenously) prepare optimally for target displays presented in the middle of the SOA range. Again, such range effects have hitherto been described only for RTs (Posner, 1978).

VSTM Storage Capacity (K). Figure 5 illustrates the time course of the parameter VSTM storage capacity K for the no-cue and the alerting-cue condition. A Cue × SOA ANOVA with K as dependent variable failed to reveal any significant effects (all $p > .16$).
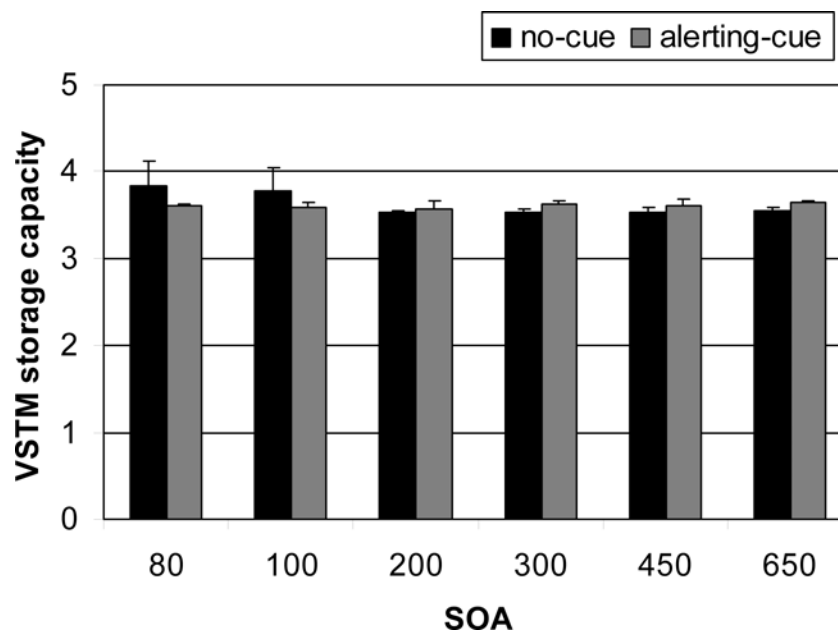
Figure 5. Parameter *K* (visual short term memory storage capacity = maximum number of objects that can be represented in parallel) as a function of SOA, separately for the no-cue and the alerting-cue condition in Experiment 1. The error bars show the standard errors.

According to TVA, processing efficiency is not only defined by the perceptual processing speed (TVA parameter *C*, see above), but also by VSTM storage capacity *K*. The present results indicate that the latter parameter is independent of the level of alertness. The fact that the speed of processing can be distinctly affected by the alertness manipulation, without consequences for the VSTM storage component, supports one of the main assumptions underlying TVA (e.g., Bundesen, 1990), namely, that the two parameters determine visual processing in an independent manner.

3.2.5 Experiment 2

As outlined in the Introduction, the processing of each display element is associated with two separate parameters: sensory effectiveness and spatial distribution of attentional weighting (Bundesen, 1990, 1998; Duncan et al., 1999). Sensory effectiveness, which is independent

of attentional weighting, reflects how well an element is processed when presented alone; it depends on stimulus properties such as luminance, contrast, retinal eccentricity, etc. On the other hand, the spatial distribution of attentional weighting, a spatial parameter of visual selective attention, is important in displays containing multiple elements. These elements compete to be processed, and the attentional weight reflects how strongly any given element is competing. The aim of Experiment 2 was to examine the influence of the level of alertness on both the spatial distribution of attentional weighting (the spatial parameter of selective attention) and on the sensory effectiveness.

3.2.5.1 Method

Participants: 14 right-handed healthy volunteers (M_{age} = 24, SD_{age} = 3.01; range: 23–30 years; 3 male, 11 female) participated in Experiment 2.

Procedure. Figure 6 illustrates the sequence of frames presented on a trial in Experiment 2. Targets appeared with equal frequency at each of the possible stimulus locations in the corners of an imaginary square (with an edge length of 5°): upper left, lower left, upper right, lower right corner (see Figure 6, bottom panel). On each trial, either a single target or two targets (on the same side or on opposite sides) were presented. Dual targets were placed either vertically (column display) or horizontally (row display), but never diagonally. All target stimuli were masked.
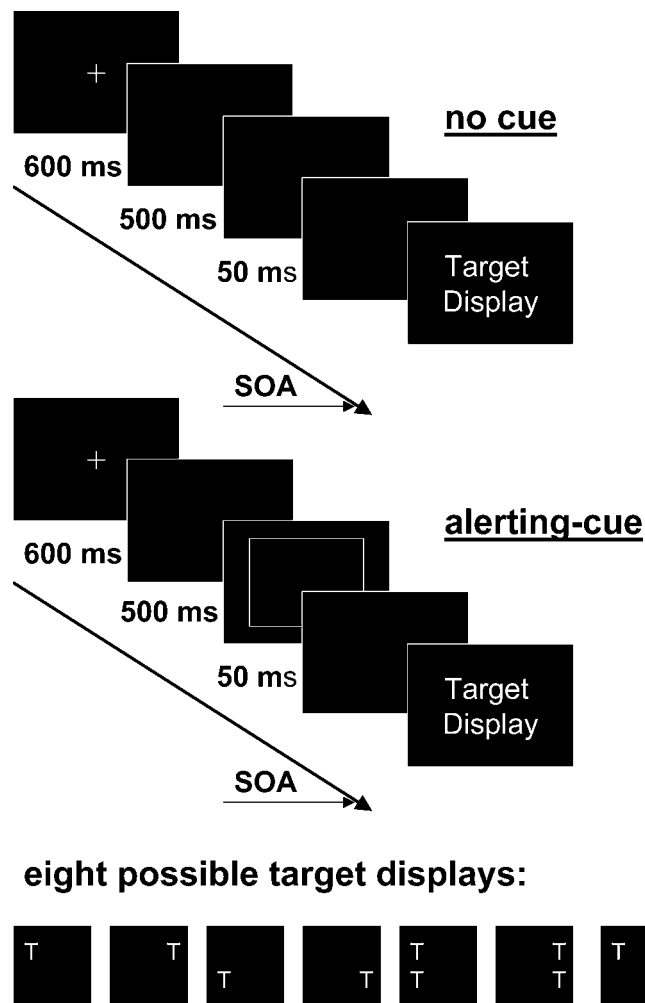
Figure 6. Sequence of frames presented on a no-cue trial (top panel) and an alerting-cue trial (middle panel) together with the eight possible target displays (bottom panel; the 'T' symbols denote target locations) in Experiment 2.

Experimental design. The experiment was divided into two 1.5-hour sessions, each comprising four blocks that were separated by five-minute breaks. The order of the sessions was counterbalanced across subjects to control for sequence effects.

Subjects completed each of the two sessions at the same time of day and within the same week. Before each block of trials, subjects were given standardized written and verbal instructions.

The experimental phase comprised eight different target conditions (four single target and four dual target conditions) for each SOA (80, 100, 200, 300, 450, 650 ms) and each of the two cueing conditions (no-cue, alerting-cue). In previous studies using a similar paradigm (Finke et al., 2006; Finke et al., 2005), highly reliable estimates for the parameter spatial distribution of attentional weighting (w_λ) were obtained on the basis of 18 trials per target condition. Therefore, in the present Experiment 2, 18 trials were used for each target, SOA and cueing condition. In total, the experiment comprised 1728 trials per subject.

Performance accuracy rate was recorded continuously and reported to the subject as a feedback indicator after each testing block.

Target exposure duration. At the beginning of each session, the target exposure durations were determined individually for each participant. A pre-test (no-cue condition, 72 trials, with three trials for each SOA and single-target display) with a fixed exposure duration of 71 ms was used to determine whether a participant was able to reach an accuracy of 60–80% for single-target report. If the participant performed outside this range, the exposure duration in the experimental phase was adjusted accordingly (i.e., extended to 100 ms if < 50% and to 86 ms if 50–60%, and shortened to 57 ms if 80–90% and to 43 ms if > 90%). Thus, in the main test 9 participants had a exposure duration of 57 ms, 4 of 71 ms and 1 of 86 ms.

3.2.5.2 Results and Discussion

Response Accuracy

To start with, performance accuracy was examined by a repeated-measures ANOVA with the factors Side (left, right visual field), Target Type (single target, dual targets in same hemi-field, dual targets in opposite hemi-fields), SOA (80, 100, 200, 300, 450, 650 ms), and Cue (no-cue, alerting-cue). This ANOVA revealed a plethora of significant effects (Side, Target Type, Side × Target Type, Side × SOA, Target Type × SOA, Target Type × Cue, Side × Tar-

get Type × Cue, Side × Target Type × SOA, Side × SOA × Cue, and Target Type × SOA × Cue); the four-way interaction of Side × Target Type × SOA × Cue was also significant (with all $F > 6.53$; all $p < .05$). To further analyze the four-way interaction, separate ANOVAs were carried out for the two Cue types, with the factors Side, Target Type, and SOA.

Alerting-cue condition: For the alerting-cue condition, the ANOVA revealed significant effects for Target Type, SOA, Side × Target Type, and Side × SOA; the three-way interaction Side × Target Type × SOA was also significant (with all $F > 3.64$; all $p < .05$). The latter interaction was analyzed further by carrying out separate ANOVAs for the different Target Types, with Side and SOA as factors.

Alerting-cue condition, single targets(Figure 7): Performance for single targets (and dual targets in the same hemi-field; see below) was examined to assess the general sensory effectiveness, that is, basic sensory efficiency in target discrimination at a given exposure duration. In unilateral displays, this basic efficiency is assumed to be *independent* of the spatial attentional weighting across the two hemi-fields. There was a significant main effect of Side [$F(1,13) = 41.17$; $p < .001$; $\eta^2 = .76$], and the Side × SOA interaction was significant [$F(5,9) = 16.37$; $p < .001$; $\eta^2 = .90$]. *Pos-hoc* tests revealed significantly higher report accuracy for the right compared to the left visual hemi-field for the SOAs of 80 [$t(13) = -4.59$; $p < .05$], 100 [$t(13) = -6.38$; $p < .01$], 200 [$t(13) = -5.77$; $p < .01$], and 300 ms [$t(13) = -4.32$; $p < .01$]. This is in accordance with Kimura (1973), who has shown that letters and words are processed faster when presented in the right visual hemi-field, due to the lateralization of speech processing. Moreover, *post-hoc* tests revealed a significant increase in accuracy between the SOAs of 300 and 450 ms [$t(13) = -6.89$; $p < .01$] in the left visual hemi-field.
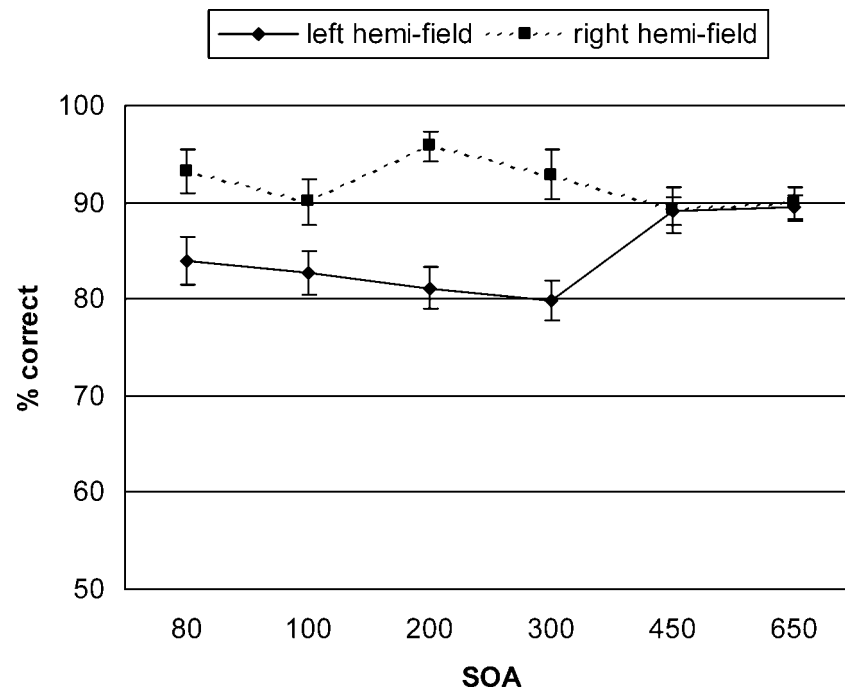
Figure 7. Mean proportions of correctly identified single target letters in the alerting-cue condition as a function of SOA, separately for the left and right hemi-fields.

Alerting-cue condition, dual targets in the same hemi-field (Figure 8): There was a significant main effect of SOA [$F(5,9) = 17.75$; $p < .001$; $\eta^2 = .90$], due to an increase in performance in both the left and the right visual hemi-field between the SOAs of 80 and 650 ms.

Figure 8. Mean proportions of correctly identified dual target letters in the same hemi-field (% correct) in the alerting-cue condition as a function of SOA, separately for each hemi-field.

Alerting-cue condition, dual targets in opposite hemi-fields (Figure 9): The dual-target condition with (row) displays containing a target in each hemi-field is crucial for the TVA-based estimation of the attentional weighting parameter: it is the only condition in which spatial-attentional weights have to be distributed across the left *and* the right visual hemi-field, with the weight allocation determined by a competitive process between the two hemi-fields. If attentional weights are biased towards one hemi-field, performance in the bilateral (compared to the unilateral) target condition will suffer more for the target presented in the hemi-field with relatively low attentional weight, compared to the target in the hemi-field with high weight.

Again, there was a significant main effect of SOA [$F(5,9) = 20.15$; $p < .001$; $\eta^2 = .92$], reflecting a decrease in performance in the left and the right visual hemi-field between the 80-

and 650-ms SOAs. Moreover, the Side × SOA interaction was marginally significant (p = .06). This interaction occurred because, for most SOAs (80, 100, 450, and 650 ms), accuracy was slightly higher for the left visual hemi-field – the typical 'pseudo-neglect' pattern (Jewell & McCourt, 2000); in contrast, for 200- and 300-ms SOAs, performance was comparable for the two hemi-fields.
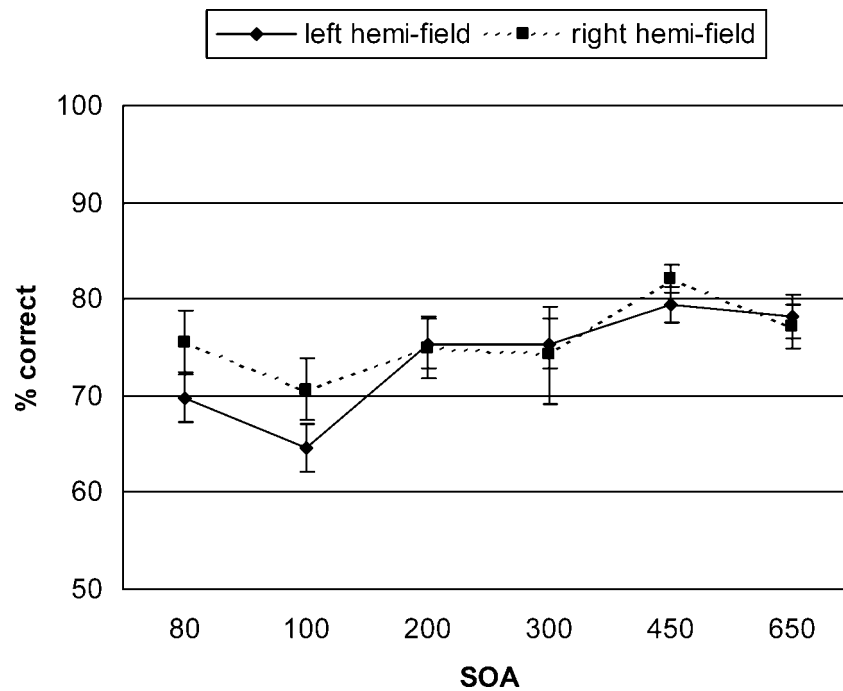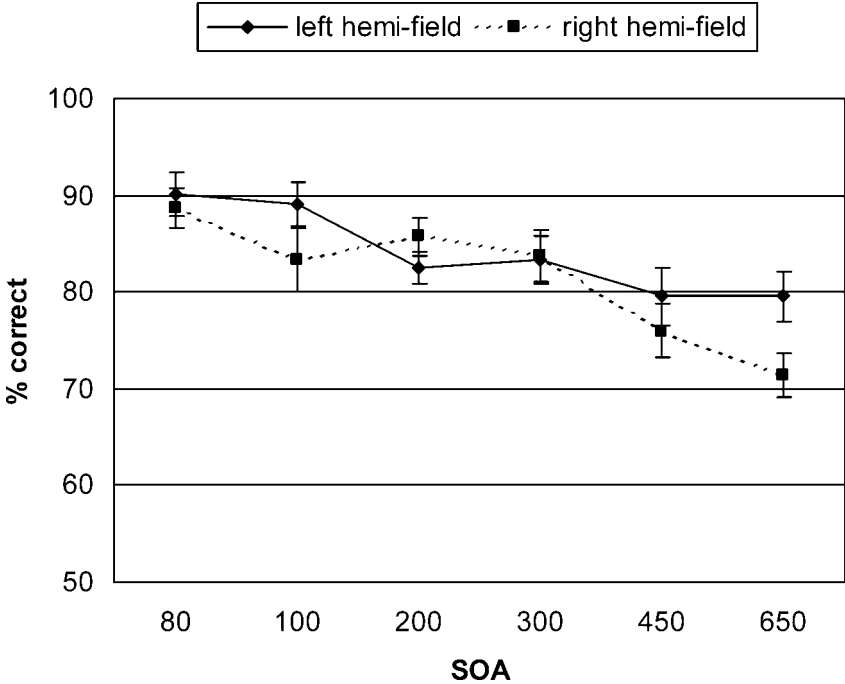

Figure 9. Mean proportions of correctly identified dual target letters in opposite hemi-fields in the alerting-cue condition as a function of SOA, separately for each hemi-field.

In summary, in the alerting-cue condition, performance showed the 'classical' pattern. In conditions with unilateral presentation (i.e., with single targets and dual targets in the same hemi-field), participants showed better performance for the right compared to the left hemi-field. In contrast, in conditions with bilateral presentation (i.e., with dual targets in opposite hemi-fields), accuracy was slightly better for the left compared to the right hemi-field (pseudoneglect) for most SOAs, and report of letters appearing in the right hemi-field was more

disturbed by additional targets in the left hemi-field, than vice versa. As will be seen below, in the no-cue condition, a break-up of this typical performance pattern was observed.

No-cue condition: Significant effects were found for the main effects of Side, Target Type, and SOA, as well as for the two-way interactions Side × SOA, and Target Type × SOA, and for the three-way interaction Side × Target Type × SOA (with all $F > 7.98$; all $p < .05$). To further analyze the three-way interaction, separate ANOVAs were conducted for the different Target Types with Side and SOA as factors.

No-cue condition, single targets (Figure 10): There were significant main effects of Side $[F(1,13) = 9.62; p < .01; \eta^2 = .42]$, and SOA $[F(5,9) = 8.27; p < .01; \eta^2 = .82]$, and the Side × SOA interaction was significant $[F(5,9) = 9.42; p < .01; \eta^2 = .84]$.
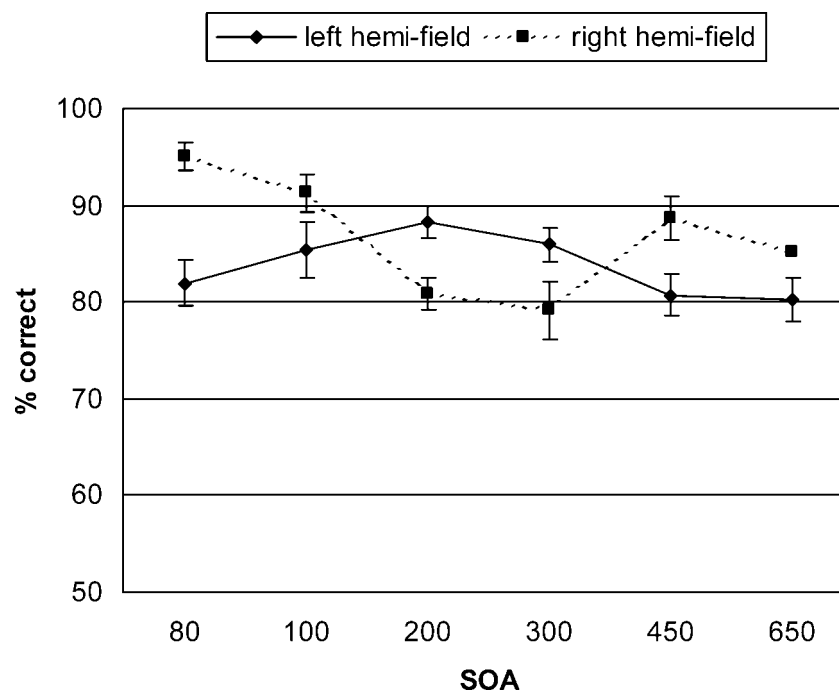

Figure 10. Mean proportions of correctly identified single target letters in the no-cue condition as a function of SOA, separately for each hemi-field.

Post-hoc tests revealed superior performance in the right visual hemi-field for the SOAs of 80 [$t(13) = -5.83$; $p < .01$], 100 [$t(13) = -3.28$; $p < .05$], 450 [$t(13) = -4.68$; $p < .01$], and 650 ms [$t(13) = -2.76$; $p < .05$] which is again consistent with Kimura (1973). Moreover, participants showed better performance for the targets in the left, compared to the right, hemi-field for the 200-ms SOA [$t(13) = 3.35$; $p < .05$], due to a significant decrease in accuracy between the 80- and 200-ms SOAs for the right visual hemi-field [80 vs. 100 ms: $t(13) = 3.00$; $p < .05$; 100 vs. 200 ms: $t(13) = 7.02$; $p < .001$]. Between the 300- and 450-ms SOAs, there was also a significant decrease in accuracy in the left [$t(13) = 3.14$; $p < .05$] and a significant increase in the right hemi-field [$t(13) = -3.86$; $p < .05$].

No-cue condition, dual targets in the same hemi-field (Figure 11): The main effect of SOA [$F(5,9) = 9.67$; $p < .01$; $\eta^2 = .84$] and the Side × SOA interaction [$F(5,9) = 16.13$; $p < .001$; $\eta^2 = .90$] were significant.

Participants showed better performance for the right compared to the left hemi-field at the SOAs of 80, 100 and 450 ms [$t(13) = -6.62$; $p < .01$; $t(13) = -5.05$; $p < .01$; $t(13) = -5.72$; $p < .01$], but the reverse effect of superior performance for the left compared to the right hemi-field at the SOAs of 200 and 300 ms [$t(13) = 3.27$; $p < .05$: $t(13) = 6.15$; $p < .01$]. This pattern is due to a significant increase in performance for the left hemi-field between the SOAs of 100 and 200 ms [$t(13) = -6.03$; $p < .01$], and a significant decrease of performance in the left visual hemi-field between the SOAs 300 and 450 ms [$t(13) = 6.35$; $p < .01$].

Figure 11. Mean proportions of correctly identified dual target letters in the same hemi-field in the no-cue condition as a function of SOA, separately for each hemi-field.

No-cue condition, dual targets in opposite hemi-fields (Figure 12): All effects were significant – Side [$F(1,13) = 16.54$; $p < .001$; $\eta^2 = .56$], SOA [$F(5,9) = 57.10$; $p < .001$; $\eta^2 = .96$], and Side × SOA [$F(5,9) = 13.54$; $p < .001$; $\eta^2 = .88$]. *Post-hoc* tests revealed superior accuracy for the right compared to the left hemi-field for the SOAs of 200 and 300 ms [$t(13) = -4.23$; $p < .05$; $T(13) = -3.83$; $p < .05$], due to a significant increase in accuracy in the right hemi-field between the 100- and 200-ms SOAs [$t(13) = -3.50$; $p < .05$] and a significant decrease in the left hemi-field between the 200- and 300-ms SOAs [$t(13) = 3.32$; $p < .05$]. Moreover, *post-hoc* tests revealed significantly lower accuracy for the right compared to the left hemi-field for the SOAs of 450 and 650 ms [$t(13) = 4.64$; $p < .01$; $t(13) = 5.26$; $p < .01$], as a result of a significant increase in accuracy in the left hemi-field between the 300- and 450-ms SOAs [$t(13) = -10.66$; $p < .01$].
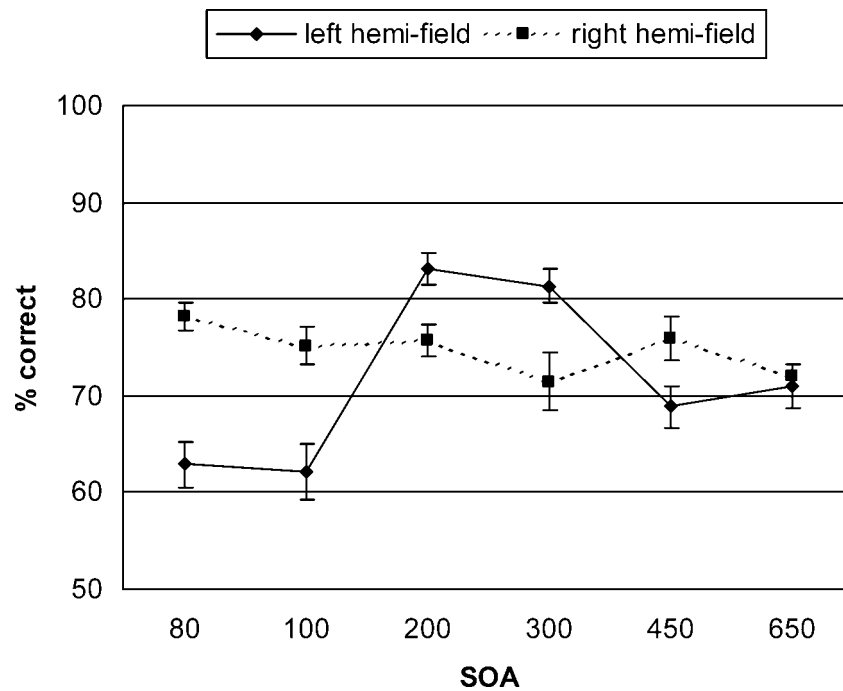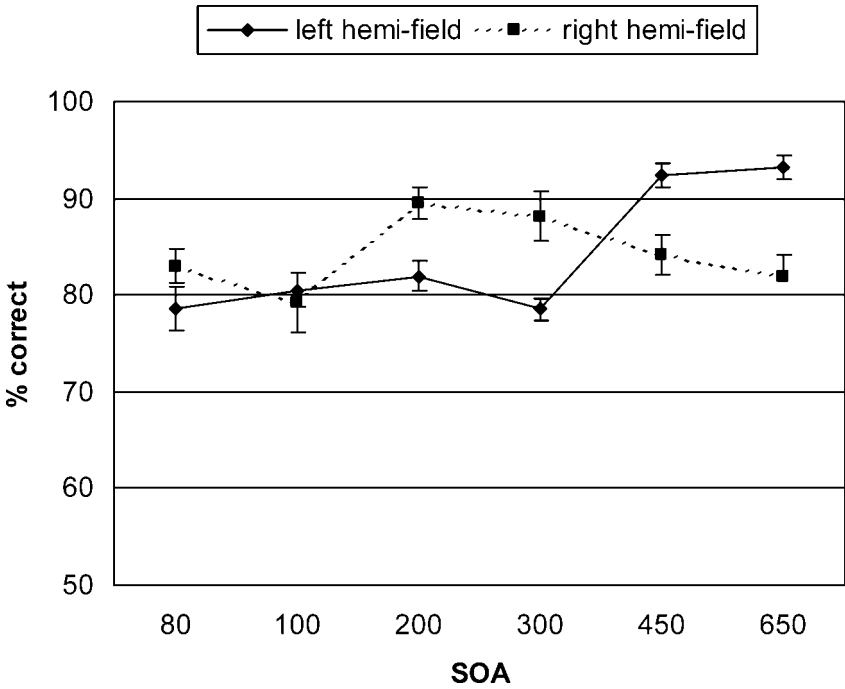
Figure 12. Mean proportions of correctly identified dual-target letters in opposite hemi-fields in the no-cue condition as a function of SOA, separately for each hemi-field.

Taken together, in the no-cue condition, a break-up of the performance pattern seen in the alerting-cue condition was found for the SOAs of 200 and 300 ms. For these SOAs, when stimuli were presented unilaterally (i.e., with single targets and dual targets in the same hemi-field), so that there was *no* spatial-attentional competition between objects in opposite hemi-fields, participants showed a significant decrease in accuracy for the right visual hemi-field accompanied by a significant increase for the left hemi-field. Moreover, when stimuli where presented bilaterally (i.e., with dual targets in opposite hemi-fields, requiring spatially selective weighting of attention), there was a significant improvement in performance for the right hemi-field and a reduction for the left hemi-field at the same SOAs of 200 and 300 ms. This means that, at these SOAs, report of letters appearing in the left hemi-field was more disturbed by additional letters in the right hemi-field, than vice versa.. This pattern of 'inverse pseudo-neglect' has also been found in patients with damage of the right inferior parietal lobe

and in neglect patients (Bublak et al., 2005; Duncan et al., 1999), and was interpreted as the result of contralesionally reduced attentional weighting, unbalancing the competition between targets in the left and the right hemi-field.

The patterns of performance described above can more easily be understood in the analysis of the TVA estimates of the parameters for spatial distribution of attention and sensory effectiveness, which will be presented and discussed in the following sections.

Parameter Estimates

Laterality of Attentional Weighting. In the following, the qualitative pattern of performance (correctly identified target letters) is quantitatively analysed by examining the TVA-based model fits to the data. The data fitting provides individual estimates of attentional weighting separately for each target location.

The probability of perceiving an object depends not only on its relative attentional weight (i.e., the weight allocated to a particular object relative to the weights attributed to the other display objects), but also on the sensory effectiveness (*A*) of an object (Duncan et al., 1999), which is independent of its attentional weight. Two laterality indices were computed from the raw data of the *A* and *w* estimates (for more detailed information see Introduction topic 1.1.8): the 'index of the spatial distribution of sensory effectiveness' (A_λ) and the 'index of spatial distribution of attentional weighting' (w_λ). The mean scores for the different experimental conditions and the values predicted (based on the best fits of the TVA model parameters) showed a satisfactory correspondence. The mean correlation between the observed and predicted scores across all SOAs was .71 ($SD = .15$) in the no-cue condition and .76 ($SD = .14$) in the alerting-cue condition.

Spatial distribution of attentional weighting (w_λ). In TVA, the lateral attentional bias index w_λ is derived by comparing w_{left} and w_{right}, which reflects the relative performance for

both sides in multi-target displays (Duncan et al., 1999), according to the equation $w_\lambda = w_{left}$ $/(w_{right}+w_{left})$. Thus, an index of $w_\lambda > 0.5$ reflects a lateralization to the left, and of $w_\lambda < 0.5$ a lateralization to the right hemi-field (an index of 0.5 means no lateralization of attentional weighting). Figure 13 illustrates the SOA dependent time course of the spatial distribution of the attentional weighting parameter w_λ for the no-cue and the alerting-cue condition.
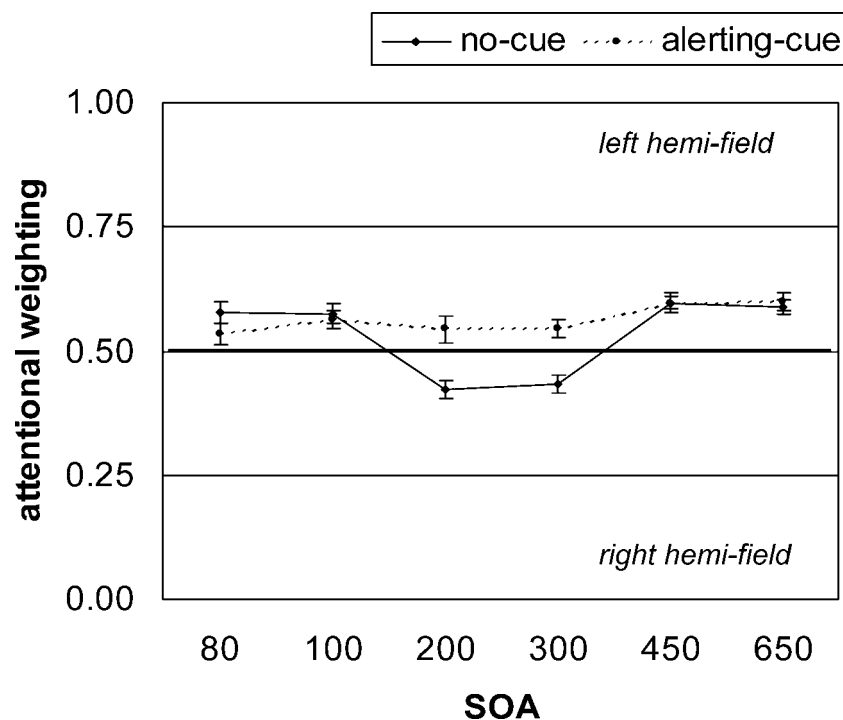
Figure 13. Parameter w_λ (spatial distribution of attentional weighting) as a function of SOA for the no-cue and the alerting-cue condition in Experiment 2. The error bars give the standard errors. Values of $w_\lambda > .50$ = leftward attentional bias; $w_\lambda < .50$ = rightward attentional bias; $w_\lambda = .50$ = no bias.

A Cue (no-cue, alerting-cue) × SOA (80, 100, 200, 300, 400, 450, 650 ms) repeated-measures ANOVA with w_λ as dependent variable was conducted. This analysis revealed sig-

nificant main effects for Cue [$F(1, 13) = 9.89$; $p < .01$; $\eta^2 = .43$] and SOA [$F(5, 9) = 11.68$; $p < .001$; $\eta^2 = .87$], and a significant Cue × SOA interaction [$F(5, 9) = 5.68$; $p < .05$; $\eta^2 = .76$].

Significant differences between the no-cue and the alerting-cue condition were found for the 200- and 300-ms SOAs [$t(13) = -3.14$; $p < .05$, and $t(13) = -3.74$; $p < .01$], due to a rightward attentional bias in the no-cue condition, compared to a (constant) leftward bias in the alerting-cue condition. In the latter condition, a slight, but relatively stable leftward lateralization of spatial attention (known as 'pseudo-neglect') was evident across the range of cue-target SOAs (see also the pattern of performance in the condition 'dual targets in opposite hemi-fields' in Figure 9); in fact, *post-hoc* tests revealed this leftward bias to increase between the shortest and the longest SOAs [80 vs. 450 ms, $t(13) = -2.113$; $p < .05$; 80 vs. 650 ms, $t(13) = -1.80$; $p < .05$)]. In contrast, in the no-cue condition, there was a significant decrease in the initial leftward lateralization – that is, an increase in rightward lateralization – between the SOAs of 100 and 200 ms [$t(13) = 5.91$; $p < .001$]. This rightward bias lasted until the 300-ms SOA, after which it reversed again into leftward lateralization at the longest SOAs [300 vs. 450 ms, $t(13) = -7.81$; $p < .001$]. The change in lateralization to the right at the intermediate, 200- and 300-ms, SOAs is in accordance with the performance pattern reported above for the condition 'dual targets in opposite hemi-fields', which was characterized by superior accuracy for the right compared to the left hemi-field at the same SOAs (see Figure 12). This pattern resulted from a significant increase in accuracy for the right hemi-field target between the 100- and 200-ms SOAs and a significant decrease for the left hemi-field target between the 200- and 300-ms SOAs.

One possible interpretation of this finding is that there is indeed a link between the level of phasic and intrinsic alertness and the spatial distribution of attentional weighting. In the no-cue (non-phasic alertness) condition, with increasing SOA, the leftward bias in attentional weighting changes into a bias to the right hemi-field, whereas the leftward lateralization in the

alerting-cue (phasic alertness) condition grows stronger over time. To our knowledge, this is the first demonstration that changes in the level of alertness can modulate both the magnitude and direction of spatial-attentional lateralization, even within the short time intervals used in the present study.

Based on the evidence that lowered levels of alertness result in a more rightward attentional bias (see the relevant studies reviewed in the Introduction), it may be hypothesized that the rightward lateralization observed in the no-cue condition at SOAs longer than 100 ms (specifically, the 200- and 300-ms SOAs) is caused by decreasing levels of intrinsic alertness which lead to a re-distribution of attentional weights from the left towards the right hemi-field. This hypothesis was tested in Experiment 3 (see below).

The (rightward) bias in the no-cue condition then reverted back to a leftward lateralisation between the 300- and 450-ms SOAs (reflecting in a significant increase in performance for the left hemi-field between these SOAs in the condition 'dual targets in opposite hemi-fields'). One possible explanation for this finding is that, in a state of (maximally) lowered intrinsic alertness, compensatory brain processes begin to operate to counteract the lowered alertness state. Drummond and Brown (2001), for example, hypothesized that there exists an adaptive cerebral response during cognitive performance following total sleep deprivation (TSD) with specific patterns of cerebral adaptation depending on the specific cognitive processes performed. They suggest that this recruitment of additional brain regions represents an adaptive cerebral compensatory response to the detrimental effects of TSD. In line with these findings, using a short-lasting visual reaction time task, Portas et al. (1998) observed equal performance before and after TSD. Moreover, they reported that the thalamus showed an increased hemodynamic response to the attention task only following TSD, which may be interpreted in terms of a compensatory effect when attention must be recruited in a state of lowered alertness.

An alternative explanation is that the reversal of the attentional bias that occurs between the 300- and 450-ms in the no-cue condition, and probably likewise the increase of leftward lateralization in the alerting-cue condition between 80- and 650-ms is the result of some kind of 'self-induced alertness' associated with a heightened expectancy as to target appearance. Expectancies (subjective probability of the occurrence of the target) about when an event will occur can be used to optimize behavioral responding. If subjects are capable of estimating the time till target onset (length of foreperiod/SOA), they will be able to intrinsically time accurately their readiness to respond (Coull, Frith, Buchel, & Nobre, 2000; Niemi & Naatanen, 1981). According to Sturm and Wilmes (2001), the level of alertness can intrinsically be modulated in top-down mode for a subsequent response to an expected stimulus. The accuracy of this timing process is inversely related to the subjects time uncertainty about the occurrence of the target(s). As pointed out by Niemi and Naatanen (1981), the longer the time that has elapsed since trial onset, the greater the probability (expectancy), and thus the lower the uncertainty, of immediate occurrence of the target event. Hence, in the present study, as the SOA grew longer (especially at the longest SOAs of 450 and 650 ms) time uncertainty decreased: subjects knew that the target was increasingly likely to appear in the very near future, so that they intrinsically raised their alertness to prepare for an optimal reaction. To verify this assumption of a 'self-initiated preparation/self-induced alertness' due to higher expectancies, the participants' level of expectancy was manipulated by blocking the SOAs in Experiment 3. The rationale was that keeping the SOA constant within blocks would create maximum expectancy (minimum uncertainty) and thus probably prevent the leftward lateralization due to lowered levels of intrinsic alertness in the no-cue condition for the 200- and 300-ms SOA. Moreover, the study was designed to strengthen the assumption that the reversal of the attentional bias found between the 300- and 450-ms in the no-cue condition, as well as the increase of leftward lateralization in the alerting-cue condition between 80- and 650-ms is

the result of a 'self-induced alertness' associated with a heightened alertness state .Hence, under the constant SOA condition, a stable leftward lateralization in the no-cue condition was expected, and, moreover, no significant differences between the no-cue and the alerting-cue conditions (see Experiment 3 below).

Spatial distribution of sensory effectiveness (A_λ). Analogously to the computation of w_λ, a laterality index for sensory effectiveness (A_λ) is computed. Figure 14 shows the time course of the sensory effectiveness parameter A_λ for the no-cue and the alerting-cue condition in Experiment 2.
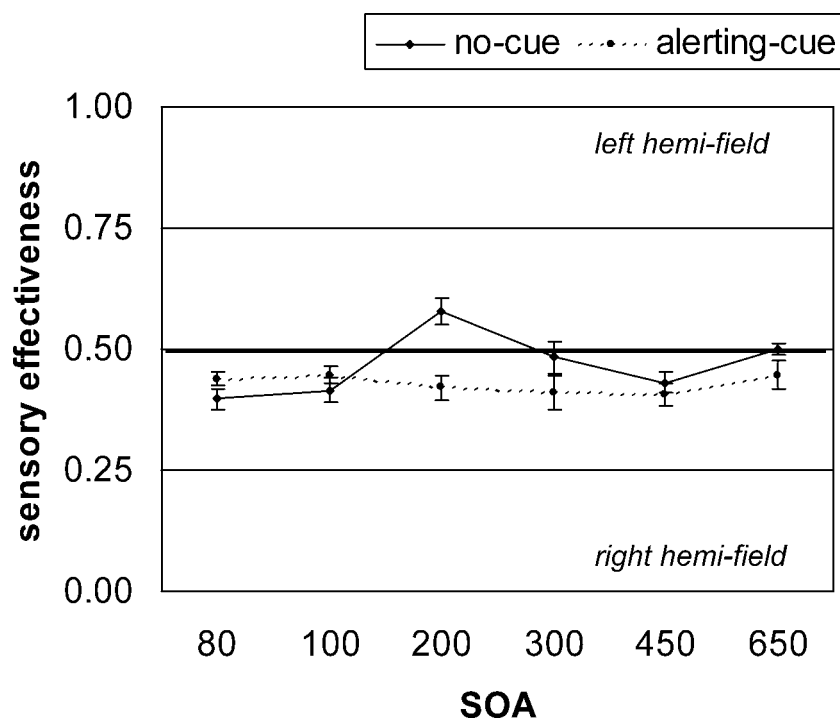

Figure 14. Values of A_λ (laterality index of sensory effectiveness) as a function of SOA for the no-cue and the alerting-cue condition in Experiment 2. The error bars give the standard errors. Values of $w_\lambda > .50$ = leftward bias; $w_\lambda < .50$ = rightward bias; $w_\lambda = .50$ = no bias.

The A_λ parameters were examined in a repeated-measures ANOVA with the factors Cue and SOA, which revealed the interaction to be significant [$F(5, 9) = 21.97$; $p < .001$; $\eta^2 = .92$], due to a significant change in A_λ in the no-cue (as compared to stability of A_λ in the alerting-cue) condition around the 200-ms SOA [$t(13) = 4.25$; $p < .05$]. Specifically, in the no-cue condition, A_λ changed towards a leftward lateralization between the 100- and 200-ms SOAs [$t(13) = -5.52$; $p < .01$], and then reverted back to a rightward lateralization by the 450-ms SOA. This pattern is also apparent in the single target condition in Figure 10, with participants showing superior performance in the left compared to the right visual hemi-field at 200-ms SOA; this follows a decrease in accuracy for the right hemi-field between the 80- and 200-ms SOAs and precedes a decrease for the left hemi-field (with a concurrent increase for the right hemi-field) between the 300- and 450-ms SOAs.

Taken together, the results showed a cue-dependent difference in parameter A_λ at cue-target SOAs around 200 ms. This difference was caused by a significant increase in sensory effectiveness for the left hemi-field in the no-cue condition at this SOA. Quite possibly, this is the result of a compensatory effect that works against the increasing rightward attentional bias at the 200-ms SOA. If so, then – with blocked SOAs – there should not be any changes in sensory effectiveness around this time in the no-cue condition, when an optimal temporal expectancy for target appearance is expected to result in a stable leftward lateralization, and thus no compensatory effect in A would be appropriate. This was tested in Experiment 3.

3.2.6 Experiment 3

Experiment 3 was designed to investigate (1) whether the re-distribution of attentional weights observed in the no-cue condition of Experiment 2 at 200- and 300-ms SOAs is caused by decreasing levels of intrinsic alertness at SOAs longer than 100 ms, and (2) whether the subsequent reversal of the attentional bias between the 300- and 450-ms SOAs is the result of

some kind of self-initiated preparation/self-induced alertness associated with a heightened expectancy as to target appearance. To examine these two hypotheses, participants' level of expectancy was manipulated by blocking SOAs. The rationale was that keeping the SOA constant within blocks would create maximum expectancy and thus heightened levels of intrinsic alertness across the different SOA conditions. Under the constant SOA condition, a stable leftward lateralization in the no-cue condition was expected, and, moreover, no significant differences between the no-cue and the alerting-cue conditions.

One further aim of Experiment 3 was to investigate whether the cue-dependent difference in parameter A_λ at cue-target SOAs around 200 ms, found in Experiment 2, was the result of a compensatory effect. If so, then – with blocked SOAs – there should not be any changes in sensory effectiveness around this time in the no-cue condition.

3.2.6.1 Method

Participants. 14 right-handed healthy volunteers ($M_{age} = 24.17$; $SD_{age} = 3.21$; range: 21-29 years; 4 male, 10 female) participated in Experiment 3. T-tests revealed no significant differences in terms of age, gender, or education between the participants of Experiment 2 and Experiment 3 ($p > .65$).

Procedure. In Experiment 3, the experimental procedure and the sequence of frames presented on a given trial were similar to those in Experiment 2, except that the SOAs were held constant within blocks (rather than being randomized as in Experiment 2).

Experimental design: Experiment 3 consisted of three blocks that were separated by five-minute breaks; it took about 1.5 hours to complete. The order of the SOA conditions was counterbalanced across subjects. In contrast to Experiment 2, Experiment 3 was conducted with three different SOAs (80, 200, 450 ms). These SOAs were blocked and the cueing conditions (no-cue/alerting-cue) were counterbalanced across each SOA block.

As in Experiment 2, each target condition (target location, see Figure 6), SOA, and cueing condition was repeated in 18 trials. Each block consisted of 288 trials (2 cueing conditions × 1 SOAs × 8 target conditions × 18 trials). Altogether, the experiment comprised 864 trials per subject. To establish a situation of maximum expectancy right from the start of the main test, the SOAs used in the pre-test to determine the appropriate exposure duration for each subject, was presented in a blocked manner. This, 24 trials for each of the three SOAs were presented right before the main test. However, subjects were not informed about changes in SOA length during the experiment.

3.2.6.2 Results and Discussion

Spatial Distribution of Attentional Weighting (w_λ)

The w_λ parameters were examined by a mixed-design ANOVA with Cue (no-cue, alerting-cue) and SOA (80, 200, 450 ms) as within-subject factors and Experiment (Experiment 2, Experiment 3) as between-subject factor. This analysis revealed highly significant effects for SOA, Cue × SOA, SOA × Experiment, and Cue × SOA × Experiment (with all $F > 7.79$; all $p < .01$). The main effect of Experiment was non-significant. To further analyze the three-way interaction, separate ANOVAs were carried out for the two Cue types, with the within-subject factor SOA and the between-subject factor Experiment.

Alerting-cue condition (Figure 15): For the alerting-cue condition, the ANOVA revealed only a significant main effect of SOA [$F(2;25) = 14.33$; $p < .000$; $\eta^2 = .53$]. This effect reflects an increasing leftward lateralization in the alerting-cue condition between the SOAs of 80 and 450 ms – both in Experiment 2 (see above) and in Experiment 3 [$t(14) = -3.86$; $p < .01$].

Figure 15. Parameter w_λ (spatial distribution of attentional weighting) as a function of SOA in the alerting-cue condition, separately for the Experiment 2 (unblocked SOA) and Experiment 3 (blocked SOA). The error bars give the standard errors. Values $w_\lambda > .50$ = leftward attentional bias; $w_\lambda < .50$ = rightward attentional bias; $w_\lambda = .50$ = no bias.

No-cue condition (Figure 16): For the no-cue condition, the ANOVA revealed a significant main effect of SOA [$F(2;25) = 10.03$; $p < .001$; $\eta^2 = .45$], and a significant SOA × Experiment interaction [$F(2;25) = 15.77$; $p < .001$; $\eta^2 = .56$]. The main effect of Experiment was non-significant. *Post-hoc* tests revealed a significant difference between the blocked (Experiment 3) and the unblocked experimental condition (Experiment 2) only for the 200-ms SOA [$t(26) = 4.30$; $p < .000$]. In contrast to the results of Experiment 2 (see above), no significant changes in the spatial distribution of attentional weighting were evident in the no-cue condition of Experiment 3 ($p > .51$). This is in accordance with our hypothesis that the blocked cue-

target SOAs induced a heightened state of target expectancy in the subjects, which led to a

high level of intrinsic alertness that was relatively unaffected by the length of the SOA.
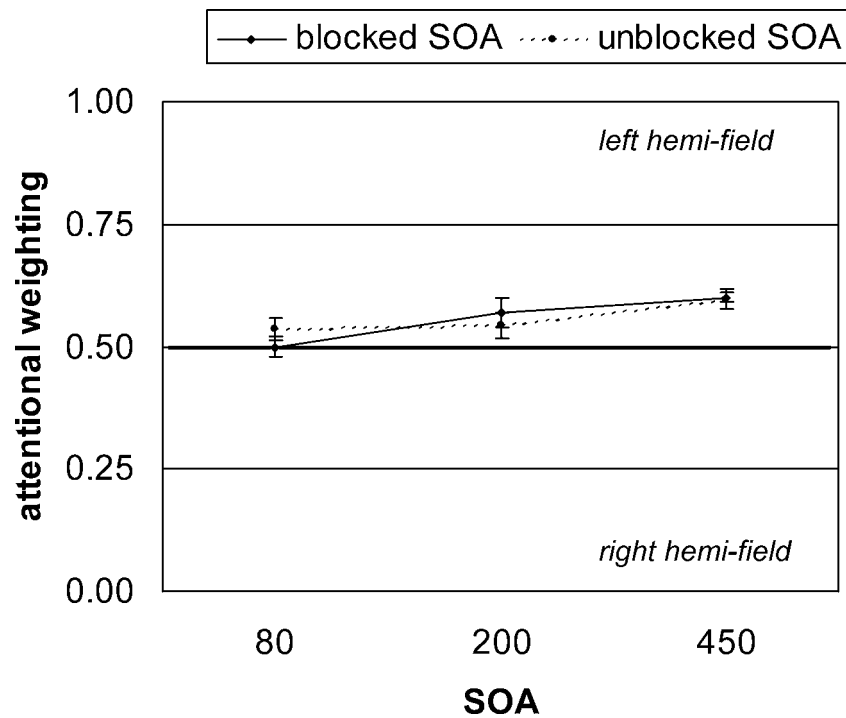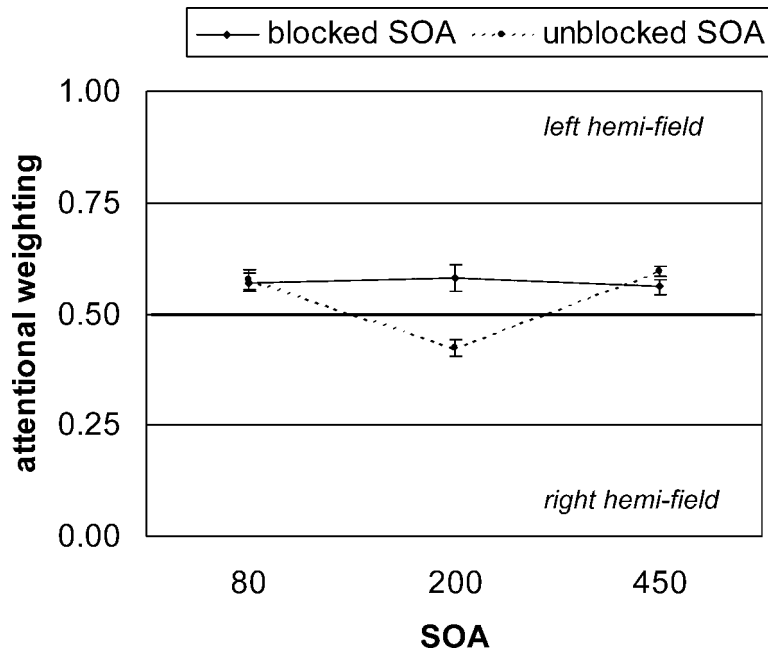

Figure 16. Parameter w_λ (spatial distribution of attentional weighting) as a function of

SOA in the no-cue condition, separately for Experiment 2 (unblocked SOA) and Experiment

3 (blocked SOA). The error bars show the standard errors. Values $w_\lambda > .50$ = leftward atten-

tional bias; $w_\lambda < .50$ = rightward attentional bias; $w_\lambda = .50$ = no bias.

Given that no significant differences in the spatial distribution of attentional weighting

were evident in Experiment 3 with high levels of intrinsic alertness in the alerting-cue and no-

cue conditions, it can be inferred that the re-distribution of attentional weights observed in

Experiment 2 at the 200- and 300-ms SOAs was caused by a lowered state of alertness at

SOAs longer than 100 ms. Moreover, it was able to strengthen the assumption that the rever-

sal of the attentional bias found between the 300- and 450-ms in the no-cue condition is the

result of a 'self-induced alertness' associated with a heightened alertness state. This might

also hold true for the found increase of leftward lateralization in the alerting-cue condition between 80- and 650-ms. However, this study was not able to demonstrate, whether this increased leftward lateralization in the alerting-cue condition is purely cue, or purely expectancy induced, or whether this is the result of an (additive) effect of both factors. Thus, in summary, the results of Experiment 3 provide further support for a close link between the level of alertness and spatial lateralization. An increase in the alertness level, either by an external alerting-cue (Experiment 2) or by self-induced alertness due to expectancy (Experiment 3) leads to an increase – or, at least, a stabilization – of leftward attentional lateralization. On the other hand, lowered levels of tonic alertness, as in the no-cue condition of Experiment 2, result in a re-distribution of attentional weights from the left to the right hemifield, and thus lead to a more rightward attentional bias.

Sensory Effectiveness (A_λ)

The A_λ parameters were also examined by a mixed-design ANOVA with Cue (no-cue, alerting-cue) and SOA (80, 200, 450 ms) as within-subject factors and Experiment (Experiment 2, Experiment 3) as between-subject factor. This analysis revealed significant effects for SOA, Cue × Experiment, and SOA × Experiment (with all $F > 5.18$, all $p < .05$). The main effects of Cue and Experiment were non-significant.

For the no-cue condition (Figure 17), *post-hoc* tests revealed a significant difference in sensory effectiveness between the two Experiments (unblocked vs. blocked SOAs) at the 200-ms SOA [$t(26) = 4.43$; $p < .000$]. Furthermore, in contrast to the variable SOA condition of Experiment 2, no significant changes in the lateralization of sensory effectiveness were evident when subjects could maintain optimum expectancy in the blocked-SOA condition of Experiment 3. Therefore, the change of lateralization in the parameter sensory effectiveness in the unblocked condition might indeed represent a compensatory effect to attenuate the

changes in attentional lateralization. As in Experiment 2 (t (13) = -6.3; $p < .001$) a significant increase of the rightward sensory bias between 80- and 450-ms SOA was found (t (11) = 4.51 $p < .01$). This increase of the rightward sensory bias was comparable for blocked as for unblocked SOAs ($p > .o5$). However, further research is needed to test this assumption of a compensatory effect.
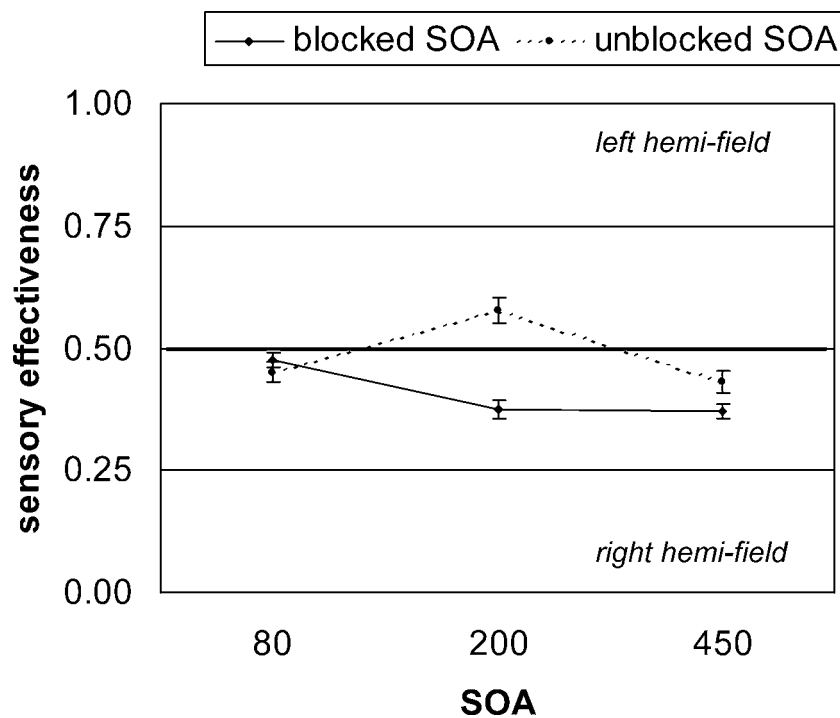
Figure 17. Parameter A_λ (laterality index of sensory effectiveness) as a function of SOA, , separately for Experiment 2 (unblocked SOA) and Experiment 3 (blocked SOA). The error bars give the standard errors. Values of $A_\lambda > .50$ = leftward bias; $A_\lambda < .50$ = rightward bias; $A_\lambda = .50$ = no bias.

3.2.7 General Discussion

The present study was designed to directly investigate the influence of cue-induced alertness on spatially non-lateralized (i.e., visual perceptual processing speed, VSTM storage ca-

pacity) and spatially lateralized (i.e., spatial distribution of attentional weighting) components of visual attention, using a within-subject design. Specifically, by varying the cue-stimulus SOA, the present experiments were aimed at disclosing the time course of the effects exerted by an alerting-cue on these different attentional components – and, by using a TVA-based approach (with accuracy of verbal letter report rather than manual reaction time as dependent measure), the experiments permitted to do this independently of potential motor confounds. An associated aim was to examine whether the level of alertness has an independent influence on the different attentional components, as expected on the basis of TVA.

Experiment 1 assessed the influence of an alerting-cue on the non-spatial attentional components visual perceptual processing speed and VSTM storage capacity, reflecting the general processing capacity as conceptualized by TVA. As one main finding, the results revealed a fast evolving and short-lasting effect of the alerting-cue on the visual processing speed, but not on the VSTM storage capacity. The number of objects that were processed in parallel was significantly increased by the alerting-cue at the shortest SOA of 80 ms, whereas the storage capacity was rather unaffected by the alertness modulation. This selective effect on the speed parameter provides strong support for one of the main assumptions underlying the TVA model (e.g., Bundesen, 1990), namely that the two parameters determine the visual processing capacity in an independent manner. It also shows that an alerting-cue can enhance perform-ance already by accelerating the build-up of stimulus representations in the visual system dur-ing visual object selection, rather than by just expediting the motor response due to enhanced response preparation and/or execution processes. To my knowledge, the present study is the first to demonstrate that an alerting-cue does not only affect the time it takes to respond to extracted and encoded target information, but also directly influences the extraction/encoding of this information itself.

Another important finding was an increase in visual processing speed with longer SOAs, which was evident whether or not an alerting-cue had been presented. This slower but longer-lasting effect of a heightened readiness to process the target objects was assumed to reflect the gradual build-up of an expectancy for the imminent presentation of the stimulus array, associated with an enhanced state of alertness endogenously generated by the subjects (rather than exogenously induced by an alerting-cue).

Experiment 2 assessed the effect of an alerting-cue on the component spatial distribution of attentional weighting and the parameter sensory effectiveness. In the alerting-cue condition, target stimuli were found to be weighted more strongly in the left compared to the right hemi-field and this leftward bias of attention – the normal pseudo-neglect effect exhibited by healthy subjects (Jewell & McCourt, 2000) – increased with longer SOAs. In contrast, in the no-cue condition, the absence of a warning signal was associated with a higher weighting of targets in the right compared to the left hemi-field at the 200- and the 300-ms SOAs, prior to the reinstatement of the leftward bias at the longer SOAs.

Effects of alertness on the distribution of spatial attention have been reported before (e.g., Bellgrove et al., 2004; Fimm et al., 2006; Manly et al., 2005), in particular: a slight rightward bias of attention with reduced, compared to normal, levels of alertness. However, such biases have typically been revealed by analyzing altered 'intrinsic' states of alertness, such as with patients or with normal subjects under sleep deprivation. By contrast, the present study is the first to show, by means of a non-spatial cueing paradigm, that changes in the alertness level of normal subjects differentially affect the report of stimuli in the left versus the right visual hemi-field: .the temporal dynamics of the TVA parameter for the spatial distribution of attentional weights reveals a weight re-distribution towards the right hemi-field in the absence of a warning signal.

Interestingly, Experiment 2 also revealed a change in the lateralization of sensory effectiveness at the 200-ms SOA in the no-cue condition, due to a significant increase in sensory effectiveness for the left hemi-field. This pattern can be hypothesized to be linked with the changes of attentional weighting in this condition, reflecting a compensatory effect to attenuate the increasing rightward spatial lateralization of attention.

This assumption was confirmed in Experiment 3, which used blocked, instead of randomly variable, cue-target SOAs to induce a stable and consistent state of target expectancy in each of the SOA conditions. As a result of the blocking, neither the re-distribution of attentional weights from the left to the right hemi-field nor the leftward lateralization of sensory effectiveness was evident in the no-cue condition. Rather, the altering-cue and no-cue conditions produced equivalent parameters estimates when SOA was blocked, compared to the differences observed with randomly variable SOAs in Experiment 2. This pattern supports the account proposed for the modulations of spatial-attentional weighting or sensory effectiveness observed in Experiment 2, as reflecting to compensatory processes intrinsically generated by the subjects when the time of target appearance remains uncertain.

Thus, the global pattern of effects revealed in the present study can be summarized as follows: There were (1) a fast evolving and short-lasting, 'phasic' modulation of perceptual processing speed by an alerting-cue (Experiment 1) and (2) a longer-lasting, 'intrinsic' effect of the alerting-cue on spatial attentional weighting (inducing a stable pseudo-neglect; Experiment 2). Both of these alerting-cue effects can be attributed to an 'exogenous', cue-induced state of alertness. Furthermore, there was (3) a rightward re-distribution of spatial attentional weighting in the absence of an alerting-cue (Experiments 2 & 3), and (4) a slowly evolving but longer-lasting effect of compensatory processes enhancing processing speed irrespective of the cue condition (Experiment 1), re-instantiation of a leftward spatial bias (Experiment 2) and leftward enhancement of sensory effectiveness (Experiment 2) in the no-cue condition,

likely associated with an 'endogenously' induced state of alertness (as confirmed in Experiment 3).

When considering the nature and time course of these effects both within and across experiments, an interesting picture of both sequential and parallel, superimposed processes emerges. Immediately after the onset of the alerting-cue, a short peak of processing speed occurs, followed by a slower evolving increase based on stimulus expectancy. In parallel, the alerting-cue sets up a stable leftward spatial bias. In the absence of an alerting-cue spatial attention drifts rightward, and the right-most spatial deviation falls into the same time window in which processing speed reaches its maximum due to expectancy (also evident in the no-cue condition). At the same time, a left-side advantage in sensory effectiveness occurs, which precedes the re-distribution of spatial attentional weighting to the left hemi-field. Hence, there seems to be a sequence of events where a speed enhancement (or change in sensory effectiveness, respectively) precedes a change in spatial weighting. Also, a rightward spatial bias, assumed to reflect decreased alertness, appears to occur in parallel with maximal processing speed. These results are in agreement with several recent studies which also found that the level of alertness has an influence on both spatial as well as non-spatial components of visual attention (e.g., Bellgrove et al., 2004; Fimm et al., 2006; George et al., 2005; Manly et al., 2005; Robertson et al., 1998; Thimm et al., 2006). In addition to these findings, however, the present results show that an alerting-cue affects the spatial and non-spatial attentional components of attention in an independent manner and in differential time windows. This demonstration was possible only by using methods that permit the different attentional components and their time courses to be assessed   independently, within the same subjects. At the same time, these results suggest that 'alertness', rather than being synonymous with a capacity parameter such as processing speed, can more be considered as a basic attentional factor influencing various components of attention in parallel, but with a different time course.

Relationship to Attentional Dysfunctions

The present results also offer new insights into the relationship between alertness and spatially lateralized as well as non-lateralized components of attention with respect to attentional dysfunctions. Consistent with these findings, it has recently been shown that, in neglect patients, alertness cues can have an ameliorating effect on the spatial bias for short periods of time (Robertson et al., 1998; Robertson et al., 1995) as well as a longer-lasting effect after weeks of alertness training (Thimm et al., 2006). Note in this context that, with the normal participants tested in the present study, two major effects of the cue manipulation became manifest within different time windows in the same subjects. This opens the door to more precisely assess in neglect patients (1) which attentional components are actually affected by alertness cueing and (2) in what time ranges the various effects occur. These questions are therefore investigated in Chapter 4.

The paradigms used in this study – which permit the independent assessment of non-spatial effects on processing speed and of spatial effects of attentional weighting across the two hemi-fields – could offer a way for disentangling these effects also in dysfunctional, pathologically biased, attentional states. The present results showed that the alerting effect on processing speed was only transitory, while studies of alertness training in neglect patients indicated that there may also be a far more durable effect of alertness cueing (Thimm et al., 2006). This raises an interesting question for future research, namely, whether repeated alerting stimulation would lead to a more long-lasting effect specifically on processing speed, or the spatial lateralization of attentional weighting, or both.

3.3 Study 2: The Influence of Decreased Intrinsic Alertness on Visual Attention

3.3.1 Abstract

Recent evidence suggests that low intrinsic alertness states in normal subjects and, especially, in patients with assumed low baseline levels of intrinsic alertness provoke lateralized visual performance indicative of a visual neglect for the left hemi-field (Husain & Rorden, 2003).

Thus, it might be the case that subjects who are not able to maintain an appropriate alertness level e.g. under conditions with low external stimulation, are vulnerable to spatially biased behavior. However, this has not yet been assessed systematically. Furthermore, it is not clear to date which (sensory or attentional) component is exactly affected in a lateralized fashion by the reduced alertness level.

The present study assessed (1) whether subjects with a low baseline alertness (indicated by slow reaction times) are particularly vulnerable to a rightward lateralization in a low alertness state, (2) whether subjects who get more drowsy under monotone conditions with low external stimulation (as assessed by subjective ratings and by RT slowing) are also those who show a more pronounced rightward shift of attentional weighting, and (3) whether lateralized performance is really related to a re-distribution of spatial attentional weights or rather to decreased sensory effectiveness and/or top-down control in the left visual hemi-field.

The study acquired the influence of lowered intrinsic alertness on the spatial distribution of attentional weighting, task-related top-down control, and sensory effectiveness based on Bundesen's TVA. A partial report task was administered twice to 16 participants, once in a normal- and once in a reduced-alertness state, after application of a 50-minutes, highly monotone vigilance task. This procedure allowed to assess the influence of alertness on the three TVA parameters independently and within the same subjects.

A rightward spatial bias of attentional weighting was found in the partial-report performance under low alertness conditions and was significantly correlated with direct (RT) and subjective (rating) measures of sleepiness. Slow baseline reaction times were correlated to a more pronounced spatial redistributions of attentional weighting indicating a higher vulnerability for a rightward lateralization in subjects with low baseline arousal. Thus, we assume that the extend of the rightward lateralization found after a monotonous vigilance task depended on the ability of a subject to maintain an appropriate intrinsic alertness level under conditions with low external stimulation. Top-down control and sensory effectiveness seemed to be unaffected, suggesting that lateralized performance under low-alertness conditions is, in fact, related to a re-distribution of attentional weights to the right side and to a neglect-like extinction behavior for stimuli on the left.

3.3.2 Scope of the Study

In general, healthy participants show a slight leftward spatial bias referred to as 'pseudoneglect' (Bowers & Heilman, 1980). Bellgrove et al. (2004) found a positive relationship between the participants´ level of intrinsic alertness and the degree of spatial lateralization. The 'pseudoneglect' bias was significantly reduced in a group of healthy participants who performed poorly on a (non-spatial) alertness attention task relative to participants exhibiting better task performance. Thus, even in healthy subject populations those with relatively low baseline alertness seem to exhibit a less leftward-, or even slightly rightward-biased attentional performance. Especially under monotonous conditions - inducing lowered intrinsic alertness levels - these subjects might be vulnerable to a more pronounced neglect-like performance pattern with inattention to left sided stimuli.

The present study was designed to assess systematically (1) whether in normal healthy participants those with a relatively low baseline alertness (as indicated by slow overall RTs)

are at risk to develop a rightward, neglect-like spatial behavior under conditions of low alertness. Furthermore, it should be investigated (2) whether the impact of a monotonous task on the individual alertness level (as assessed by an increase in subjective sleepiness ratings and more directly via RT slowing over time-on-task) is correlated to the degree of changes in the spatial behavior. Assuming that a direct link exists between the intrinsic alertness level on the one hand and the spatial bias on the other it is hypothesized that subjects with a low baseline alertness and/or a low ability to maintain an appropriate alertness state under low-stimulating conditions are also those who show a more pronounced rightward shift of attention.

To resolve these questions, a 50-minute lasting visual vigilance task was used to influence the participants´ level of alertness. According to Paus et al. (Paus et al., 1997) such a long term performance results in a linear decrease of brain activity within the fronto-parietal cortical network in the right hemisphere, responsible for maintaining an alert state. They were able to show that such changes in brain activity over time-on-task resulted in an increase of response latency in a linear fashion (increasing reaction times), whereas the number of hits and false alarms did not vary significantly over time. In order to assess these relationships systematically, a TVA based partial-report paradigm was used that was sensitive even for slight changes in spatial attentional weighting of the left and the right hemi-field and that allowed to exactly quantify the degree of the re-distribution of attentional weights.

Furthermore, lower performance in the left compared to the right visual hemi-field in alertness-deprived subjects might theoretically arise from lateralized (bottom up) sensory effectiveness rather than from lateralized spatial *attentional* preference for the right side. It is also possible that the rightward lateralization found in such subjects is accompanied by an impaired (task-related) top-down control regarding distractors presented in the left visual hemi-field (see Duncan et al., 1999, for a comparable argumentation). Thus, an appropriate paradigm, such as provided by TVA, addressing specifically spatial attentional weighting ef-

fects should allow to control for these confounding influence factors and to separately assess the respective contribution of each of these three potential factors on the assumed lateralized performance pattern under low-alertness conditions. Thus, specific conclusions on whether lateralized performance is indeed induced by a rightward lateralization of attentional weights can be drawn. Furthermore, the paradigm has been shown to reveal also slight changes in spatial attentional weighting that are not detectable by conventional procedures (Finke et al., 2006; Habekost & Bundesen, 2003). In the present study, exact quantitative estimates of attentional lateralization were derived by TVA-based mathematically modeling of the partial-report performance.

3.3.3 Method

Participants

16 right-handed healthy volunteers (M_{age} = 24.2; SD_{age} = 2.6; range: 21-30 years; 8 male, 8 female) participated in the experiment. All participants had normal or corrected to normal vision and none of them suffered from colour blindness or any psychiatric or neurological impairment. All participants were naïve as to the purpose of the experiment and received either course credits or monetary payment (€ 8 per hour) for their participation. Written informed consent according to the Declaration of Helsinki II was obtained from all participants.

Design and Procedure

The PC-controlled experiment was conducted in a dimly lit, sound-proof cubicle. Stimuli were presented on a 17" monitor (1024×768 pixel screen resolution; 70 Hz refresh rate). Participants were seated at a viewing distance of 50 cm with their head position maintained with the aid of a head- and chinrest.

Each subject completed two experimental sessions. One of the sessions lasted about one hour (baseline, assumed normal-alertness session), and the other session took about two hours (assumed low-alertness session). The sessions were counterbalanced across participants. In order to avoid day-time influences (e.g. of the circadian sleep-wake cycle) each of the two sessions of the same subject took place at the same time of day and within one week. Before each task participants were given standardized written and verbal instructions.

At he beginning of each session participants were asked to fill out the Stanford Sleepiness Scale (SSS; Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973). The baseline session consisted of a partial-report task based on Bundesens' TVA model (Bundesen, 1990, 1998a; Bundesen, Habekost, & Kyllingsbaek, 2005a).

The assumed low-alertness session comprised two different tasks. First, participants had to conduct a 50-minute vigilance task taken out of the 'Test for Attentional Performance' (TAP; Zimmermann & Fimm, 1993). This vigilance task has been reported to attenuate the participants´ level of alertness (Paus et al., 1997). Before and immediately after the vigilance task participants were asked to fill out the SSS. Then, the partial-report task was accomplished.

Stanford Sleepiness Scale (SSS): A German translation of the Stanford Sleepiness Scale (SSS; Hoddes et al., 1973) was used to asses the subjectively experienced state of alertness at the beginning of both sessions, and after accomplishing the vigilance task. The SSS is a brief indirect measure, in which a rating of zero reflects feeling 'very awake' and a score of seven reflects feeling 'very sleepy'.

Vigilance Task: The participants' task was to look at a bar in the middle of the computer screen which is moving up and down with a changing amplitude. As soon as the bar reaches a default height the participant has to press a key as fast as possible. The critical stimulus (= default height) appears at irregular intervals. This task requires the subject to stay alert for a prolonged period of time in order to detect relevant, but very infrequent stimuli. In the present

study the difference between RTs of the first ten minutes and the last ten minutes of the task was used as an indicator for the degree of alertness reduction of a subject. Because the task is expected to lower the level of alertness (Zimmermann & Fimm, 1993) each subject was observed by the experimenter, to ensure that a subject was not falling asleep or closing the eyes while performing the vigilance task.

Partial-Report Task: To assess the TVA parameters 'spatial distribution of attentional weighting', 'top-down control' as well as 'sensory effectiveness' a TVA based partial-report task was conducted. Figure 18 illustrates the sequence of frames presented on a given trial.
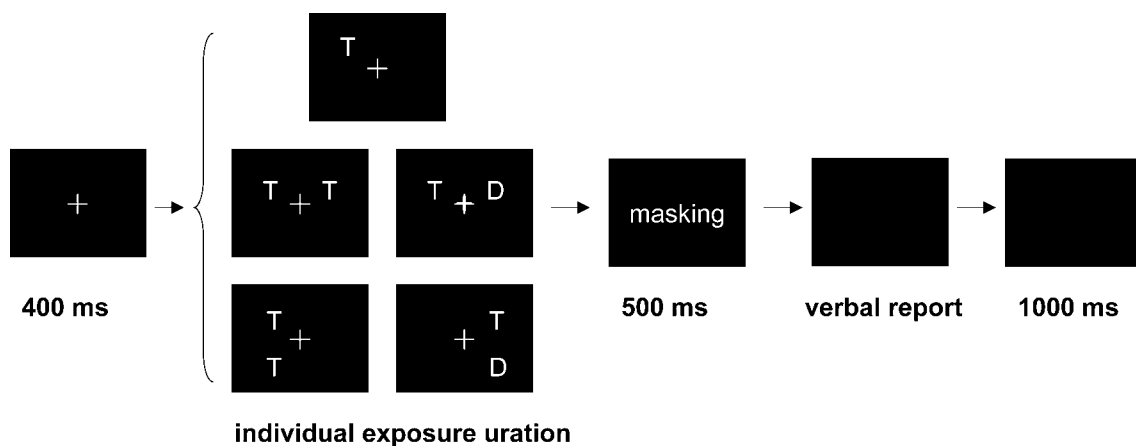
Figure 18. Sequence of frames presented on a given trial in the used partial-report task with samples of the different trial types. Targets (depicted as 'T') and distractors (depicted as 'D') differed with regard to color; targets were red and distractors were green. Presentation of a single target (at the top) of a target accompanied by a distractor in the same or the opposite visual hemi-field (right panels) and of two targets in the same or in opposite hemi-fields (left panels).

First, participants were instructed to fixate a white fixation cross (0.3°) presented for 400 ms at the beginning of each trial at the centre of the screen and to keep fixation for the com-

plete trial duration. Then, red and/or green letters (0.5 high x 0.4 wide) were presented on a black background for a brief exposure duration. The letters of a given trial were randomly chosen from a pre-specified set (ABEFHJKLMNPRSTWXYZ), with a particular letter appearing only once at a time. Letters appeared with equal frequency at each of the possible display locations (see Figure 18). The letter array involved four possible target locations (upper left, lower left, upper right, lower right). On each trial either a single target, or a target and a distractor (on the same side or on opposite sides), or two targets (on the same side or on opposite sides), were presented at the corners of an imaginary square with an edge length of 5° centred on the screen. Two letters were either presented vertically (column display) or horizontally (row display), but never diagonally. Each subject received the same displays in a random sequence. All stimuli were masked. Masks consisted of squares of 0.5° filled with a '+' and an 'x' presented for 500 ms at each stimulus location.

The participants' task was to report only the red target letters, and to ignore the green distractor letters. The verbal target-letter report was performed in arbitrary order and without speed stressing. Participants were instructed to report only those letters they had surely recognized. The experimenter entered the responses on the keyboard and then started the next trial. After an inter-trial interval of 1000 ms the next trial began.

The partial-report task consisted of 16 different display conditions (four single target, eight target-plus-distractor, and four dual target conditions). Because, highly reliable estimates for the parameter 'spatial distribution of attentional weighting (w_λ)' were obtained on the basis of 18 trials per target condition (Finke et al., 2005) the present experiment comprised 288 trials per subject (16 display conditions × 18 trials). All trials were presented in one single block lasting about 30 minutes.

Target exposure duration: At the beginning of the first experimental session of a subject the target exposure duration for the partial-report task was determined for each subject indi-

vidually. A pre-test period with an exposure duration of 71 ms was used to test whether a participant was able to reach an accuracy of 60–80% for single target report. If the participant performed outside this range, the exposure duration in the experimental phase was adjusted accordingly (extended to 100 ms if < 50% and to 86 ms if 50-60%; shortened to 57 ms if 80-90% and to 43 ms if > 90%). The experimental design of the pre-test was equivalent to the partial-report task used in the experimental sessions, but only single target displays were used in the pre-test phase. The pre-test consisted of 64 trials. The so-determined exposure duration was then used in the partial-report task in both experimental sessions. Seven subjects had an exposure duration of 57 ms, four of 71 ms, and five of 100 ms. In any case, since the stimulus exposure durations were relatively short, eye movements were unlikely to affect performance systematically.

3.3.4 Results

Stanford Sleepiness Scale (SSS): Vigilance Task Session

   Mean SSS scores for the long (vigilance task) session are shown in Figure 19. The mean SSS score was 2.06 (SD = .25) before and 4.88 (SD = 1.09) after the vigilance task. A repeated-measures ANOVA with the factor Point in Time (before versus after the vigilance task) revealed a significant increase of subjective sleepiness, representing a decrease of the alertness level [$F(1,15)$ = 131.49; $p < .001$; η^2 = .90]. The mean difference (see Figure 19) between SSS scores before and after the vigilance task ($\Delta SSS_{after/before} = SSS_{after} - SSS_{before}$) was 2.81 ($SD$ = .98).

Figure19: The left figure shows the SSS scores before and after the vigilance task averaged over all 16 participants. The error bars indicate the standard error. The right figure shows the difference between the SSS scores after and before the vigilance task (ΔSSS = SSS$_{after}$ − SSS$_{before}$), separately for each of the 16 participants. A positive SSS score indicates an increased sleepiness or a decreased alertness level over the time of the vigilance task.

Stanford Sleepiness Scale (SSS): Vigilance task session versus baseline session

The mean SSS score at start of the baseline session was 2.13 (SD = .18), and before the vigilance task 2.06 (SD = .25). A repeated-measures ANOVA with the factor Point in Time (baseline session versus before vigilance task) showed no significant differences of subjective sleepiness (p = .71), indicating that the indirectly experienced level of alertness of the participants at start of both sessions was equivalent.

Figure 20 shows the mean scores and the differences between SSS scores reported in the baseline session and after accomplishing the vigilance task. A repeated-measures ANOVA with the factor Point in Time (baseline versus after vigilance task) revealed a significant difference between SSS scores: Participants felt significantly more sleepy after completing the 50-minute lasting vigilance task ($F(1,15)$ = 64.22; p < .001; η^2 = .81). The mean difference

(see Figure 20) between SSS scores in the baseline session and after the vigilance task ($\Delta SSS_{after/baseline} = SSS_{after} - SSS_{baseline}$) was 2.75 ($SD = 1.1$).
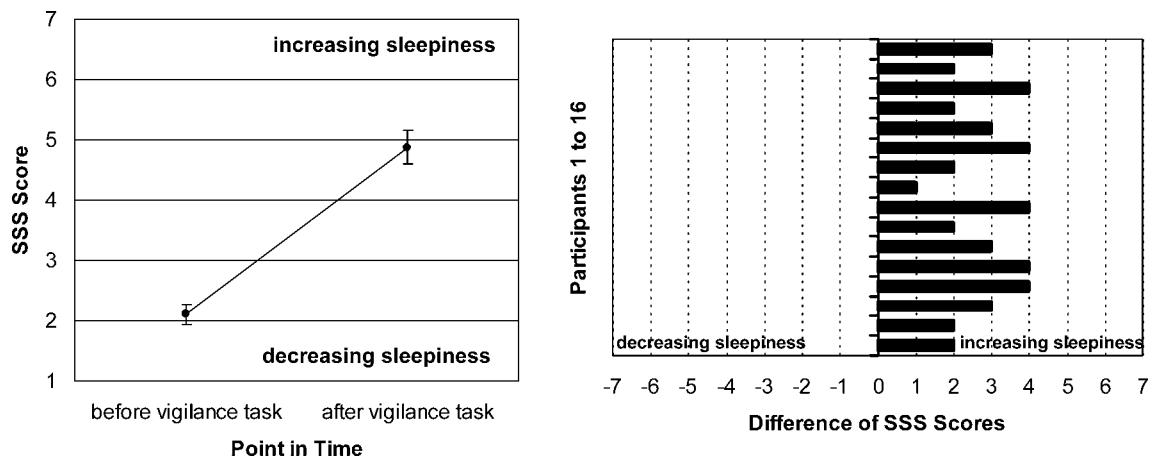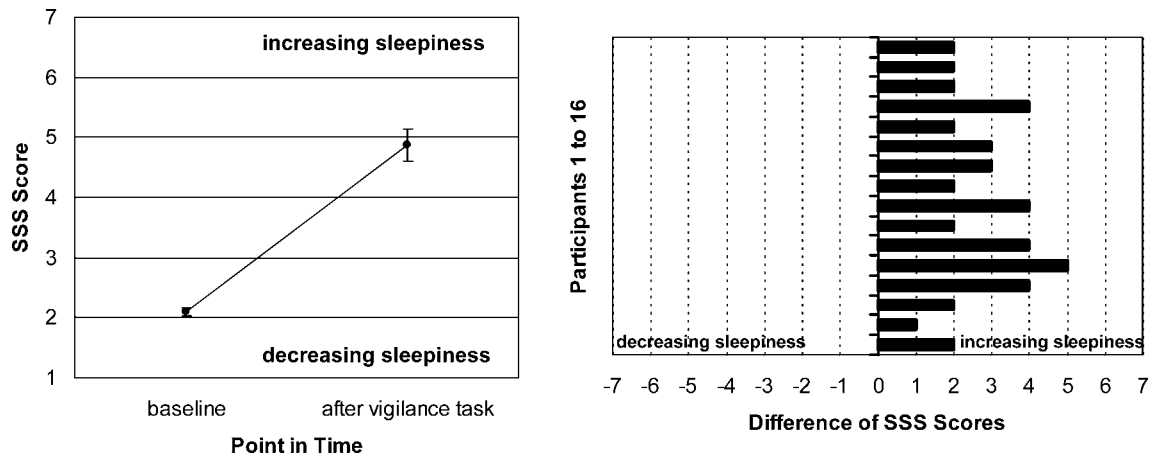

Figure 20. The left figure shows the SSS scores at baseline and after completing the vigilance task averaged over all 16 participants. The error bars indicate the standard error. The right figure shows the difference between the SSS scores after the vigilance task and at baseline ($\Delta SSS_{after/baseline} = SSS_{after} - SSS_{baseline}$), separately for each of the 16 participants.

Vigilance Task

To more directly assess changes in the alertness level the mean RTs of the first ten minutes (RT_{first}; $M = 422.07$ ms; $SD = 74.36$), and the last ten minutes (RT_{last}; $M = 459.25$ ms; $SD = 71.98$) in the vigilance task were compared. A repeated-measures ANOVA with the factor Point in Time (first ten minutes versus last ten minutes) revealed a highly significant increase of RTs ($F(1,15) = 19.43$; $p < .001$; $\eta^2 = .56$), and therefore a significant decrease of the level of alertness. The mean difference between RTs (see Figure 21) at the last ten minutes and at the first ten minutes of the vigilance task ($\Delta RT_{last/first} = RT_{last} - RT_{first}$) was 37.19 ms ($SD = 33.74$). In Figure 21 it can bee seen that nearly all subjects showed a slowing of RTs, however, to a different extent.
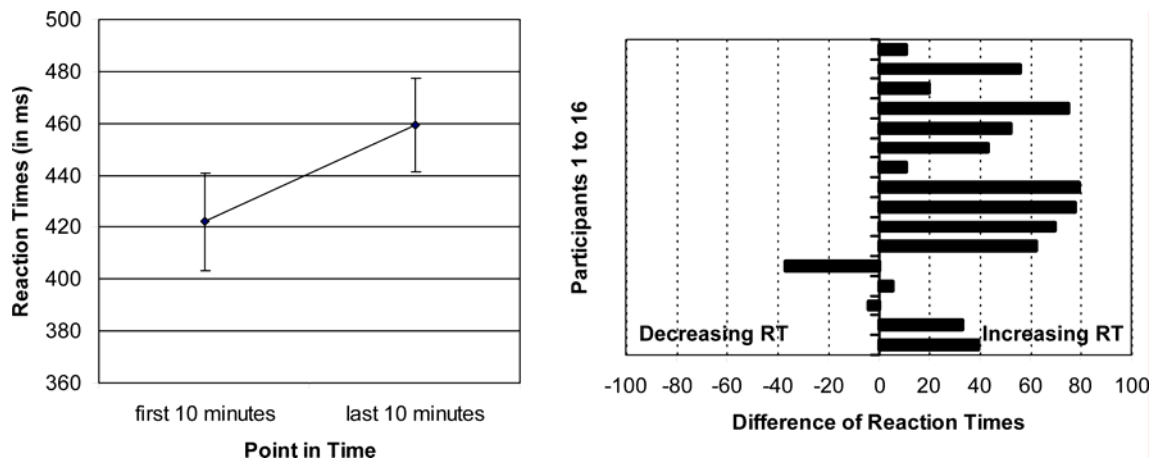
Figure 21. The left figure shows the RTs for the first and the last 10 minutes in the vigilance task averaged over all 16 participants. The error bars indicate the standard error. The right figure shows the difference between RTs of the first and the last 10 minutes in of the vigilance task ($\Delta RT = RT_{last} - RT_{first}$), separately for each participant.

As expected, we found decreasing levels of alertness between the start and the end of the vigilance task reflected indirectly in higher SSS scores and more directly in increasing RTs. From mow on, the vigilance task session is termed 'low-alertness', and the baseline session 'normal-alertness' session. In a next step we tested our hypotheses on the influence of the lowered level of alertness on the spatial distribution of attentional weighting, sensory effectiveness and top-down control.

Spatial distribution of Attentional Weighting, Sensory Effectiveness and Top-down Control

Response Accuracy

Figure 22 illustrates the mean proportions of correctly identified target letters in percent correct (response accuracy) for each hemi-field (left field, right field), separately for the five target types (single target letter, target accompanied by a second target in the ipsilateral or

contralateral hemi-field, and target accompanied by a distractor in the ipsialteral or in the con-tralateral hemi-field), and the two alertness levels (normal-alertness, low-alertness).
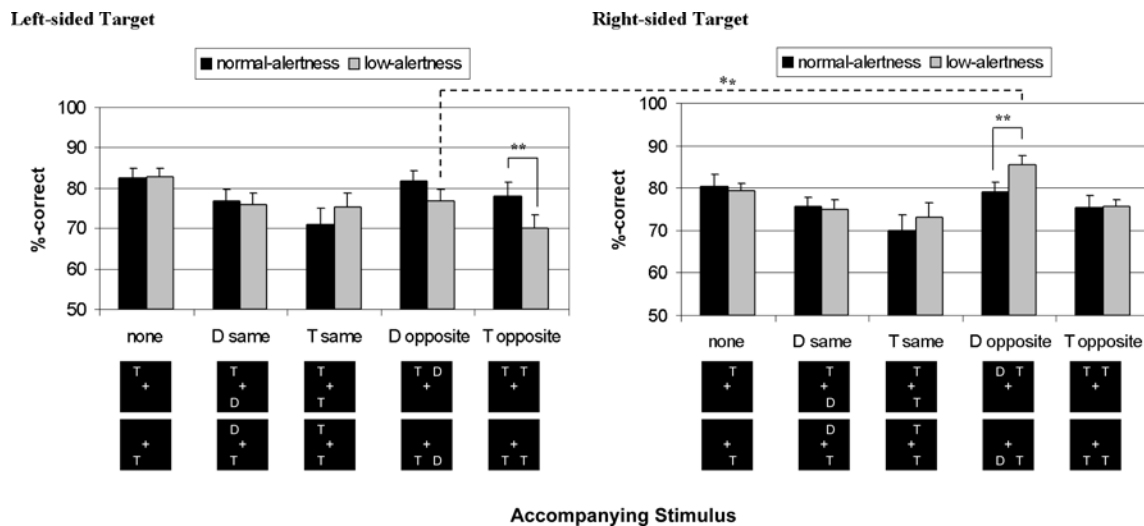
Figure 22. Main proportions of correctly identified target letters (%-correct) for each hemi-field (left field, right field), separately for the five target types (single target letter, target accompanied by a second target in the ipsilateral or contralateral hemi-field, and target ac-companied by a distractor in the ipsilateral or in the contralateral hemi-field), and the two alertness levels (normal-alertness, low-alertness); with ** = $p < .01$.

Overall, the general performance level was very similar to those in other experiments us-ing the method described above (Bundesen, 1990, 1998a; Duncan et al., 1999; Finke et al., 2005) and were in accordance with the predictions made by the TVA: Performance was best for a target presented alone. An accompanying target was more distracting than an accompa-nying distractor, which is in line with TVA´s postulation that targets receive more attentional weight relative to distractors. In addition, visual inspection of Figure 22 revealed obvious dif-ferences between the normal- and the low- alertness condition. Performance in the single tar-get condition seemed to be uninfluenced by the alertness level. In conditions where two stim-uli were presented in opposite hemi-fields a normal-alertness level led to a prioritization of

left-sided targets, whereas a lowered alertness state resulted in a drop of performance of left-sided targets and an increase of accuracy for targets presented in the right visual field.

A repeated-measures ANOVA with accuracy as dependent variable was conducted with the within-subject factors Side (left or right visual field), Target Type (single target letter, target accompanied by a distractor in the ipsilateral or in the contralateral hemi-field, and target accompanied by a second target in the ipsilateral or contralateral hemi-field), and Alertness Level (low-alertness, normal-alertness),

A significant main effect for Target Type [$F(4,12) = 5.94$; $p < .01$; $\eta^2 = .66$)], the significant Side $\times$ Alertness Level [$F(1,15) = 7.98$; $p < .01$; $\eta^2 = .35$)], and Target Type $\times$ Alertness Level [$F(4,12) = 7.06$; $p < .01$; $\eta^2 = .70$)] two-way interactions, and a significant Side $\times$ Target Type $\times$ Alertness Level [$F(4,12) = 13.42$; $p < .001$; $\eta^2 = .82$)] three-way interaction were revealed. To further analyze the significant three-way interaction five separate ANOVAs for the different Target Types, each of them with Side and Alertness Level as within-subject factors, were conducted.

Single target: Performance for single targets (and dual targets in the same hemi-field; see below) was examined to assess the general sensory effectiveness, that is, basic sensory efficiency in target discrimination at a given exposure duration. In unilateral displays, this basic efficiency is assumed to be *independent* of the spatial attentional weighting across the two hemi-fields. There was a significant main effect of Side [$F(1,15) = 6.59$; $p < .05$; $\eta^2 = .31$)], indicating a lower response accuracy in the right than in the left hemi-field across the normal- and the low-alertness condition. The main effect of Alertness Level, and the Side $\times$ Alertness level interaction was not significant (with all $F < .62$; all $p > .45$).

Target accompanied by a distractor in the ipsilateral hemi-field: No significant main or interaction effects were revealed (with all $F < .48$; all $p > .50$).

Target accompanied by a second target in the ipsilateral hemi-field: No main or interaction effects were significant (with all $F < .21$; all $p > .20$).

Target accompanied by a distractor in the contralateral hemi-field: The dual-target conditions with (row) displays are crucial for the TVA-based estimation of the attentional weighting parameter: spatial-attentional weights have to be distributed across the left *and* the right visual hemi-field, with the weight allocation determined by a competitive process between the two hemi-fields. If attentional weights are biased towards one hemi-field, performance in the bilateral (compared to the unilateral) target condition will suffer more for the target presented in the hemi-field with relatively low attentional weight, compared to the target in the hemi-field with high weight. No significant main effects were revealed (with all $F < 1.87$; all $p > .20$). The found significant two-way interaction Side $\times$ Alertness Level [$F(1,15) = 22.52$; $p < .001$; $\eta^2 = .60$)] reflected a significantly better performance in the right hemi-field in a state of low-alertness compared to a normal-alertness level [$t(15) = 2.94$; $p < .01$)]. Moreover, in the low-alertness condition accuracy was significantly higher for targets in the right compared to the left hemi-field [$t(15) = -3.08$; $p < .01$)].

Target accompanied by a second target in the contralateral hemi-field: No significant main effects were found (with all $F < 1.80$; all $p > .20$), but a significant two-way interaction Side $\times$ Alertness Level was revealed [$F(1,15) = 19.68$; $p < .001$; $\eta^2 = .57$)], indicating a significantly better performance for the target in the left visual hemi-field in the normal-alertness condition compared to the low-alertness condition [$t(15) = -2.79$; $p < .01$)]. However, performance in the right visual hemi-field was comparable across alertness conditions (with $p = .97$).

Parameter Estimation

In the following, the qualitative pattern of performance (correctly identified target letters) is quantitatively analyzed by the TVA-based model fits to the data. The mean scores for the different experimental conditions and those predicted on the basis of best fits of the TVA model parameters showed a good correspondence. Mean correlation of measured and predicted scores was .81 (range: .65 - .91; $SD = .09$; $r^2 = .66$) in the normal-alertness session and .79 (range: .64 - .93; $SD = .09$; $r^2 = .63$) in the low-alertness session.

Spatial distribution of attentional weighting (w_λ): Figure 23 shows the parameter 'spatial distribution of attentional weighting' in a state of normal-alertness and at a level of low-alertness.
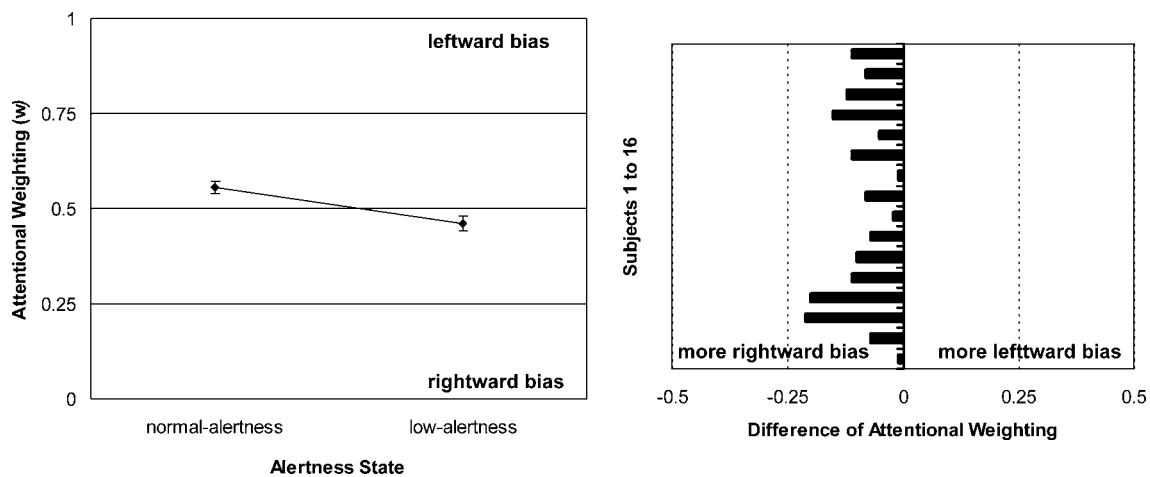
Figure 23. The left figure shows parameter w_λ (spatial distribution of attentional weighting) at a level of normal and low-alertness averaged over all 16 participants The error bars show the standard errors. With $w_\lambda > .50$ = leftward attentional bias; $w_\lambda < .50$ = rightward attentional bias; $w_\lambda = .50$ = no bias. The right figure shows the difference between parameter w_λ a level of normal- and low-alertness ($\Delta w_\lambda = w_{normal\text{-}alertness} - w_{low\text{-}alertness}$) separately for each participant.

In Figure 23 it can bee seen that in a state of normal-alertness participants showed the expected pseudoneglect pattern, and hence were slightly, however significantly lateralized to the left visual hemifield [$t(15) = 3.40$; $p < .01$]. In contrast, lowering of alertness resulted in a significant rightward bias and thus a prioritization of stimuli presented in the right visual hemifield [$t(15) = -1.95$; $p < .05$]. A significant difference [$t(15) = 6.46$; $p < .001$] of the parameter spatial distribution of attentional weighting between the normal ($M = .55$; $SD = .06$) and the low-alertness session ($M = .46$; $SD = .08$) was found. That is, the slight leftward spatial bias in the normal-alertness state turned into a slight rightward spatial bias in the state of decreased alertness. The mean difference between the spatial distribution of attentional weighting w_λ in the low- and in the normal-alertness session ($\Delta w_\lambda = w_{normal\text{-}alertness} - w_{low\text{-}alertness}$) was .09 ($SD = .06$).

Sensory effectiveness (A_λ): To assess the influence of the level of alertness on the parameter 'sensory effectiveness' a repeated measures ANOVA with Alertness Level (normal-alertness versus low-alertness) as independent variable was conducted. No significant effect of the factor Alertness Level on the parameter A_λ was found [with $F = 1,04$; $p = .34$; $M_{normal\text{-}alertness} = .48$ ($SD = .11$); $M_{low\text{-}alertness} = .51$ ($SD = .09$)]. This is in accordance with the results presented for the response accuracies (see Figure 22) where no significant differences between alertness conditions was revealed when targets were presented unilaterally.

Top-down control (α): No significant effect of the alertness level on the parameter α was found [with $t = .80$; $p` = .43$; $M_{normal\text{-}alertness} = .57$ ($SD = .24$); $M_{low\text{-}alertness} = .50$ ($SD = .20$)]. To further analyze whether there was a significant difference between hemi-fields a repeated-measures ANOVA with Alertness Level (normal-alertness versus low-alertness) and Side (left versus right hemi-field) as independent variables was conducted. No significant main or interaction effects were revealed [with all $F < 1.82$; $p` > .15$].

Correlations between direct and indirect measures of the level of alertness and the parameter spatial distribution of attentional weighting

The following section investigated whether the re-distribution of attentional weights to the right visual hemi-field induced by lowered levels of alertness is related to changes in the subjectively reported alertness. The relevant changes are those over time-on-task ($\Delta SSS_{after/before}$) and those between SSS scores measured before the partial-report task at start of the normal-alertness session and after the vigilance task at the low-alertness session ($\Delta SSS_{after/baseline}$). Moreover, it was acquired whether a possible vulnerability for the rightward re-distribution of attentional weights is determined by a subject's overall performance over time on a monotonous vigilance task, reflecting the ability to maintain an appropriate alertness state. The overall performance was assessed by calculating the mean RT ($RT_{overall}$) across all RTs measured over time-on-task.

Correlations between the subjectively reported level of alertness and the spatial distribution of attentional weighting

As can be seen in Table 1 significant negative correlations between $\Delta SSS_{after/before}$ and $w_{low\text{-}alertness}$, as well as between $\Delta SSS_{after/baseline}$ and $w_{low\text{-}alertness}$ were significant. These correlations indicate, that participants who rated their decrease of alertness to be more pronounced, and those who felt less alert after completing the vigilance task compared to the baseline session showed the larger rightward lateralization at a state of low-alertness ($w_{low\text{-}alertness}$). No comparable relations were found between $w_{normal\text{-}alertness}$ and the self rating of alertness changes.

	ΔSSS$_{\text{after/before}}$	ΔSSS$_{\text{after/baseline}}$
$w_{normal\text{-}alertness}$	-.36 (n.s.)	-.41 (n.s.)
$w_{low\text{-}alertness}$	**-.54***	**-.47***
Δw_{λ}	.32 (n.s.)	.15 (n.s.)

Table 1. Correlations between changes of the subjectively reported level of alertness in the SSS and the spatial distribution of attentional weighting w_{λ}; with *** = $p < .001$, ** = $p < .01$, and * = $P < .05$.

Correlations between the directly measured level of alertness (RTs) and the spatial distribution of attentional weighting

As can be seen in Table 2 significant correlations between Δw_{λ} and RT$_{\text{vigilance task}}$, as well as between $w_{low\text{-}alertness}$ and RT$_{\text{vigilance task}}$ were found: Participants who responded slower in the vigilance task showed a significantly larger rightward lateralization in a state of lowered alertness. Moreover, these subjects showed a more pronounced re-distribution of attentional weights to the right visual field after the vigilance task.

	RT$_{\text{vigilance task}}$
$w_{normal\text{-}alertness}$	.03 (n.s.)
$w_{low\text{-}alertness}$	**-.52***
Δw_{λ}	**.78***

Table 2. Correlations between the directly measured level of alertness in the vigilance task and the spatial distribution of attentional weighting w_{λ}; with *** = $p < .001$, ** = $p < .01$, and * = $P < .05$.

3.3.5 Discussion

The present study was designed to investigate the influence of the level of intrinsic alertness on the spatial distribution of attentional weighting, as it is defined by the formalization of TVA. The spatial distribution of attentional weighting is a spatially lateralized component that defines whether one hemi-field receives more attentional weighting than the other. It was assessed (1) whether subjects with a low baseline level of intrinsic alertness (indicated by slow RTs) are particularly vulnerable to a rightward lateralization in a low alertness state, (2) whether subjects who get more drowsy under monotone conditions with low external stimulation (as assessed by subjective ratings and by RT slowing) are also those who show a more pronounced rightward shift of attentional weighting, and (3) whether the lateralized performance due to lowered intrinsic alertness is a purely attentional effect, or if it could also be ascribed to a biased change in (non-attentional) sensory effectiveness, or by an impaired (task-elated) top-down control regarding distractors presented in the left visual hemi-field. For resolving these questions a within-subject design was used. Participants performed a partial-report task twice, once in a state of normal (baseline) alertness and once in a state of low alertness.

The present study therefore provides several findings about the relationship between the level of intrinsic alertness and the extent of changes of spatial attentional lateralization, and gives new insight into the influence of alertness on sensory effectiveness and top-down control. Concerning these parameters, simple changes of the participants´ level of alertness produced different patterns of performance in the TVA based partial-report task, although stimuli and exposure durations remained the same.

An associated aim was to examine whether the level of alertness has an independent influence on the different attentional components, as expected on the basis of TVA. The present study is the first investigating the influence of a direct (alertness based) manipulation on the

three distinct TVA parameters 'spatial distribution of attentional weighting', 'top-down control', and 'sensory effectiveness'.

As expected, in the <u>normal-alertness condition</u> (baseline) target stimuli were found to be weighted higher in the left compared to the right visual hemi-field (leftward bias of attention) – similar to the well-known pseudoneglect effect exhibited by healthy subjects (for a review see, Jewell & McCourt, 2000). The values of the assessed parameters of attentional selection and sensory processing were comparable to those found in previous studies measuring spatial and non-spatial aspects of visual attention under normal-alertness conditions in healthy subjects (e.g., Finke et al., 2005).

In contrast to the leftward 'pseudoneglect' bias in a state of normal-alertness, in the <u>low-alertness condition</u> a clear rightward lateralization was observed. One drawback of this increased salience of right-sided stimuli is a reduction in resources allocated towards the processing of any competing left-sided stimulus. Thus, in a state of low-alertness participants reported significantly less targets in the left when accompanied by a second stimulus (target or distractor) in the right hemi-field. This result indicates a biased attentional competition towards the right side in a state of low-alertness, with attentional weights re-distributing to the right hemi-field. This re-distribution of attentional weights correlated with direct (RT) and subjective (rating) measures of sleepiness. Slow baseline RTs were correlated to a more pronounced spatial re-distributions of attentional weighting indicating a higher vulnerability for a rightward lateralization in subjects with low baseline levels of intrinsic alertness. Thus, it can be assumed that the extend of the rightward lateralization found after a monotonous vigilance task depended on the ability of a subject to maintain an appropriate intrinsic alertness level under conditions with low external stimulation.

The parameter top-down control seemed to be unaffected by changes in the level of alertness. Irrespective of alertness states, subjects were able to ignore distractors equally well in

both hemi-fields. In addition, lowered levels of alertness did not have an effect on the non-attentional parameter sensory effectiveness. Thus, subjects were able to report unilaterally presented targets in the left and the right visual hemi-field comparably well under both alertness conditions.

Taken together, the present study demonstrated that alertness-deprived healthy participants developed a neglect-like behavior such as a rightward lateralization and (mild) unilateral extinction, stressing the relevance of intrinsic alertness in disturbed attentional competition, and thus spatial attentional asymmetries. Interestingly, subjects with a low baseline level of intrinsic alertness showed a higher vulnerability for a more pronounced spatial re-distributions of attentional weighting with decreasing levels of intrinsic alertness. It can be concluded that low levels of intrinsic alertness result in a specific re-distribution of attentional weights, independent of any changes in top-down control or sensory effectiveness. This demonstration was only possible by using a method based on Bundesen´s TVA that allowed the different attentional and sensory components to be assessed independently and within the same task and subject.

Chapter 4: The Influence of the Level of Alertness in Neglect Patients

4.1 The Influence of Increased Phasic Alertness

4.1.1 Abstract

The most prominent behavioral symptom of patients with visual hemi-neglect consists in a spatial rightward bias reflected in e.g. asymmetries in spatial exploration and motor performance. There is increasing evidence however that non-spatial deficits, such as e.g. reduced intrinsic alertness, may also play a crucial role in the disorder. It has been shown that phasically alerting patients may overcome their pathological rightward lateralization (e.g., Robertson et al., 1998). However, it is not precisely clear to date which attentional components are actually influenced by an increase in phasic alertness.

In the present study a TVA based whole-report paradigm combined with a non-spatial, visual alerting-cue was used which allowed to observe spatially lateralised (spatial distribution of attentional weighting) and spatially non-lateralised (sensory effectiveness/processing speed) attentional components to be assessed independently of each other within the same paradigm and within the same patients. One aim of the study was to disentangle the influence of cue-induced phasic alertness on spatially lateralized and on spatially non-lateralized components of visual attention. Furthermore, by using three different cue-target SOAs we wanted to assess the time course of potential changes in the different attentional components.

Several independent effects were revealed in the present study. A fast evolving and short-lasting, 'phasic' modulation of spatial attentional weighting was found with a re-distribution of attentional weights from the pathological rightward bias to a more balanced spatial lateralization. Furthermore, a longer-lasting effect of the alerting-cue on sensory effectiveness (proc-

essing speed) occurred. It can be concluded, that higher levels of alertness indeed overcome the rightward lateralization in neglect patients stressing the relevance of alertness in disturbed attentional competition. These results support the hypothesis that the presence of spatial neglect is at least in part based on intrinsic alertness deficits and can hence be improved by phasically alerting patients or by alertness training.

4.1.2 Introduction

Neuroanatomically, unilateral spatial neglect is most commonly seen following stroke affecting the middle cerebral artery (MCA) and resulting lesions of the right hemisphere, especially in the area of the right inferior parietal lobe (Bisiach & Vallar, 1988; Vallar & Perani, 1986), or of the right superior temporal gyrus (Karnath, 1988; Karnath et al., 2003). These regions seem to play an important role not only in spatial attention (e.g., Corbetta et al., 2000; Corbetta & Shulman, 2002) but also in maintaining intrinsic alertness (e.g., Posner & Petersen, 1990; Sturm et al., 1999; Sturm et al., 2006; Sturm & Willmes, 2001; Thiel & Fink, 2007). Furthermore, Husain and Kennard (1996) reported that patients with lesions confined to the right frontal lobe can also show neglect symptoms. Thus, lesion in brain regions involved in mediating intrinsic alertness, such as frontal as well as parietal areas, seem to induce a pathological rightward bias. .

Behaviorally, the most prominent symptoms often found in left unilateral spatial neglect are a pathological rightward (ipsilesional) attentional bias and contralesional extinction. Both symptoms are affecting the ability to detect and to respond to contralesional (left-sided) stimuli and cannot be explained by basic motor or sensory deficits (e.g., Bartolomeo & Chokron, 2002; Bisiach & Vallar, 1988; Heilman et al., 2003; Karnath, 1988). In extinction a contralesionally presented stimulus is detected or identified relatively well when presented alone (i.e. without competing stimuli in the ipsilesional field), but that same stimulus is disregarded (ex-

tinguished) or poorly identified in the presence of simultaneously presented ipsilesional input (Bender, 1952). Such results suggest unbalanced or biased attentional competition towards the ipsilesional side which would have no effect in unilateral, but a strong effect in bilateral displays. Apart from this spatial deficit, however, there is increasing evidence that non-spatial deficits – such as e.g. reduced processing speed probably caused by decreased intrinsic alertness - may play a crucial role in the disorder. Accordingly, neglect patients are slower compared to healthy controls also when responding to visual stimuli even in the ipsilesional, non-neglected field (Bartolomeo & Chokron, 2002). Using a TVA-based approach, Duncan et al. (1999) found – besides the expected rightward lateralization - a bilateral decrease of processing speed (for comparable results, see also Bublak et al., 2005). As suggested, for example, by Husain and Rorden (2003) and Robertson et al. (1998; 1995) these deficits in terms of reduced processing capacity might reflect attenuated intrinsic alertness in neglect patients. Consistent with these findings it has been shown that the degree of the neglect-related pathological rightward spatial bias is especially severe with profoundly lowered intrinsic alertness (Bartolomeo & Chokron, 2002; Heilman et al., 2003; von Cramon & Kerkhoff, 1993). Furthermore phasic alerting cues can have an ameliorating effect on the spatial bias for short periods of time (Robertson et al., 1998; Robertson et al., 1995), as well as a longer-lasting effect after weeks of alertness training (Thimm et al., 2006). In the study of Robertson et al. (1998) phasically alerting patients with a warning tone temporarily decreased their tendency to report the rightmost of two bars as coming first in a temporal order judgment task.

In sum, these results suggest that the spatial deficit shown by neglect patients might not only be accompanied by but also functionally coupled to non-spatial deficits in intrinsic alertness.

4.1.3 Scope of the Study

By using a non-spatial alerting-cue paradigm the study of Robertson et al. (1998) provided important evidence for the beneficial effect of a phasic alerting-cue in neglect patients´ performance. However, it is not clear to date which attentional components are actually influenced by the alerting-effect. More precisely, this effect might refer to 1) a re-distribution of *selective attentional* weighting of the left and of the right hemi-field. It might also be induced however by 2) a generally enhanced sensory effectiveness/processing speed for objects in both, or especially in the left visual hemi-field. Furthermore, it might be related to 3) a variation of both, a re-distribution of the pathological bias of selective attentional weighting *and* a bottom-up induced general enhancement of processing speed. The present study includes the independent estimation of sensory and attentional parameters within the same task, and thus, is designed to disentangle these possible influences. A TVA based whole-report paradigm was combined with a non-spatial, visually presented alerting-cue (comparable to study 1). This paradigm allows to independently and separately assess the influence of increased phasic alertness on spatial and non-spatial components of visual attention within the same patient. The paradigm included three display conditions: two conditions in which stimuli occurred in either the left or the right hemifield and one condition where stimuli occurred on both sides. The unilateral conditions allowed for estimation of sensory effectiveness which can bee seen as an indirect measure of processing speed C separately for each hemi-field. In the bilateral condition, accuracy for left and right sided stimuli could differ due to reduced sensory effectiveness/processing speed in one side, but this factor was controlled for by data from the unilateral target conditions. Remaining side differences could therefore be directly attributed to different attentional weighting of each hemifield, which in TVA is quantified by the parameter w_λ. Thus, w_λ represents a pure estimate of spatial attentional bias (controlled for sensory factors or processing speed) and asymmetries in this parameter correspond closely to the defi-

nition of visual extinction. Taken together, by combining a TVA based whole-report approach with a non-spatial alerting-cue paradigm the present study shall offer new insight into the relationship between alertness and spatially lateralized and non-lateralized deficits of visual attention in neglect. The paradigm used allows the independent assessment of non-spatial effects on sensory effectiveness/processing speed and of spatial effects on the spatial distribution of attentional weighting across the two hemi-fields, and thus could offer a new way for disentangling the effects of an alerting-cue on different attentional components in neglect patients.

4.1.4 Method

Six right-handed stroke patients (EW, FP, KKL, ML, OB, and PB) with unilateral right hemisphere lesions were examined Table 3 shows their demographic and clinical data.

Patient	Gender	Age (years)	Education (years)	Visual field restriction	Time since stroke (months)
EW	F	76	10	Hemianopia	2
FP	F	79	10	Hemianopia	2
KKL	M	65	13	Quadrantanopia (lower left)	3
ML	M	73	10	-	4
OB	M	72	10	-	2
PB	M	71	13	-	6
Mean	-	72.7	11.0	-	3.2
SD	-	4.8	1.5	-	1.6

Table 3. demographic and clinical data for all six patients, with F = female and M = male, with the mean values and standard deviations (*SD*).

Figure 24 shows the anatomical reconstruction of brain damage according to 'Damasio templates' (Damasio & Damasio, 1989) as demonstrated by CT or MRI scans.
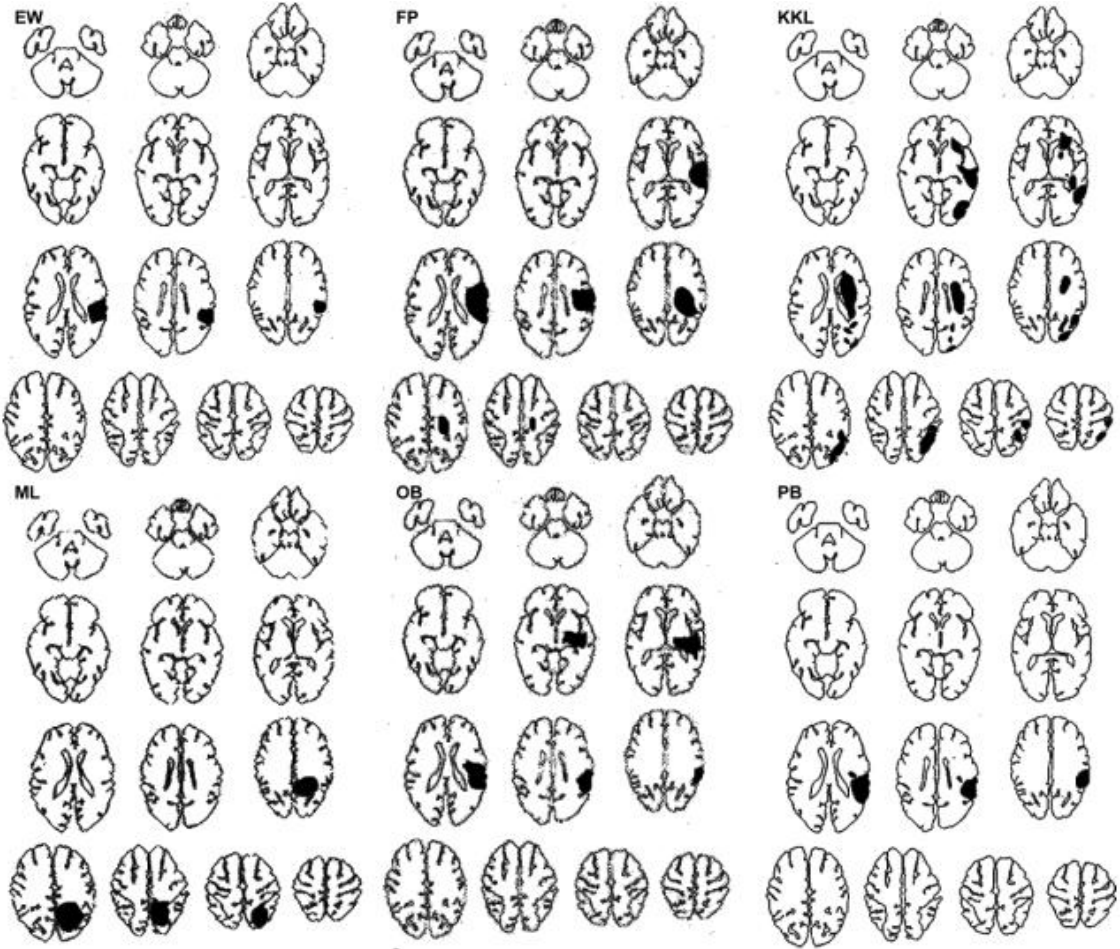
Figure 24. Reconstruction of brain regions according to Damasio and Damasio (1989) in each patient.

At the time of investigation all patients had mild visuo-spatial neglect on the conventional part of the 'Behavioral Inattention Test' (BIT, Wilson et al., 1987), a standard neglect test battery, including line crossing, letter, and star cancellation, figure and shape copying, line bisection and representational drawing (see Table 4). Each patient performed below the cut-off indicative for neglect in at least three of the six subtests and the sum core.

Patient	Line crossing	Letter cancellation	Star cancellation	Figure/shape copying	Line bisection	Representational drawing	BIT score (conventional)
EW	36	**23**	53	**0**	7	**1**	**120**
FP	36	**32**	**49**	2	5	3	**127**
KKL	36	35	**40**	3	6	3	**123**
ML	36	**31**	**48**	4	6	3	**128**
OB	36	33	**45**	1	6	3	**124**
PB	36	**32**	**45**	1	6	3	**123**
Cut off ≤	**34**	**32**	**51**	**3**	**7**	**2**	**129**

Table 4. Scores in the 'Behavioral Inattention Test ' (BIT, Wilson et al., 1987) in each patient for each subtest, and the BIT conventional score with the cut off scores of each subtest (bottom row). Scores below cut off are printed in bold.

Three patients (ML, OB, PB) had intact visual fields, two (FP and EW) had an incomplete, partial left hemianopia with macular sparing, which allowed presentation of stimuli in the parafoveal field of 2.5° of visual angle (on both hemi-fields), and one (KKL) had a visual field impairment in the lower, left quadrant (also with macular sparing). All participants had normal or corrected to normal vision and none of them suffered from color blindness or any psychiatric or prior neurological impairment. All participants were naïve as to the purpose of the experiment. Written informed consent according to the Declaration of Helsinki II was obtained.

Design and Procedure

To examine the influence of the alertness state on the TVA parameter 'spatial distribution of attentional weighting' and 'sensory effectiveness/processing speed', the present study compared an alerting-cue condition versus a no-cue condition and was comparable to the previously described study 1 (Chapter 3) including healthy participants. In the alerting-cue condition, observers were provided with a warning signal at the start of a trial, an outline frame flashed briefly around the whole (potential) display array, which was non-informative as to the location of the upcoming target letters. Thus, while alerting the observers to the imminent appearance of the target array, this warning signal was designed to induce a spatially diffuse distribution of attentional weighting across the (potential) stimulus display (i.e., it could not be used to systematically orient spatial attention to specific stimulus locations). Moreover, since the alerting-cue used was spatially uninformative with regard to the upcoming target location it can be assume that eye movements were rather unlikely affecting performance systematically. However, to better control for cue-induced eye movements and the head position of the patients in general a light sensitive web-cam was used. When eye or head movements were observed patients were reminded to hold fixation and to try to avoid such movements.

Procedure: The PC-controlled experiment was conducted in a dimly lit room. Stimuli were presented on a 17" monitor (1024×768 pixel screen resolution, 70 Hz refresh rate). Participants viewed the monitor from a distance of 50 cm, controlled by the aid of a head- and chinrest Figure 25 illustrates the sequence of frames presented on a given trial.
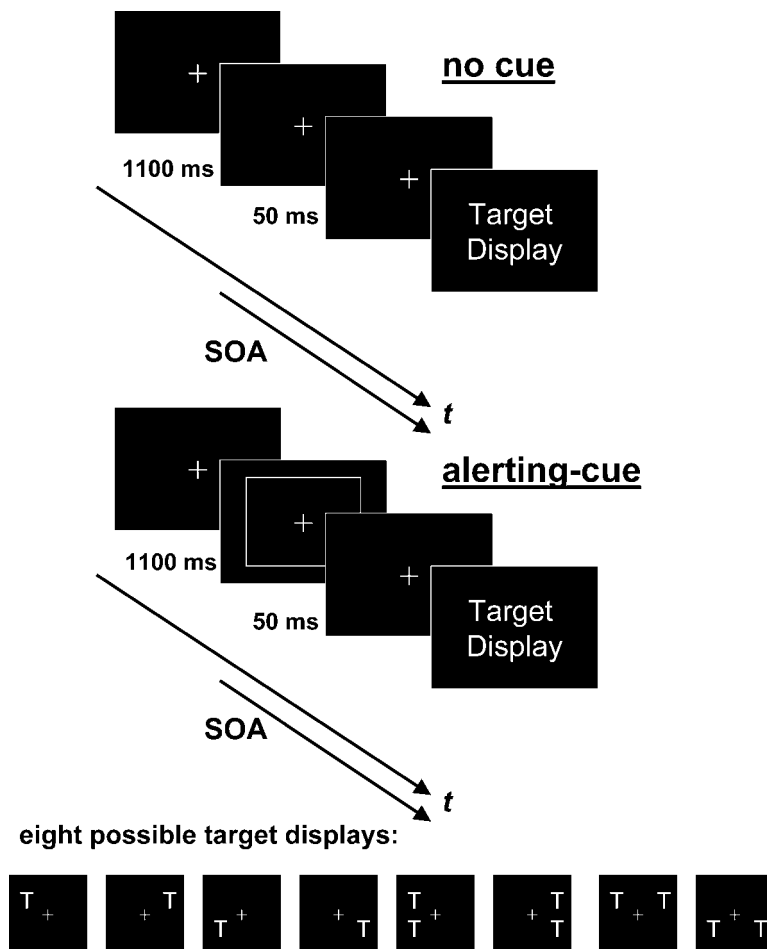
Figure 25. Sequence of frames presented on a no-cue trial (top panel) and an alerting-cue trial (middle panel) together with the eight possible target displays (bottom panel; the 'T' symbols denote target locations).

Participants were first instructed to fixate a white fixation cross (0.3° × 0.3°) presented for the entire trial duration in the centre of the screen, on a black background. As mentioned above fixation was controlled by a light sensitive web-cam, and participants were admonished to hold fixation for the complete trial duration. Then, after 1100 ms either a white outline square (5° × 5°) appeared on the screen for 50 ms (alerting-cue condition) or the screen remained blank for the same length of time (no-cue condition). After a variable cue-target SOA (randomly of 80, 200, or 650 ms) red letters (0.5° high × 0.4° wide) were presented as targets

for a pre-set exposure duration determined in a pre-test part of the experiment. Targets appeared with equal frequency at each of the possible stimulus locations in the corners of an imaginary square (with an edge length of 5°): upper left, lower left, upper right, lower right corner (see Figure 25, bottom panel). Thus, targets were presented 2.5° away from the fixation cross in the parafoveal fields on both sides. On each trial, either a single target or two targets (on the same side or on opposite sides) were presented. Dual targets were placed either vertically (column display) or horizontally (row display), but never diagonally. These dual target displays allowed to examine attentional competition not only across hemi-fields but also within the contralesional and ipsilesional fields. All target stimuli were masked. The masks consisted of letter-sized squares (of 0.5°) filled with a '+' and an '×' and presented for 500 ms at each letter location. The letters for a given trial display were chosen randomly from the set {ABEFHJKLMNPRSTWXYZ}, with a particular letter appearing only once at a time.

The participants' task was to verbally report the letters they had recognized with certainty. The target letters could be named in any arbitrary order, and there was no emphasis on reporting speed. The experimenter entered the reported letter(s) using the computer keyboard and initiated the next trial after the observers had indicated that they were ready. The trial started after an inter-trial interval of 1000 ms.

Experimental design. The experiment was divided into one 30-minute session, and three 45-minute sessions, each comprising two blocks that were separated by five-minute breaks. Every participant started with the 30-minute session, which consisted of the pre-test to determine the individual presentation times of the stimuli, and the BIT. The order of the other sessions was counterbalanced across patients to control for sequence effects. To avoid or minimize the possible influence of the alerting-cue on the no-cue condition, alerting-cue and no-cue trials were presented in different blocks. Hence, for three patients the order of sessions and blocks was AB, BA, AB and for the other three BA, AB, BA (with A = block with no-cue

trials, and B = block with alerting-cue trials). To control for 'time-on-day' effects, participants completed each of the four sessions at the same time of day and within one week. Before each block of trials, subjects were given standardized written and verbal instructions.

The experimental phase comprised eight different target conditions (four single target and four dual target conditions) for each SOA (80, 200, 650 ms) and each of the two cueing conditions (no-cue, alerting-cue). Because, highly reliable estimates for the parameter spatial distribution of attentional weighting (w_λ) were obtained on the basis of 18 trials per target condition (Finke et al., 2005), in the present experiment, 18 trials were used for each target, SOA and cueing condition. In total, the experiment comprised 846 trials per subject.

Target exposure duration. Target exposure durations were determined individually for each participant in a pre-test period. The pre-test (no-cue condition, 72 trials, with 6 trials for each SOA and single-target display) with a fixed exposure duration of 171 ms was used to determine whether a participant was able to reach an accuracy of 60–80% for single target report. If the participant performed outside this range, the exposure duration in the experimental phase was adjusted accordingly (i.e., extended to 200 ms if < 50% and to 186 ms if 50–60%, and shortened to 157 ms if 80–90%). The individual exposure durations are given in Table 5.

	EW	FP	KKL	ML	OB	PB
Exposure Duration	200	200	171	157	157	200

Table 5. Target exposure durations (in ms) for the six neglect patients (EW, FP, KKL, ML, OB, and PB).

4.1.5 Results

The experimental results will be described first in terms of the qualitative pattern of performance, followed by the TVA parameter estimates for the 'spatial distribution of attentional weighting' and 'sensory effectiveness/processing speed'.

Response Accuracy (Qualitative Pattern of Performance)

Figure 26 illustrates the mean percentages of correctly identified target letters for the neglect patient group in percent correct (response accuracy) for each hemi-field (left field, right field), separately for the three target types (single target letter, target accompanied by a second target in the ipsilateral, and target accompanied by a second target in the contralateral hemi-field), the three SOAs (80, 200, 650 ms), and the two cueing conditions (no-cue, alerting-cue).

Visual inspection of Figure 26 revealed obvious differences between the cued and the uncued condition. As expected, in the no-cue condition the typical (pathological) rightward spatial bias was obvious across all SOAs, reflected in a pronounced better performance in the right compared to the left hemi-field when an ipsilesional target was accompanied by a second target in the left hemi-field. Compared to unilateral target conditions performance seemed to decrease for the contralesional target as soon as a second target was presented ipsilesionally. In this case the contralesionally presented target seemed to be more or less extinguished.

In contrast to the no-cue condition, in the alerting-cue condition, target stimuli were found to be processed better in the left compared to the right hemi-field at the shortest SOA of 80 ms – probably comparable to the normal pseudo-neglect pattern exhibited by healthy subjects in study 1. This short-lasting alerting effect seemed to decrease with longer SOAs. Furthermore, unilaterally presented targets seemed to be processed faster in the alerting-cue com-

pared to the no-cue condition, indicating enhanced processing speed in both hemi-fields after presentation of the alerting-cue.
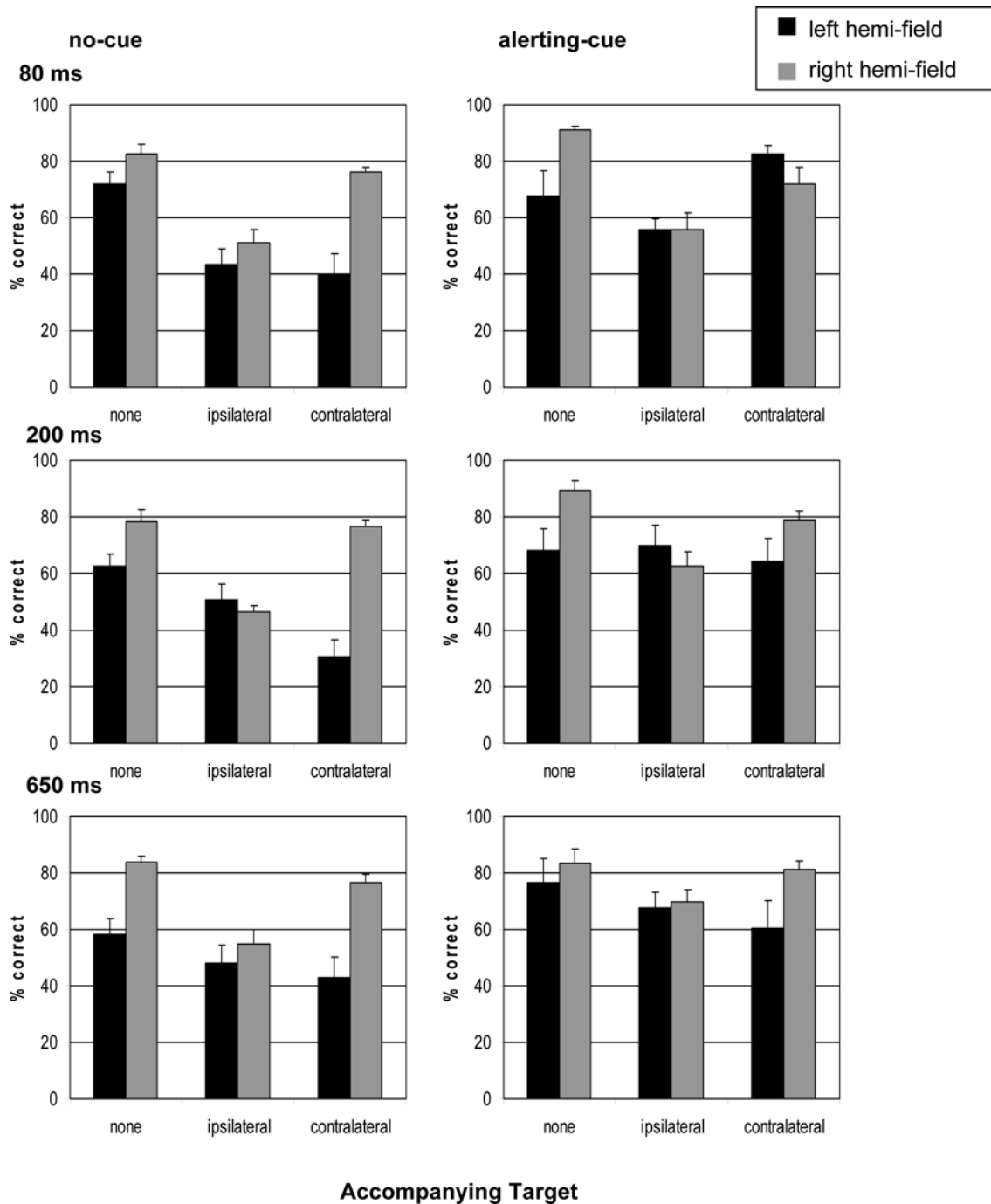

Figure 26. Mean proportions of correctly identified target letters (% correct) for each hemi-field (left field, right field), separately for the three target types (single target letter (none), target accompanied by a second target in the ipsilateral hemi-field, target accompa-

nied by a second target in the contralateral hemi-field), the three SOAs (80, 200, 650 ms), and the two cueing conditions (no-cue, alerting-cue; see left- and right-hand panels, respectively).

Parameter Estimates

In the following, the qualitative pattern of performance (correctly identified target letters) is quantitatively analyzed by TVA-based model fits to the data. The data fitting provides individual estimates of attentional weighting separately for each target location. The mean scores for the different experimental conditions and the values predicted (based on the best fits of the TVA model parameters) showed a very good correspondence. The mean correlation between the observed and predicted scores across all SOAs was .92 ($SD = .04$) in the no-cue condition and .88 ($SD = .09$) in the alerting-cue condition.

Because in TVA, the absolute attentional weighting has no meaning, only relative intra-individual values can be compared. Therefore, a laterality index was computed from the raw data of the w estimates: the 'index of the spatial distribution of attentional weighting' (w_λ).

Spatial distribution of attentional weighting (w_λ). For a detailed description of the parameter w_λ see 1.1.8.2. Figure 27 illustrates the SOA-dependent time course of the spatial distribution of the attentional weighting parameter w_λ for the no-cue and the alerting-cue condition for the neglect patients group (see Table 6 for individual w_λ values).
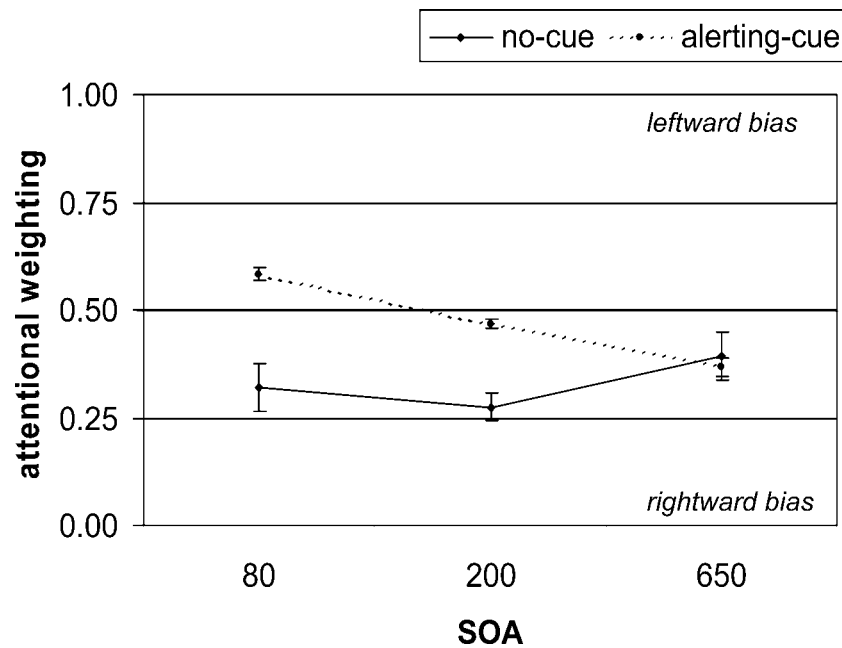
Figure 27. Parameter w_λ (the spatial distribution of attentional weighting) as a function of SOA for the no-cue and the alerting-cue condition for the neglect patients group. The error bars give the standard errors. Values of $w_\lambda > .50$ = leftward attentional bias; $w_\lambda < .50$ = rightward attentional bias; $w_\lambda = .50$ = no bias..

A Cue (no-cue, alerting-cue) × SOA (80, 200, 650 ms) repeated-measures ANOVA with w_λ as dependent variable was conducted. This analysis revealed a significant main effect for Cue [$F(1, 5) = 14..43$; $p < .01$; $\eta^2 = .74$], and a significant Cue × SOA interaction [$F(2, 4) = 53.09$; $p < .001$; $\eta^2 = .96$]. No significant main effect for the factor SOA was found (with $F = 3.12$; $p = .15$).

In general, neglect patients showed a pronounced rightward lateralization of the spatial distribution of attentional weighting under uncued conditions. This result is in accordance with previous studies showing a rightward prevalence in exploration behavior and a unilateral rightward lateralization in neglect (e.g., Bartolomeo & Chokron, 2002; Heilman et al., 2003; Karnath, 1988). In contrast to this rightward spatial bias in the no-cue condition, the alerting-

cue resulted in a re-distribution of attentional weights towards the left hemi-field at the SOAs of 80- and 200-ms [$t(5) = -3.92$; $p < .01$, and $t(5) = -6.48$; $p < .01$]. This 'alerting effect' decreased significantly with increasing SOAs [$t(5) = 11.51$; $p < .001$]. These results are in accordance with the performance pattern in conditions with bilaterally presented targets described above. Under this condition the alerting effect was reflected in a significant increase of performance in the left hemi-field.

Patient	no-cue			alerting-cue		
	SOA (in ms)			SOA (in ms)		
	80	200	650	80	200	650
EW	.13	.29	.15	.62	.47	.40
FP	.43	.28	.47	.59	.47	.37
KKL	.32	.22	.32	.58	.46	.30
ML	.19	.32	.47	.58	.43	.44
OB	.37	.39	.46	.60	.51	.38
PB	.49	.16	.49	.52	.46	.31

Table 6. Single case values of the spatial distribution of attentional weighting separately for each patient, cueing condition, and SOA

Sensory Effectiveness *A*

Figure 28 illustrates the SOA-dependent time course of the parameter sensory effectiveness (averaged over both hemi-fields) for the no-cue and the alerting-cue condition.
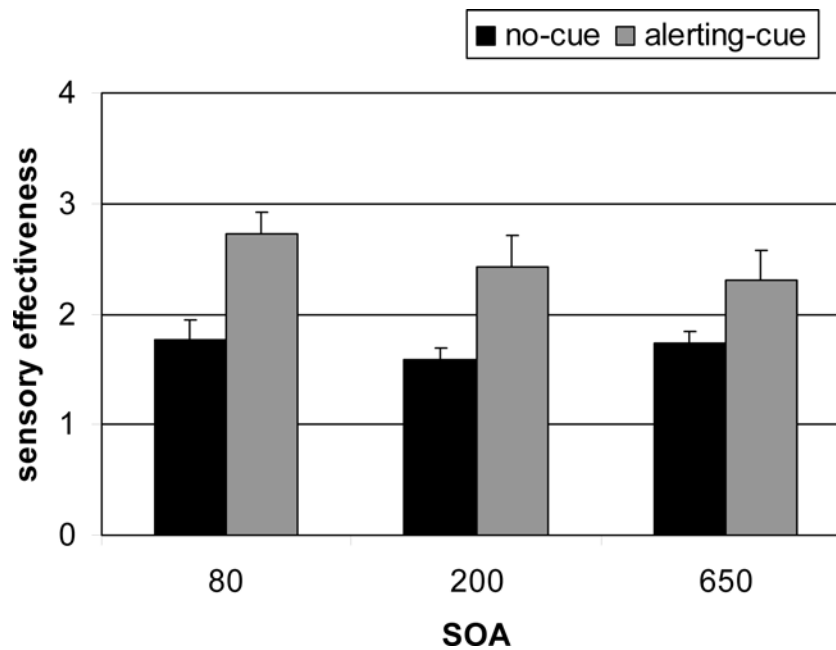
Figure 28. Parameter *A* (sensory effectiveness) as a function of SOA for the no-cue and the alerting-cue condition. The error bars give the standard errors.

A Cue (no-cue, alerting-cue) × SOA (80, 200, 650 ms) repeated-measures ANOVA with *A* as dependent variable was conducted. This analysis revealed a significant main effect for Cue [$F(1, 5) = 9.98$; $p < .05$; $\eta^2 = .69$], and a significant Cue × SOA two-way interaction [$F(2, 4) = 10.48$; $p < .05$; $\eta^2 = .84$]. No significant main effect for the factor SOA [$F(2, 4) = .89$; $p = .28$)] was found. This result indicates a significant general faster processing of stimuli in the alerting-cue condition compared to the no-cue condition over the 80- and 200-ms SOA [$t(5) = -3.50$; $p < .05$); $t(5) = -3.431$ $p < .05$)] and a marginally significant faster processing at the 650-ms SOA [$t(5) = -2.39$; $p = .06$)]. Moreover, a significant decrease of general sensory processing was found in the alerting-cue condition between the SOAs of 80 and 200 ms [$t(5) = 2.48$; $p < .05$)].

To investigate whether this alerting-effect in unilateral target conditions is caused by side-specific changes in sensory effectiveness/processing speed, a detailed analysis separately for

each visual hemi-field was conducted (A_{left}; A_{right}). The results are shown in Figure 29 (see

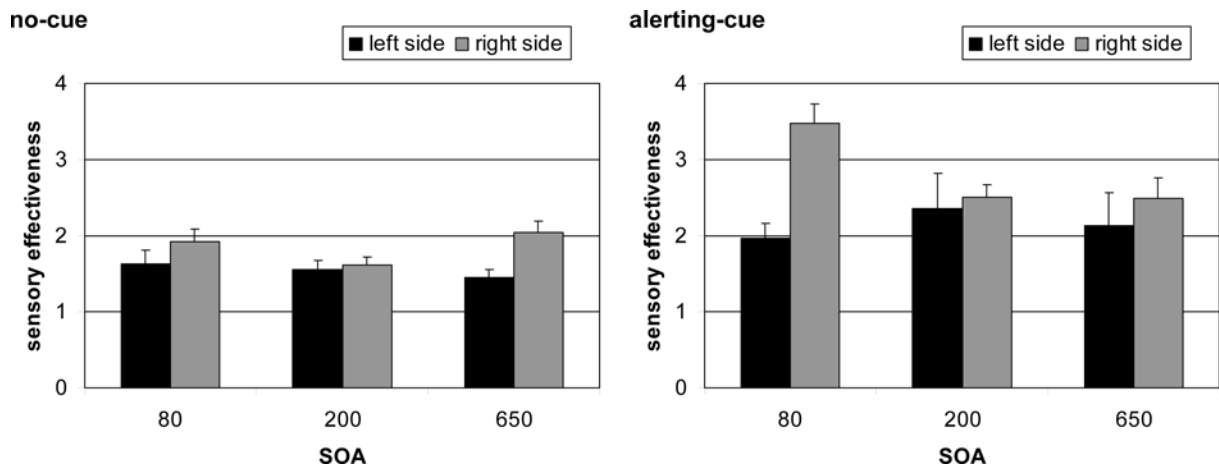Table 7 for individual A_{left} and A_{right} values).

Figure 29. Parameter A (sensory effectiveness) for the left and the right visual hemi-field

as a function of SOA for the no-cue and the alerting-cue condition. The error bars give the

standard errors.

A Cue × SOA × Side repeated-measures ANOVA with A as dependent variable was con-

ducted. This analysis revealed a significant main effect for Cue [$F(1, 5) = 9.98$; $p < .05$; $\eta^2 =$

20.69] and Side [$F(1, 5) = 19.11$; $p < .01$; $\eta^2 = .79$]. Furthermore, the Cue × SOA [$F(2, 4) =$

10.48; $p < .05$; $\eta^2 = .84$] and the SOA × Side [$F(2, 4) = 12.80$; $p < .05$; $\eta^2 = .86$] two-way in-

teractions, and the Cue × SOA × Side [$F(2, 4) = 19.36$; $p < .001$; $\eta^2 = .91$] three-way interac-

tion were significant. The remaining main effect for SOA and the Cue × Side interaction were

non-significant (with all $F < 1.78$; all $p > .28$). To further analyze the three-way interaction

separate ANOVAs for the left and the right hemi-field with Cue and SOA as within-subject

factors were conducted.

Left hemi-field: No significant main effects (with all $F < 3.43$; all $p > .12$) were revealed. However, a marginally significant Cue × SOA two-way interaction (with $F = 5.83$; $p = .07$) was found.

Right hemi-field: The main effects of Cue [$F(1, 5) = 21.66$; $p < .01$; $\eta^2 = .81$] and SOA [$F(2, 4) = 14.88$; $p < .05$; $\eta^2 = .88$], as well as the Cue × SOA two way-interaction [$F(2, 4) = 40.49$; $p < .01$; $\eta^2 = .95$] were significant. *Post-hoc* tests revealed a significant better sensory processing in the alerting-cue compared to the no-cue condition at 80- and 200-ms SOA [$t(5) = -6.64$; $p < .001$); $t(5) = -7.15$; $p < .001$)]. Moreover, a significant better sensory processing in the right compared to the left hemi-field was found for the alerting-cue condition at 80-ms SOA [$t(5) = -4.82$; $p < .01$)]. This peak of sensory processing in the right visual hemi-field decreased significantly between 80- and 200-ms SOA [$t(5) = 6.15$; $p < .01$)].

Patient	no-cue			alerting-cue		
	SOA (in ms)			SOA (in ms)		
	80	200	650	80	200	650
EW	1.07 / 1.52	1.37 / 1.33	1.24 / 1.59	1.36 / 2.42	.80 / 1.78	.95 / 1.46
FP	1.87 / 1.98	2.12 / 1.87	1.86 / 2.01	2.64 / 3.30	3.00 / 2.43	2.93 / 3.02
KKL	2.39 / 2.52	1.47 / 1.95	1.63 / 2.27	1.71 / 3.38	1.51 / 2.80	2.59 / 1.58
ML	1.55 / 2.24	1.65 / 1.55	1.41 / 2.38	1.98 / 3.92	2.59 / 2.61	1.30 / 3.70
OB	1.36 / 1.69	1.39 / 1.40	1.11 / 2.39	1.71 / 3.63	2.26 / 2.41	2.04 / 2.40
PB	1.56 / 1.55	1.33 / 1.65	1.44 / 1.57	2.40 / 4.21	3.97 / 2.96	2.48 / 3.30

Table 7. Single case values of sensory effectiveness *A* separately for each hemi-field (left/right), patient, cueing condition, and SOA.

4.1.6 Discussion

Understanding what factors are determining whether and when a contralesional event is detected or extinguished in neglect patients may provide variable insights to the mechanisms of attention and its operation in visual processing. By using a TVA-based whole report paradigm the present study was designed to independently and separately observe the influence of cue-induced phasic alertness on spatially non-lateralized (i.e., sensory effectiveness/visual perceptual processing speed) and spatially lateralized (i.e., the spatial distribution of attentional weighting) components of visual attention, using a within-subject design in a group of neglect patients. With accuracy of verbal letter report rather than manual reaction time as dependent measure this paradigm allowed to do so independently of potential motor confounds. This is a huge advantage in neurological patient groups with often impaired motor functions. Additionally, the paradigm includes the independent estimation of sensory and attentional parameters within the same task and patient. Previous studies have suggested that extinction - as a prominent symptom in neglect patients - might result from sensory imbalance due to weaker or delayed afferent inputs in the affected hemisphere rather than from attentional factors (e.g., Farah, Monheit, & Wallace, 1991; Habekost & Rostrup, 2006; Vallar, Rusconi, Bignamini, Geminiani, & Perani, 1994). Thus, in the paradigm used in the present study, in bilateral target conditions performance for left and right sided stimuli could differ due to reduced sensory effectiveness/processing speed in one hemi-field. However, this factor was controlled for by data from the unilateral target conditions. Hence, remaining side differences found in the present study should therefore be directly attributed to different attentional weighting of each hemifield rather than to impaired sensory function.

Furthermore, by varying the cue-stimulus SOA, the present experiment was aimed at disclosing the time course of the effects exerted by the alerting-cue on spatial and non-spatial attentional components.

As expected, patients showed a pronounced biased attentional competition towards the right hemi-field reflected in a pronounced rightward spatial bias and extinction behavior when no external alerting signal was present. As soon as patients were phasically alerted by the non-spatial, visually presented alerting-cue a re-distribution of attentional weights to a more leftward spatial lateralization was observed. This alerting-effect was especially evident for the shortest SOA of 80 ms. At this SOA neglect patients showed a leftward spatial lateralization probably comparable to the pseudo-neglect pattern normally exhibited by healthy subjects (e.g., as seen in study 1.). This alerting effect was short-lasting and decreased with longer SOAs until it vanished at the longest SOA of 650 ms. Independently of these changes in the spatial distribution of attentional weighting the present study additionally provided evidence that the warning signal led to enhanced speed of processing of target stimuli across all three SOAs. This strongly supports the claim of study 1 (chapter 3) that phasic alerting can directly affect the speed of perceptual processing, rather than merely affecting motor readiness. The increase in sensory processing speed was especially pronounced for the right visual hemi-field. Hence, the beneficial effect of the alerting-cue with regard to the re-distribution of attentional weights to the left hemi-field occurred independently of enhanced sensory processing in this hemi-field.

Taken together, the global pattern of effects revealed in the present study can be summarized as follows: There was (1) a fast evolving and short-lasting, 'phasic' modulation of spatial attentional weighting and (2) a longer-lasting effect of the alerting-cue on sensory effectiveness/processing speed. Both of these (independent) alerting-cue effects can be attributed to an 'exogenous', cue-induced state of phasic alertness, probably overcoming the lowered intrinsic alertness state and the related lowered processing speed and rightward spatial bias of neglect patients. These results clearly indicate that the spatial lateralization in neglect patients is a definite attentional disorder and can not simply be attributed to sensory imbalance as sug-

gested by previous studies (e.g., Farah et al., 1991; Habekost & Rostrup, 2006; Vallar et al., 1994).

These results concur with functional imaging data concerning the neural networks involved in alertness and in spatial attention. More specifically, these results support the assumptions of independent but partially overlapping neural networks of intrinsic and phasic alertness, as well as of intrinsic/phasic alertness and spatial attention. On the one hand, the results showed that phasic alerting was preserved in the neglect patients group, despite their intrinsic alertness impairment. Additionally, the results indicated that the intrinsic alertness deficit contributed to their spatial lateralization, because phasically increasing alertness could overcome their rightward spatial attentional bias.

From these results it can be concluded that higher levels of alertness can overcome the typical neglect symptoms such as a rightward lateralization and unilateral extinction, stressing the relevance of alertness in disturbed attentional competition, and thus, spatial attentional asymmetries.

Chapter 5: General Conclusion

The studies of Chapters 3 and 4 were designed to disentangle the influence of intrinsic and phasic aspects of alertness on a bunch of spatial and non-spatial attentional components postulated by Bundesen´s TVA. The studies revealed that decreasing levels of intrinsic alertness lead to a reduction in visual perceptual processing speed as well as to a more rightward spatial distribution of attentional weighting, whereas increasing levels of phasic alertness result in enhanced processing speed and a more leftward spatial bias. The VSTM storage capacity and the parameter top-down control seem to be independent of changes in the intrinsic or phasic alertness state. These results are in accordance with the view of independent but partially overlapping neural networks for intrinsic and phasic alertness as well as for spatial attention functions.

A number of important questions for future studies arise from these results. For example, the assessment of effects of spatially non-informative alerting cues should be contrasted with those of spatially informative cues, again with respect to possible distinct effects on non-spatial and spatial TVA parameters and on their temporal dynamics at different cue-target SOAs. The starting point of such a study is the assumption that, in a Posner-type spatial cueing paradigm, spatially lateralized and non-lateralized components may interact with non-spatial, phasic alerting effects overlaying spatial cueing effects: The cue may not only put the processing system in a specific lateralized set but also into a generalized state of higher (phasic) alertness. As a result, the effects of spatial orienting to the spatially cued side may at least partially be caused by non-spatial alerting effects. A second important aim would be to assess additional patient groups with attentional, spatial or non-spatial impairments, e.g. patients

with ADHD, using the same paradigm in order to find out whether and how the documented effects are modified by the specific pathology. Third, combining the presented experimental approach with, for example, pharmacologically induced modifications of alertness would be relevant to further assess the neural hypotheses derived from the present results. Fourth, due to the use of verbal (letter) stimuli it cannot be fully ruled out that the laterality of language processing somehow influenced the time course of the estimated parameters. Thus, in future studies results should be replicated by using e.g. symbolic stimuli.

Deutsche Zusammenfassung (Abstract in German)

Der Einfluss des Grades der Alertness auf räumliche und nicht-räumliche Aufmerksamkeitsleistungen bei gesunden Probanden und Neglektpatienten

(The influence of the level of alertness on spatial and non-spatial components of visual attention in healthy subjects and neglect patients)

Bisherige Studien mit Gesunden und Patienten mit räumlichen Aufmerksamkeitsstörungen (z.B. Neglekt oder ADHS) deckten einen engen Zusammenhang zwischen dem Grad der intrinsischen und der phasischen Alertness und räumlichen sowie nicht-räumlichen Aufmerksamkeitsleistungen auf (z.B., Bellgrove et al., 2004; Fimm et al., 2006; Husain & Rorden, 2003; Robertson et al., 1998; Thimm et al., 2006). Bislang blieb jedoch unklar, auf welche Aufmerksamkeitskomponenten sich variierende Aktivierungsniveaus konkret auswirken und in welchem zeitlichen Zusammenhang sich solche Einflüsse abspielen.

Die vorliegende Arbeit untersuchte daher den Einfluss intrinsischer und phasischer Alertness auf räumlich lateralisierte und räumlich nicht-lateralisierte Komponenten visueller Aufmerksamkeit bei gesunden Probanden (Kapitel 3) und Neglektpatienten (Kapitel 4). Zum einen sollte untersucht werden, welche Komponenten visueller Aufmerksamkeit vom Grad der Alertness beeinflusst werden, zum anderen sollte erfasst werden, in welchem zeitlichen Rahmen sich diese, von der Alertness abhängigen, Änderungen bewegen. Durch Verwendung TVA-basierter Teil- und Ganzberichtparadigmen war es möglich räumliche und nicht-räumliche Parameter der Aufmerksamkeit am selben Probanden getrennt und unabhängig voneinander zu erheben. Diese Methode ermöglichte es, den jeweiligen Einfluss intrinsischer

und phasischer Alertness auf die verschiedenen Komponenten visueller, selektiver Aufmerksamkeit zu entflechten.

In Kapitel 3 wurde untersucht, ob und wenn ja, welche räumlichen und nicht-räumlichen Aufmerksamkeitsleistungen von Änderungen der phasischen (Studie 1) oder intrinsischen (Studie 2) Alertness beeinflusst werden. Darüber hinaus sollte überprüft werden, ob ein solcher Einfluss des Grades der Alertness auf die unterschiedlichen Komponenten selektiver Aufmerksamkeit unabhängig voneinander auftritt

In Studie 1 wurden zwei auf Bundesen´s „Theorie der Visuellen Aufmerksamkeit" (TVA) basierende Ganzberichtparadigmen eingesetzt, die mit einem kein-Cue/Alerting-Cue Paradigma kombiniert wurden. Bei dem verwendeten Alerting-Cue handelte es sich um einen nicht-räumlichen, visuellen Hinweisreiz (eine für 50 ms aufleuchtende Box in der Mitte des Bildschirms), der kurzzeitig (phasisch) das Alertnessniveau der Probanden anheben sollte, ohne dabei die Aufmerksamkeit auf ein bestimmtes visuelles Halbfeld zu lenken. So war es möglich, den Einfluss *phasischer* Alertness auf räumliche (d.h. die räumliche Verteilung attentionaler Gewichte w_λ) und nicht-räumlich Komponenten der Aufmerksamkeit (d.h. die perzeptuelle Verarbeitungsgeschwindigkeit C und die Kapazität des visuellen Kurzzeitgedächtnisses K) an gesunden Probanden unabhängig voneinander zu erfassen. Durch die Verwendung unterschiedlicher Zeitintervalle (SOA, stimulus onset asynchrony) zwischen Hinweisreiz (Cue) und Zielreiz (Target) konnte darüber hinaus der zeitliche Verlauf potentieller Veränderungen dieser Aufmerksamkeitskomponenten erfasst werden.

Die Ergebnisse aus Studie 1 zeigten einen direkten Einfluss der Cue induzierten, phasischen Aktivierung zum einen auf die räumliche Verteilung der Aufmerksamkeit und zum anderen auf die perzeptuelle Verarbeitungsgeschwindigkeit der Probanden. Ein Effekt der phasischen Alertness auf die Spanne des visuellen Kurzzeitgedächtnisses konnte nicht gefunden werden. Zusammenfassend ergab sich das folgende Bild: Der Alerting-Cue bewirkte 1.) eine

sich schnell entwickelnde aber nur kurz andauernde Veränderung der Verarbeitungsge-schwindigkeit C (Experiment 1) und 2.) einen länger anhaltenden Einfluss auf die räumliche Gewichtung der Aufmerksamkeit (= stabiler Pseudoneglekt; Experiment 2). Beide Effekte können einem „exogenen", durch den Alerting-Cue induzierten Zustand der Alertness zuge-schrieben werden. Desweiteren zeigte sich 3.) bei Abwesenheit des Alerting-Cues eine Zu-nahme der räumlichen Lateralisierung in Richtung der rechten Raumhälfte bei (mittleren) SOAs von 200 und 300 ms (Experiment 2).

Zusätzlich konnten eine Reihe kompensatorischer Prozesse beobachtet werden: neben ei-ner sich langsam entwickelnden dafür aber lang anhaltenden Erhöhung der perzeptuellen Ver-arbeitungsgeschwindigkeit C, die unabhängig von der Cueing Bedingung auftrat (Experiment 1), zeigte sich außerdem nach der beobachtbaren Rechtslateralisierung in der Bedingung ohne Warnsignal bei mittleren SOAs eine „Rücklateralisierung" zur linken Raumhälfte und damit ein Wiederauftreten des Pseudoneglekts bei längeren SOAs von 450 und 650 ms (Experiment 2). Desweiteren konnte ein Anstieg der sensorischen Effektivität im linken Halbfeld bei einem mittleren SOA von 200 ms in Bedingungen ohne Warnreiz gefunden werden. Diese Effekte können vermutlich einem „endogenen", Cue unabhängigen Zustand der Alertness zugeschrie-ben werden.

In Studie 2 wurde der Einfluss reduzierter, *intrinsischer* Alertness auf die räumliche Ver-teilung der attentionalen Gewichtung w_λ und aufgabenbezogene Top-down Kontrolle α er-fasst. Darüber hinaus sollte untersucht werden, ob das Ausmaß der (postulierten) Rechtslate-ralisierung in einem Zustand niedriger intrinsischer Alertness von der individuellen Fähigkeit einer Person abhängig ist, ein angemessenes Alertnessniveau aufrecht zu erhalten. Um den Einfluss der intrinsischen Alertness auf diese Parameter zu untersuchen, wurde ein TVA ba-siertes Teilberichtsparadigma unter normalen und unter Bedingungen erniedrigter Alertness eingesetzt. Durch Verwendung einer visuellen Vigilanzaufgabe war es möglich, das intrinsi-

sche Alertnessniveau der Probanden mit fortschreitender Bearbeitungsdauer systematisch abzusenken und zu erfassen. Während sich unter normalen Alertnessbedingungen der zu erartende Pseudoneglekt zeigte, stellte sich, wie erwartet, bei erniedrigter intrinsischer Alertness eine deutliche Rechtslateralisierung ein. Interessanterweise ähnelte dieses attentionale Ungleichgewicht der Symptomatik, die normalerweise bei Neglektpatienten beobachtetet werden kann. Das Ausmaß dieser Rechtslateralisierung war abhängig von der Fähigkeit der Person ein angemessenes Aktivierungsniveau über die Zeit hinweg aufrecht zu erhalten. Probanden, die subjektiv (erfasst über die Stanford Sleepiness Scale) oder objektiv (erfasst über den Reaktionszeitunterschied zu Beginn und zum Ende der Vigilanzaufgabe) eine stärkere Abnahme ihres Alertnessniveaus aufwiesen, zeigten auch eine stärker ausgeprägte rechtsseitige Lateralisierung bei erniedrigtem Grad intrinsischer Alertness.

Die in Kapitel 4 vorgestellte Studie untersuchte den Einfluss *phasisch* induzierter Alertness auf die räumliche Verteilung attentionaler Gewichte (w_λ) und die sensorische Effektivität (A) bzw. die Verarbeitungsgeschwindigkeit (C) in einer Gruppe von Neglektpatienten. Ein Hauptsymptom von Patienten mit Neglekt besteht in einer pathologischen Verteilung der attentionalen Gewichte zur rechten Raumhälfte. Darüber hinaus gibt es mehr und mehr Hinweise darauf, dass auch nicht-räumliche Aufmerksamkeitsleistungen, wie z.B. intrinsische Alertness bei diesen Patienten mitbetroffen sein könnten. So konnte zum Beispiel gezeigt werden dass die Rechtslateralisierung bei diesen Patienten durch Cue induzierte, phasische Aktivierung (kurzfristig präsentierter Ton) aufgehoben oder zumindest reduziert werden konnte (Robertson et al., 1998). Allerdings ist bislang nicht geklärt, welche Aufmerksamkeitskomponenten bei diesen Patienten durch die Präsentation eines Alerting-Cues tatsächlich beeinflusst werden können. Primäres Ziel dieser Studie war es also den Einfluss Cue induzierter phasischer Alertness auf lateralisierte und nicht-lateralisierte Komponenten visueller Aufmerksamkeit unabhängig voneinander zu erfassen. Die Verwendung von drei verschiedenen Cue-

Target SOAs machte es zusätzlich möglich den zeitlichen Verlauf der Veränderungen zu beobachten.

Es zeigten sich unabhängig voneinander zahlreiche Effekte. In der Bedingung ohne Hinweisreiz trat, wie erwartet, eine deutliche Lateralisierung zur rechten Raumhälfte auf. Die Präsentation des Alerting-Cues führte zu einer sich rasch entwickelnden und kurz andauernden phasischen Verschiebung der attentionalen Gewichtung in Richtung der linken Raumhälfte. Darüber hinaus zeigte sich ein länger wirkender Effekte des Hinweisreizes auf die sensorische Effektivität bzw. die perzeptuelle Verarbeitungsgeschwindigkeit. Der Einfluss des Alerting-Cues auf die attentionale Gewichtung, sowie die perzeptuelle Verarbeitungsgeschwindigkeit traten unabhängig voneinander auf. Zusammenfassend lässt sich also sagen, dass ein höheres Alertnessniveau die typische Neglektsymptomatik, wie z.B. die rechtsseitige Lateralisierung und die unilaterale Extinktion aufheben , zumindest aber reduzieren kann. Dieser Befund unterstreicht die Relevanz der Alertnesskomponente bei Patienten mit einer pathologischen Lateralisierung der räumlichen Aufmerksamkeit.

Schlussfolgerung: Die Ergebnisse aus Kapitel 3 und 4 konnten einen engen aber unabhängigen Einfluss des intrinsischen und phasischen Alertnessniveaus und den räumlichen bzw. nicht-räumlich Komponenten visueller Aufmerksamkeit bei gesunden Probanden und Neglektpatienten demonstrieren. Bei ansteigender *phasischer* Alertness zeigte sich ein Anstieg der perzeptuellen Verarbeitungsgeschwindigkeit, sowie eine (stabile) räumliche Lateralisierung zur linken Raumhälfte. Bei abnehmender *intrinsischer* Alertness konnte demgegenüber ein Abfall der Verarbeitungsgeschwindigkeit, sowie eine Zunahme der Lateralisierung zur rechten Raumhälfte beobachtete werden. Ein direkter Einfluss phasischer und intrinsischer Alertness auf die beiden Parameter „Top-down Kontrolle" und „Kapazität des visuellen Kurzzeitgedächtnisses" konnte nicht gezeigt werden. Diese Ergebnisse liefern einen deutlichen Beleg für die Annahme eines direkten, aber unabhängigen Zusammenhangs des Grades intrin-

sischer und phasischer Alertness auf räumliche und nicht-räumliche Aufmerksamkeitskomponenten. Diese Analyse des Einflusses des Grades der Alertness war nur durch die Verwendung der TVA Methode möglich, die es erlaubte, die unterschiedlichen attentionalen Komponenten, sowie deren zeitliche Veränderungen innerhalb desselben Probanden unabhängig voneinander zu erfassen.

Die vorliegende Arbeit legt die Vermutung nahe, dass das Konzept der „Alertness" nicht lediglich mit dem Parameter der Verarbeitungsgeschwindigkeit gleichzusetzen ist, sondern vielmehr als grundlegender attentionaler Faktor angesehen werden sollte, der verschiedene Komponenten der Aufmerksamkeit parallel, im Zeitverlauf jedoch unterschiedlich und unabhängig voneinander beeinflusst.

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