Visual Attention and Temporal Binding

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Chapter 1: Introduction

Visual Attention

If we open our eyes, one has the natural impression of seeing and recognizing objects or persons without any effort. However, at the same time, our brain copes with a huge mass of information that continuously streams to us through our eyes. A mechanism is neccessary which selects the most relevant information at a time in an efficient and economic way. Examples of everyday life are the identification of a required level button in an elevator or the quick recognition of the sought-for link on a website. Visual attention provides our brain with such a selection mechanism. By means of visual attention, behaviorally relevant information can be selected and irrelevant information can be ignored or suppressed. Visual attention can also enhance or modulate the selected information according to the state and goals of a perceiver. In this way, we become active agents in information processing and we can interact with our environment in a goal-directed manner.

Selection of Information

Our visual system has some 'hard-wired' selection mechanisms. For example, high resolution can only be provided at the fovea of our retina, because of a nearly one to one connections of sensory receptor cells with ganglion cells, whose axons make their way up the optic nerve. Visual attention is a set of mechanism that can be deployed on information which has already passed the early hard-wired selection stages. In the middle of the last century, a debate arose about the locus of attentional selection. On 'early-selection' theory (Broadbent, 1958), irrelevant information is filtered by physical attributes of the input information (e.g., left or right ear). The other extreme, late-selection, proposed that selection occurs only after categorization and semantic analysis of the input (Deutsch & Deutsch, 1963). Treisman (1960) proposed an intermediate alternative in her ‘attenuation theory’, which states that unattended information is attenuated rather than completely filtered out or completely identified.

The controversy ended in a draw, but there is recent evidence that selection stage is flexible and depends on task requirements (e.g., Lavie, 1995), in line with Treisman´s proposal.

Selective Visual Attention

Space-based Attention

A good way to examine phenomena in science and make them more graspable, is to invent metaphors. Two of them, which can be well combined, led to intensive research on visuo-spatial attention. The ‘zoom lense’ metaphor (e.g., Eriksen & St. James, 1986; Eriksen & Yeh, 1985) describes the attentional focus as a flexibel lense. The narrower the lense is focused (up to 1° of visual angle), the more details can be extracted from the attended area. If the lense zooms out, the attentional focus is wider, but less details can be discerned. According to this view, attention is equally distributed over space within the area of lense focus and detail resolution depends on the lense diameter. There is also the notion of attentional distribution over space as a gradient. That is, the larger the eccentricity of a point relative to the attentional focus, the smaller are attentional effects. (Downing & Pinker, 1985; Eriksen & Yeh, 1985; Hoffman & Nelson, 1981; LaBerge, 1983; Shaw & Shaw, 1977). Another prominent metaphor is that of the ‘spotlight’ (e.g., Posner, 1978), which describes attention in terms of the spot of a light beam that can be deployed anywhere in the visual field. Stimuli within this spotlight are processed more rapidely and more thoroughly. Apart from the natural understanding of attention as a light beam which can be moved around by an act of will, the spotlight view of attention in psychological science was also derived from experimental findings. Posner (e.g., Posner, Nissen, & Odgen, 1978) devised the so-called 'spatial cueing paradigm'. Here, they presented subjects with a simple task, in which they had to press a button as soon as they detect a target, a brief flash of light. The target was presented either to the left or to the right. In addition, a 'spatial cue', for instance an arrow, was presented in the center of the visual field prior to the light flash. A 'valid' cue provided information about where the light flash was likely to appear. Thus, it should have initiated deployment of spatial attention to the likely target location. However, the cue was not always valid. That is, in 20% of the trials the cue indicated the wrong side, and it could also be 'neutral' (e.g., a cross, rather than an arrow, in the middle of the screen), which indicated that the flash was equally likely to appear on both sides. The results were that the observers were fastest to detect the flash on valid-cue trials, intermediate on neutral-cue trials and slowest on invalid-cue trials. Thus, there were benefits in reaction time (RT) for a valid cue and costs for an invalid cue relative to the neutral (baseline) condition (see Figure 1.1). The interpretation was that spatial attention is 'moved', like a spotlight,

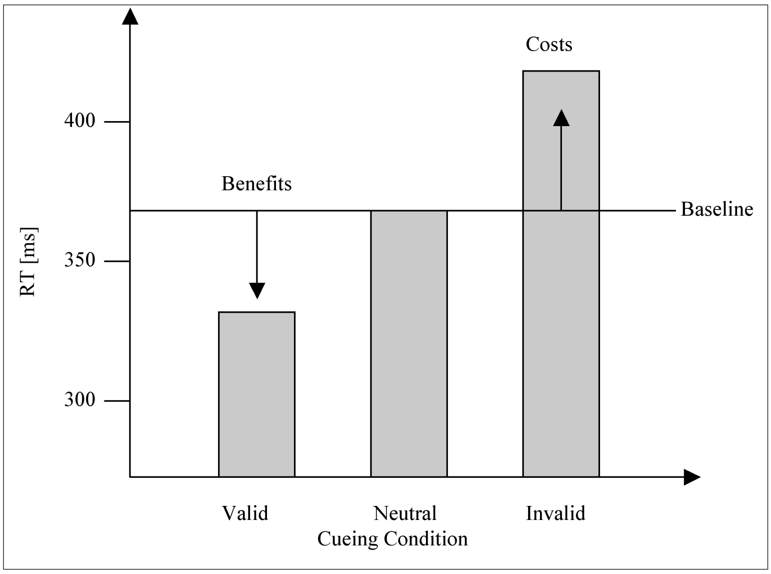

Figure 1.1: Costs and benefits in a Cueing experiment. Responses are faster on valid trials than on neutral trials, whereas on invalid trials responses are slower than on neutral trials.

following cue presentation and ‘engaged’ at the cued location, and that it needs a time-consuming mechanism to later ‘disengage’ it from this position and move it to another one (e.g., Posner & Petersen, 1990).

Cues can be a symbol, like an arrow, which indicates where attention should be deployed (Jonides, 1981; Posner & Cohen, 1984). By means of a symbolic cue, endogenous (i.e., controlled) attention deployment is initiated, which can be seen as top-down (or goal-driven) expectancy of target appearance at a particular location (e.g., Jonides & Yantis, 1988). Cues can also trigger exogenous attentional deployment, like the rapid brightening (Posner & Cohen, 1984) or the sudden onset of a stimulus (Eriksen & Hoffman, 1973; Posner, Snyder, & Davidson, 1980). These cues are thought to draw spatial attention to the indicated location in an automatic or reflexive way, and are meant to do this in a quicker manner than endogenous cues (Cheal & Lyon, 1991; Jonides, 1981; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Posner et al., 1980; Weichselgartner & Sperling, 1987). Thus, attentional deployment through exogenous cues has been referred to as ‘bottom-up’, stimulus-driven orienting.

In general, directing attention to a location in visual space has a facilitatory effect on processing at the attended location. However, recent studies could show that directing attention away or broadening its focus can also facilitate the performance of certain tasks (Olivers & Nieuwenhuis, 2005; Shapiro, Arend, & Johnston, 2005).

Object-based Attention

Spotlight and zoom lense metaphors assume that attention selects a region in space. However, there are other accounts of how visual attention might work. It is, for example, difficult to explain how attention can be selectively allocated to different levels of depth in 3D scenes (Nakayama & Silverman, 1986), because the input of visual information is

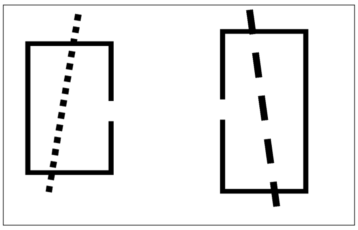

Figure 1.2: Stimuli used by Duncan (1984). Observers should report two features of either the line or the box, or one feature of the box and the line.

necessarily 2D. On an object-based account of attention, perceptual objects are selected independently of their 2D position in space (e.g., Duncan, 1984; Baylis & Driver, 1993). For example, Duncan (1984) addressed this in an experiment in which the stimuli consisted of two overlapping object shapes (see Figure 1.2). These shapes were presented briefly and then masked by a stimulus which overlaid both shapes. In the critical conditions, observers had to report two attributes of the two objects (e.g., orientation). The finding was that report accuracy was higher when they were asked to report two attributes from a single object compared with one attribute from both objects. These results could not be explained by a space-based account of attention, because both objects were presented at the same location. Object-based attention makes sense because it can explain experimental findings such as those of Duncan (1984), but it makes also sense from an ecological point of view. In natural scenes, perceptual objects are built of fragmentary parts (e.g., because of partial occlusion of one object by another) by perceptual grouping, completion or other mechanisms which might bind the parts together (Kanizsa, 1979; Kellman & Shipley, 1991; Nakayama, He, & Shimojo, 1995). Thus, attention may be often directed to object representations rather than to regions in space from the 2D input. Like with spatial attention, there also exists a metaphor for a mechanism during object-based attentional processing. Kahneman & Treisman (1984) suggested that an episodic representations of attended perceptual objects (‘object files’) are generated. These object files, like the temporary data files on a computer, can be referenced at and thus “maintain the identity and continuity of an object perceived in a particular episode” (Kahneman & Treisman, 1984, p. 54).

Space-based and object-based accounts of attention do not necessarily exclude each other. Perhaps space-based attention selects the location of a relevant object at a given time and object-based attention processes the object further. Much more could be said about further aspects and mechanisms of selective visual attention. By now it is important to understand that nature invented sophisticated mechanisms for selecting information out of a visual scene and that even simple-sounding questions such as how we are moving the attentional ‘spotlight’, are not understood sufficiently. To gain more insight into how these mechanisms work, the paradigm of visual search was extensively used to study the spatial selection of objects.

The Visual Search paradigm

As soon as we open our eyes in the morning, we start to search for objects which we are behaviorally relevant, for example, the glasses that one has left next to the bed. The visual search paradigm is a simple method to examine processes of visual attention, yet it provides a more ‘realistic’ situation than other experimental paradigms which present only one or two objects in the display.

In a visual search task, observers have to detect a target stimulus which is presented together with other, distracting, stimuli. By this means, it is possible to examine in which manner different attributes of visual objects are processed. The search efficiency, or which attributes lead to fast detection of a target stimulus, is but one of the possible issues adressed. A typical search experiment has the following pattern: Observers` task is to search for a target which is presented amongst distractors within a search display. The number of presented stimuli (i.e., the set size or display size) can vary on a trial-by-trial basis (e.g., 4, 9, or 16 stimuli). A target is presented in 50% of all trials and observers have to indicate, normally as rapidly and accurately as possible, the presence of a target by pressing one button and another one to indicate the absence of a target. Usually, the display remains on the screen until the observers respond. As the number of distracors is varied, it is possible to map the reaction times as a function of the display size. The slope of this function is a measure of search efficiency. Search rates per item (search slope) range from very fast (i.e., ~ 10 ms/item) to very slow (i.e., ~ 100 ms/item or even more). This led to a distinction between two search modes (e.g., Treisman & Gelade, 1980): parallel and serial search. Search slopes of 10 – 15 ms/item are meant to reflect a highly efficient ('parallel') search. That is, a target is found by a search mechanism which works in parallel across the visual field, leading to flat search functions. In contrast, if slopes are larger than ~10 ms/item and the search function rises linearly, it is assumed that the presented stimuli were scanned serially, item per item.

Feature Integration Theory

A theory which is based on this strict distinction between parallel and serial processing was formulated by Anne Treisman (Treisman & Gelade, 1980): Feature Integration Theory (FIT). In FIT, visual selection is assumed to be based on a two-stage processing. The first is a 'preattentive' stage of processing, by which features of an object (e.g., colour and orientation) are encoded in dimension specific modules. Such a module consists of a set of retinotopically organized feature maps signalling the presence of an object with a particular feature at a particular location in the visual field. The second stage of this object detection process involving the focusing of spatial attention on an area within a master map of locations. On this map activations from all feature maps are summed, but the attentional retrieval of the individual feature values can only take place by focusing spatial attention on a location of interest. That is, the combination of individual feature values and, thus, the complete (integrated) information of an object becomes available only at the 2nd stage of the system by focal attention. This combination of object attributes is recorded in a temporary 'object file' (c.f. object-based attention), which can be matched with an already stored object representation in memory.

If several objects are presented in a display and the target is unique and clearly distinguishable from all the others by a colour difference, for example, then only one signal is necessary from the corresponding (colour) feature map in order to detect the target. In such a 'single feature search', the target can be found very quickly. This would be reflected in flat search functions in a visual search task. By contrast, if an object can only be distinguished from all others by a combination of two or more features (e.g., colour and orientation), the search will be more time-consuming. According to FIT, such a conjunction search needs the time consuming combination of the relevant features by focal attention. That would explain steep search functions of a serial search in a visual search task.

However, FIT was challenged by findings in several studies, which showed that conjunction search did not necessarily give rise to steep search functions. That is, there are combinations of object features which lead to flat search functions, such as, shape and binocular disparity (Enns & Rensink, 1991; He & Nakayama, 1992); colour and direction of motion; binocular disparity and colour; size, spatial frequency, and contrast (Nakayama & Silverman, 1986), shape and direction of motion (McLeod, Driver, & Crisp, 1988; Kingstone & Bischof, 1999; von Mühlenen & Müller, 2000), colour and orientation (Wolfe, Cave, & Franzel, 1989; Wang, Kristjánsson, & Nakayama, 2001; Kristjánsson, Wang, & Nakayama, 2002).

These findings led to a revision of FIT (Treisman & Sato, 1990). For example, to account for top-down influences, inhibitory connections were suggested which could actively suppress activation from feature maps onto the master map corresponding to distractor stimuli, thereby making it easier for focal attention to be directed to the most promising target location on the master map.

Guided Search

Wolfe's Guided Search Theory (GST, e.g., Cave & Wolfe, 1990; Wolfe, 1994) also assumes the existence of a location-based master map, the overall map of activations. Activity on the overall map 'guides' focal attention to those locations that exhibit the highest activations. The activations are computed in two stages. In a 'bottom-up' process, saliency maps are computed on basis of feature contrasts (i.e., the difference of feature values at different locations within a feature module), separately for each dimension (e.g., colour). The more a stimulus differs in a given dimension from another stimulus, the higher is its saliency in this dimension. In a single feature search, the target differs in only one feature from all other stimuli and therefore can be selected very fast. All dimension-specific saliency values are summed up, in weighted fashion (Müller, Heller, & Ziegler, 1995), by units of the overall map of activations, and attention is directed to the highest master map activation by a winner-take-all selection process. As in FIT, feature values within the focus of attention are then integrated and build a temporary object representation for further processing. The second, top-down, process plays an important role in conjunction search. If target-defining features are known, a modulatory influence on saliency computation can be implemented by a top-down activation. This results in a higher overall activation of the relevant features and, thus, faster detection of the target. However, saliency computation is not perfect, otherwise search for conjunction targets, the features of which are known in advance, would be always very efficient, with flat search functions. However, assuming a certain degree of noise in saliency computation, the proposed mechanisms of Guided Search proved adequate in simulating empiric data of search functions. These findings and ideas led to the rejection of a strict serial/parallel dichotomy, instead, Wolfe (1998) argued in favour of a continuum of search efficiency, with search rates ranges from ‘very efficient’ (e.g., ~ 0 ms/item) to ‘inefficient’ (e.g., ~30 – 50 ms/item).

This – incomplete – overview shows that theories of visual attention not only try to explain mechanisms of object selection and identification, but also to account for a very central ‘problem’ in the field of vision science, namely: the binding problem. In Treismans´ FIT (Treisman & Gelade, 1980) and Wolfes´ GST (e.g., 1994), it is spatial attention that provides the ‘glue’ for the independently registered features of a single object. There are also completely different approaches, for example, Duncan and Humphreys´ Attentional Engagement Theory (AET, Duncan & Humphreys, 1989, 1992). AET assumes that binding, that is, the formation of ‘structural units’, occurs at a parallel-preattentive stage of processing. The following section will provide an overview of the binding problem and its possible solutions.

The Binding Problem

In the 20th century, the Gestalt psychologists (Wertheimer, 1912, 1923; Köhler, 1924; Koffka, 1935) formulated ‘laws’ of perceptual organisation. Their Gestalt principles embody the basic idea that “*The whole is more than the sum of its part*”, are constitutive for the perceptual organisation (or, respectively, grouping), and figure-ground segregation (e.g., Rubin, 1915). In order to ‘become’ an object, its parts must be organized in a meaningful way. According to Gestalt psychologist, this organizational process operates on basis of good continuation (e.g., collinearity), proximity, similarity, common fate (motion), and closure. Recently, psychologists working in Gestalt tradition formulated additional laws, for example, uniform connectedness and common region (Palmer, 1992;

Palmer & Rock, 1994; Palmer, 1999) (see Figure 1.3). After organizing the parts to a whole, the percept can be interpreted. However, this interpretation can be pushed to its limits as is attested by many optical illusions.

The structural elements of a visual object are called ‘features’, which must be ‘bound’ together to form a coherent whole (feature binding). That means that binding is an integrational process, which may work in different ways. For example, mechanism underlying the binding of objects parts (which are, for example, spatially divided through occlusion) may be different from binding mechanisms of object features which share the same location and are, nevertheless, identifiable as those features. This means that features in different dimensions (e.g., colour and orientation) of an object must also be bound together. Possible solutions of how this binding of features may be achieved, namely FIT (e.g., Treisman & Gelade, 1980) and GST (e.g., Wolfe, 1994), were already described.

The visual system can be divided into many cortical areas. It is known, for example, from neuropsychological and single-cell recording studies that different features of visual objects are detected and processed by distinct parts of the visual brain, that is distinct neuronal modules, such as motion (e.g., area MT) or colour (V4). Even within each single feature dimension (e.g., colour), particular values (e.g., blue or red) are represented by the activity of distinct groups of neurons within and across several

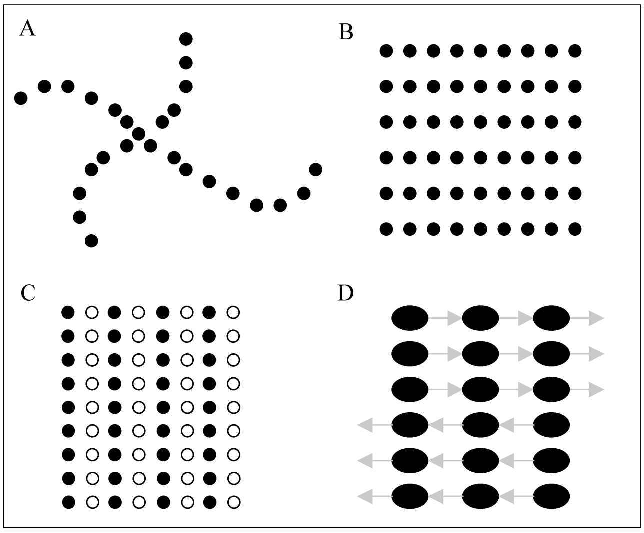

Figure 1.3: The Gestalt laws describe principles of perceptual organization. A) Good continuation B) Proximity C) Similarity D) Common fate (movement in the same direction).

stages of processing.

The ‘stream’ of visual processing has been divided into separate pathways with different functionality, the ventral What- and the dorsal Where-path (e.g., Ungerleider & Mishkin, 1982). The (infero-) temporal running What-pathway is thought to process information about the shape of an object and is therefore seen as important for object identification. The parietal Where-pathway is thought to process information about object locations, but may also be involved in providing information for motor behavior (‘how-system’, Milner & Goodale, 1995). This separate (modular) information processing shows again a need for combining (binding) the information again at some point in time. As the brain is a network with myriads of interconnections this may not happen at a certain location within the system, but through different mechanisms of ‘neuronal communication’. However, it shows also a quasi-hierarchical organization, where modules, specialized for certain feature dimensions, communicate through fibres from ‘lower’ to ‘higher’ modules (bottom-up). These connections are often bidirectional and projections can also come from the opposite direction (top-down). Much of the processing can also happen in parallel, because of interconnections of modules of the same hierarchical stage.

Evidence of separated feature processing from cognitive psychology

Assigning different attributes to the corresponding objects and, thus, providing a meaningful interpretation of the visual input is usually no problem for our brain, even when there are several objects simultaneously present. However, with very brief presentations, mis-perceptions may actually happen. Treisman and Schmidt (1982) presented letters (e.g., a red X and a blue S) for 200 ms on a monitor screen and it happened (in 39 % of all trials) that observers report a blue X or a red S. This misbinding is called an illusory conjunction. Another example is provided by a study of Prinzmetal (1981), who found that observers were more likely to form illusory conjunctions between elements within a perceptual group rather than elements that were part of separate groups. According to Treismans´ FIT, illusory conjunctions occur when selective attention cannot bind the features (in this case colour and shape) at the corresponding location together (for example, under conditions of brief presentation durations). Alternative theories of preattentive feature-conjunctions (e.g., Duncan & Humphreys, 1989) suggest that at least some forms of feature bindings occur at the parallel stage of visual coding, and that the resulting feature-ensembles compete against each other for access to a capacity-limited object-recognition stage. Evidence for the latter theory was obtained by visual search experiments, which suggest that Kanizsa-figures defined by virtual (illusory) contours of good continuation could be detected in parallel (e.g., Davis & Driver, 1994; but see Gurnsey, Poirier & Gascon, 1996).

Neurophysiological background of the binding problem

Several works could show that attributes of visual objects are processed separately. For instance, Livingstone and Hubel (1988) found out that neurons selectively respond to differential visual features.

When light comes into our visual system through the eyes, each point in the visual field corresponds to one ‘point’ on the retina. The spatial organization of information, after it left the eye via the optic nerve, at the different hierarchical stages of visual processing is roughly maintained. This is called retinotopic organization. A crucial concept in this regard is that of the classical receptive field (CRF). These fields can be described as areas, which are not only retinotopically organized, but also sensitive to certain object features (e.g., certain degrees of line orientation). At ealier stages of visual processing, the size of CRFs can be very small (e.g., V1), whereas at higher stages (e.g., IT) neurons can have receptive fields as large as a hemifield (and respond on more complex stimuli). This implies two important problems for the visual system. First, given large CRFs, two or more objects in the visual field trigger the same neuronal population. How can these be differentiated between each other? Second, with small receptive fields, big objects trigger many neurons at the same processing stage. Here, every object would have its own neuronal population, but how knows the system where one object starts and the other ends? Some mechanism is needed which can bind cells corresponding to one particular object and another which can separate them in the neuronal population with largely overlapping receptive fields.

There are indeed such mechanisms which go beyond the idea of CRFs (e.g., Lamme, 1995; Zipser, Lamme, & Schiller, 1996; Kastner, Nothdurft, & Pigarev, 1997). For example, Lamme (1995) recorded activity of neurons in the primary visual cortex of awake monkeys while presenting them an array of oriented line segments. The animals were trained to respond to a square patch which was made to perceptually pop out as a circumscribed figure by virtue of differences between the orientation within that patch and the surround. Neurons gave a significantly larger response to elements belonging to the figure than to similar elements belonging to the background. The strength of the effect had no relation with classical receptive field properties like orientation, but showed that cells within primary visual cortex respond to an evaluated perceptual context.

The underlying neurophysiology of the visual system shows us the need for binding mechanisms. Clearly, there can not be only one solution, but the integrational processes themselves must be integrated and linked together in order to become a comprehensive understanding of the processing and respresentation of visual objects.

Solutions to the binding problem

In the next section, possible solutions to the binding problem are considered, which are not mutually exclusive. Like with selective visual attention, where space-based and object-based solutions were proposed, a single solution to the binding problem may not account for all demands of feature binding or figure-ground segregation. For example, feature binding within a single dimension (e.g., two coloured object) may need other binding mechanisms than feature binding across dimensions (e.g., colour and orientation of a single object).

Convergent projections. The most straightforward idea is that incoming information is integrated and, the higher the processing stage, more and more condensed, so that, at the end, a single cell fires which would constitute the representation or recognition of an object. In this account, neurons from earlier stages in the visual stream would project onto a population with less neurons (or even only one neuron) at the next stage of processing, which are projecting their outputs onto a next (again smaller) population of neurons and so forth. That means the population of neurons at a lower stage converge their output onto less neurons at a next stage, therefore the name *convergent projections*. The more neurons are active the higher will be the activation of the subsequent neurons, as their input is summed up. If one imagines different weights for each neuronal projection (like it is done in computational accounts), it is possible to represent with such relatively simple additive processes a large amount of object feature combinations. This would imply that the higher the stage of processing the more complex the feature combinations to which neurons would respond. This is indeed the fact and they are known as complex cells or even hypercomplex cells. These cells are quite invariant with respect to the position within the visual field of the object to which they respond. This is due to the increasing size of receptive fields the higher one gets on the visual processing stream. In the extreme, the system would build up 'grand-mother' cells (Barlow, 1972), which responds exclusively to one stimulus (e.g., the grand-mother) in the visual field.

As there is evidence for highly specialized cells in the visual system (e.g., Hegdé and van Essen, 2000), this concept surely plays a role. However, this can not be the complete solution, because our brain has not enough neurons for representing all possible feature combinations we are able to perceive.

Spike-rate modulations. Thinking of neurons projecting onto others, a different approach of information differentiation may be the modulation of their output, in terms of increasing or decreasing it. Let us assume that all objects in the visual field compete against each other for getting up the ladder of visual processing stages. I already came across a mechanism which could select a single object out of many, namely selective attention (cf. section above). The role of attention as a spotlight is quite clear and easy to understand, but how would attention modify objects being 'in' the spotlight on the neurophysiological level. An account comes from Desimone and Duncan (e.g., 1995), they proposed that the competition among the objects in the visual field is 'biased' by attention.

That means, the object in the attentional spotlight gains an advantage over objects outside the spotlight. This gain comes through a (e.g., top-down) spike-rate modification of the object representing neurons. The spike rate modulations do not necessarily come from higher cognitive areas, but also from neurons at the same level. As reported above context sensitive processing can be found on levels as early as V1 (Lamme, 1995). Moreover, spike rate modulation may also come from feedback connections from later onto earlier levels of visual processing (e.g., Lamme & Roelfsema, 2000; Roelfsema, Lamme, Spekreijse, & Bosch, 2002). These modulations can not account for the figure-ground segementation, this is something which must happen before such modulations come into play. However, the important point of spike rate modulations is that processing of visual objects is made more specific, with respects to location or identity, and this reduces the possible combinations of feature binding possibilities in a visual scene.

Synchronized assemblies. The third approach is the most important for this thesis. A population of neurons is defined as a synchronized assembly on the basis of the temporal correlation of their firing (Hebb, 1949). Such ‘temporal’ groups of neurons may represent features, e.g., of a current object in the visual field. The synchronized in- and output of firing of a cell assembly provides a highly effective signal while the assembly exists. As the representation is not hard-wired this approach could account for the combinatory explosion of possible feature conjunctions. Synchrony may also be ‘tag’ which defines which neuron belongs to which assembly (e.g., Milner, 1974; von der Malsburg & Schneider, 1981, 1986). That means, problems like differentiation between two separable object at the same level of visual processing could be solved by two different synchronized cell assemblies which fire out of phase. The hypothesis of *temporal binding* states that different attributes, i.e., different features of a visual object, are bound together by means of synchronized firing of neurons which code those different object features. As the firing patterns of each cell assembly are independent from each other (e.g., by firing in another phase), they can form multiple distributed representations of feature conjunctions at the same time. The binding by synchronization can also work across large separations between cortical areas and, by this, build a bridge between modules which code different attributes. Studies on this topic could show that synchronous activity occurs preferentially with perceptual (Gestalt) laws of grouping, and that temporal binding is considered for activity within the gamma-frequency range (30 – 90 Hz; Gray, König, Engel, & Singer, 1989; Kreiter & Singer, 1996; Frien & Eckhorn, 2000; for a review: Singer, 1999; Tallon-Baudry & Bertrand, 1999). For example, Gray et al. (1989) recorded from neurons in area 17 of the cat visual cortex and found that, when receptive fields were stimulated by separate bars of light moving in opposite directions, oscillatory neural activity showed low cross-correlation. However, when bars were passed across neural receptive fields in the same direction, a correlative relationship was observed between oscillatory activity within 40 – 60-Hz frequency range. The strongest cross-correlations were obtained when two neurons were stimulated by a single bar. Using similar stimulus conditions, Gray and Singer (1989), and Brosch, Bauer, and Eckhorn, (1997) have found evidence of an oscillatory and phase-locked response across neurons within different cortical regions (areas 17 and 18 in the cat) within the 20 – 70-Hz frequency range. Furthermore, Engel, König, Kreiter, and Singer, (1991) have shown inter-hemispheric synchronized activity, which supports the binding of visual features across the visual midline.

Psychophysical approach to test the Temporal Binding Hypothesis

Several attempts have been made to examine the hypothesis of ‘temporal binding’ psychophysically (e.g., Milner, 1974; von der Malsburg, 1981), for example, by systematic variation of stimulus element synchrony and/or oscillation frequency at which stimuli were presented. Investigations of the synchronized presentation of target elements asynchronous relative to the presentation of background elements facilitates efficient target coding (Fahle & Koch, 1995; Leonards, Singer & Fahle, 1996; Blake & Yang, 1997; Kiper, Gegenfurtner & Movshon, 1996; Usher & Donnelly, 1998). For example, Leonards et al. (1997) examined the extent to which the perceptual segmentation of a subregion of a visual display might be enhanced through the presentation asynchrony of that region relative to the reminder of the display. In addition, the authors examined the interactions between presentation asynchrony and textural cues, which also defined either the same or a competing display subregion. Leonards et al. found that offset asynchronies (between figure and ground) play a role during perceptual grouping. More importantly, the studies implicate that temporal cues may be fundamentally dependent upon the relationship they exhibit with additional form-based cues for facilitation of target detection. This relationship is described as both synergistic and, if temporal and form-based cues define different figures, competitive with textural cues dominating temporal cues on grouping judgments (see also Kiper et al., 1996). However, there is also evidence that, when spatial and textural cues are controlled, temporal cues alone are able to perceptually segment a subregion of a visual display (Fahle, 1993; Blake & Yang, 1997).

The idea that neural coding mechanisms subserving stimulus binding could be entrained by external modulation is based upon evidence showing that neurons in the visual cortex can respond in a phase-locked manner to oscillatory stimulus activity. Gur and Snodderly (1997) demonstrated this with flickering LED displays and Tallon-Baudrey, Bertrand, Delpeuch, and Pernier (1996, 1997) using vertical scan rates of a raster display CRT monitor. Proceeding from this idea, Elliott and Müller (1998) have presented evidence that detection of a Kanizsa-type target figure within a matrix of (non-grouping) distractor elements is enhanced by 'synchrony priming'. Precisely, in their synchrony priming paradigm, the premask display consisted of 3×3 crosses and the target display of 3×3 matrix of 90°-corner junctions, where four of the corner junctions in one matrix quadrant could form the target figure, a Kanizsa-type square. Detection of this figure was expedited if four premask crosses were repeatedly presented together, that is, 'synchronously' (within the same display frame) at the matrix quadrant in which the target figure appeared relative to a 'random' control condition in which the preceding premask crosses at the relevant quadrant were presented asynchronously (that is, in different display frames). It is important to note that this priming effect only occured if the frame components of the premask matrix, including the frame of the four synchronous crosses (i.e., the 'synchronous premask'), are presented with a presentation frequency of 40-Hz (but also other 'preferred' gamma band frequencies: e.g., 33, 46, 53, 59, 66 Hz; Elliott & Müller, 1999, 2004).

As the synchrony priming effect was dependent on target presence, Elliott and Müller (1998) interpreted the priming as a mechanism which expedites target figure coding for later object recognition processes, without acting as a spatial-attentional cue. However, concerning the issue of spatial attention, Elliott and Müller´s evidence was only of indirect nature: there were no 'costs' relative to the random control condition when the target figure appeared in another matrix quadrant to that of the (preceding) synchronous premask. It remains, thus, unclear wether the priming is dependent on the presentation of a (subsequent) target figure which accords with a Gestalt principle (e.g., collinearity). In a further study Elliott and Müller (2000) showed that the synchronous prime had a 'life-span' of about 150 – 200 ms and was sensitive to the phase relationship between the offset of the premask relative to the onset of the target. These results were interpreted as a demonstration of the existence of a very short-term visual memory that oscillates at 40-Hz. Additionally, Elliott and Müller proposed that the pattern of 40-Hz activity extends across cortical regions. That is, the prime is generated in later stages in the visual processing stream, but becomes subsequently active in earlier mechanisms of the visual system (e.g., V1) through backpropagation of a global 40-Hz pattern. In more detail, neurons with larger receptive fields, which encompass the whole spatial extension of the premask matrix, such as cells in inferotemporal cortex (IT), entrained at the 40-Hz rhythm through integration of the single premask frame 10-Hz signals. Earlier neurons` rhythms would then be determined by both recurrent 40-Hz activity from higher visual areas and the repeated presentations of (local) premask elements at 10-Hz (Elliott & Müller, 2000, 2004).

In sum, the synchrony-priming paradigm is based on the assumption that feature coding mechanisms are entrainable by external temporal stimulus modulation and provides a method through which variations of solely temporal information can be presented, avoiding spatial attentional engagement effects that may confound the temporal information.

Chapter 2: Synopsis

One of the central problems to be solved by the (visual) brain is the integration of separately coded object features into coherent object representations. This set of questions is referred to as the 'binding problem'. A newer development is the examination of temporal factors for grouping and binding via psychophysical methods. Gestalt psychologists (e.g., Wertheimer, 1912, 1923; Köhler, 1924; Koffka, 1935) proposed that perceptual organisation and figure-ground coding are based on hard-wired, pre-attentive brain mechanisms. However, later theories developed within the information-processing approach argued that the formation of (correct) feature-object 'conjunctions' requires attention (e.g., Treisman & Gelade, 1980). According to the theory of attentional binding, a first stage of feature coding, which operates in parallel across the whole visual field and in multiple feature dimensions, is followed by the serial inspection of selected display locations a mechanism of 'focal attention'. If attention is focussed on a cluster of features, they are temporarily 'bound' into a coherent object representation (see also Crick, 1984). Further psychological investigations were inspired by single-cell studies which pointed to role of synchronized visuo-cortical cell-oscillations for feature-object binding ('temporal binding'). If feature elements were presented simultaneously and their spatial arrangement satisfied a Gestalt principle (such as collinearity), cells in the visual cortex which responded to those elements were found to adjust their firing behavior and oscillate in synchrony, without a shift in phase (e.g., Gray, König, Engel, & Singer, 1989). Several attempts were made to examine the hypothesis of 'temporal binding' (Milner, 1974; von der Malsburg, 1981; Fahle & Koch, 1995; Leonards, Singer, & Fahle, 1996; Blake & Yang, 1997; Kiper, Gegenfurtner, & Movshon, 1996). The results of these studies revealed no consistent picture of 'temporal binding' effects. However, several new experimental paradigms were devised subsequently, the results of which support the notion that feature-object binding and perceptual grouping may involve temporal coding

(Elliott & Müller, 1998; Usher & Donnelly, 1998). That is, the evidence obtained in these studies points to the possibility that perceptual organization is based on early, probably pre-attentive, stages of visual processing and that temporal coding can play a role in these organization processes.

The experiments presented in this dissertation are based on the 'synchrony priming' paradigm developed by Elliott and Müller (e.g., 1998, 2000). In this paradigm, a 40-Hz flickering (oscillating) matrix (premask) of figurally neutral premask-elements is presented, which is replaced after a certain time by a target display matrix of figure and distractor elements. Priming by solely temporal information can be achieved by presenting observers a so-called 'synchronous prime' which is embedded in the flickering matrix of premask elements. Without any phenomenal awareness of the synchronous prime responses to a following target figure are expedited relative to a baseline condition. (for a more detailed explanation of the paradigm see Figure 3.1. in the next Chapter).

This synchrony priming effect (e.g., Elliott & Müller, 1998) was subject of the present dissertation. Chapter 3 examines the relationship of spatial attention and synchrony priming by combining Elliott and Müllers` paradigm with the classical paradigm of spatial-cueing (e.g., Posner, 1978). Further, in Chapter 4, the effects of multiple synchronous primes and variations of their position in space relative to each other, but also relative to the following target, was investigated through an extension of the standard 3×3 matrix used by Elliott & Müller. Chapter 5 investigates the dependency of the synchrony priming effect on the onset of figural information by using simple dot-target stimuli, instead of Kaniszsa-type target figures, and a dot-probe technique (e.g., Kim & Cave, 1995).

Chapter 3. Elliott and Müller (1998) argued that the synchronous prime does not act as a spatial-attentional cue. However, the evidence for this argument was only of indirect nature: there were no ‘costs’ relative to the random control condition when the target figure appeared in another matrix quadrant to that of the (preceding) synchronous premask. Such costs would be expected, under certain assumptions, if the synchronous prime stimulus attracts spatial attention to its location within the display matrix. Also theoretical considerations (e.g., Crick, 1984) as well as recent neurophysiological findings (Fries, Reynolds, Rorie, & Desimone, 2001; Engel, Fries, & Singer, 2001) point to the possibility of attentional mediation, or modulation, of temporal binding processes. To examine the relationship between synchrony priming and spatial attention directly a series of five experiments combined the synchronicity-priming paradigm of Elliott and Müller (e.g., 1998, 2000, 2001) with a spatial-cueing paradigm (e.g., Posner, 1978, 1980; Müller & Rabbitt, 1989).

With symbolic central cues (endogenous attention) and long cue–target SOAs (Experiment 1), only additive effects of cueing and synchrony priming were found. That is, the synchronicity priming effect was equally large for all (neutral, valid, and invalid) cueing conditions, lending support to the notion of the pre-attentive nature of temporal binding mechanisms. Two findings of Experiment 1 suggest that this conclusion may be precipitant. First, the error data of Experiment 1 suggested that observers were biased to (mistakenly) accept target presence at the cued location. Secondly, there may have been also a ceiling effect for valid-cue trials such that the prime could have added only little to enhance. A signal-detection experiment (Experiment 2) ruled out that the synchronicity priming effects were mediated by explicit perception of the location of the prime: discrimination of the prime (location) was at chance, even when the prime was presented at the cued location.

To adress the issue that the lack of interaction between spatial cueing and synchrony priming may be due to a top-down bias (or ‘expectation’) which are likely with endogenous cues, the next experiments introduced exogenous cues to direct spatial attention and minimize such expectations (e.g., see Müller & Humphreys, 1991, who found differential bias effects between these two types of cue).

In Experiment 3 observers were presented visual cues after the flickering premask display (with a short cue-target SOA). The results revealed an interaction between Cueing and synchrony priming, suggesting that visuo-spatial attention does indeed modulate the synchronicity priming effect. However, the pattern of this modulation was somewhat counter-intuitive: the facilitatory effect of the synchronous prime was actually larger for targets at invalidly cued (relative to validly and neutrally cued) locations. In order to adress a possible confound with the additional visual information of the exogenous cue another experiment was conducted (Experiment 4) which was identical to Experiment 3 except that, instead of visual, acoustical direct cues were presented. The results showed the same pattern of results as the previous experiment. This pattern of effects is not easily consistent with the idea that visuo-spatial attention influences a relatively ‘automatic’ binding process (similar to other processes that are assumed to be pre-attentive in nature, such as target pop-out in visual search; e.g., Treisman & Gelade, 1980). Experiment 5 was designed to put cueing and synchrony priming in direct competition. In this study cue (direct visual cues as in Experiment 3) and the synchronous prime could indicate different locations relative to each other and relative to the target location. The outcome was consistent with Experiment 3 and 4. However, there was no evidence for a direct competition of cue and prime information. That is, valid-cue trials were not slowed by a ‘invalidly’ located prime.

An explanation for these results could be that cueing and synchrony priming involve largely independent processes and that their beneficial ‘outputs’ are (non-additively) combined when they point in the same (target) direction, but, on the other hand, if spatial attention is displaced, the prime can act on full strength and compensate some of the costs produced by invalid cueing. Interestingly, this works only in the described direction. Another, more likely possibility is that expedited target figure formation by synchrony priming at a non-indicated position helps to rapidly reorient attention to the primed (target) position (Elliott & Müller, 1998), provided that the cued (non-target) location can be efficiently rejected as containing the target (as a result of spatial attention being deployed there in response to the cue). In this situation, the target figure itself could become an effective ‘cue’ for reorienting attention.

Chapter 4. The study in this chapter was designed to investigate the potential role of dynamic spatial structures of multiple (dual) synchronous primes for target detection. According to a ‘recurrent model’ proposed by Elliot and Müller (2004), prime information is first generated in higher stages of the visual stream, in cortical areas with relatively large receptive fields, and subsequently backpropagated to earlier stages of visual processing in which neurons, due to their receptive field dimensions, code only smaller regions of visual space occupied by premask frame subsets, but not the entire premask display. It was the aim to examine what kinds of dynamic prime structures would be generated by presenting two primes simultaneously. In a series of four experiments the 3×3 premask (standardly used by Elliott and Müller) was extended to a 5×5 and 6×6 premask matrix, respectively. By this means, it was possible to implement varying separations the two primes could have relative to each other.

The results demonstrate that dual-prime information presented in a premask matrix flickering at 40-Hz can expedite detection of a single target in the following target matrix. Experiment 1 (5×5 matrix) showed that priming effects for dual-prime conditions were equivalent in size to the single-prime condition. The priming effects were not dependent on inter-prime distance, that is, the effects did not differ whether primes were located adjacently or spatially separated. Experiment 2 implemented a further extension of the matrix (6×6). By this way, it was possible to realize a third (the farthest) distance-between-primes condition. The results showed consistent pattern of effects with Experiment 1 for the first two distance conditions, however, the priming effects vanished in conditions in which the primes were separated by the farthest distance. It seems that primes which exceed a certain distance (here ~3° 50') lead to no facilitatory effect anymore what suggests that the two synchronous primes generate not necessarily two independent prime signals. To examine this hypothesis Experiment 3 (5×5 matrix) was conducted in which observers responded to targets appearing at locations that were between both primes. The results were that priming effects were also evident in dual prime conditions when the target was located between the two primes. Moreover, the priming effects for these ‘between-prime’ conditions were significantly larger than for ‘on-prime’ conditions. These results suggested that not two single locations are primed, but that a ‘prime field’ is generated by the two synchronous primes in which locations between the primes gain also a processing advantage. A possible confound of between-prime target locations was that in these conditions between-prime targets appeared always nearer to the central x- and y-axis than on-prime targets. To adress this issue Experiment 4 (6×6 matrix) was conducted in which targets could also appear between primes and, additionally, several conditions were implemented. The results were that the priming effects for between-prime targets were equally large for all prime distances (even the farthest), although, consistent with

Experiment 2, the farthest distance between primes produced no priming for on-prime trials. However, the pattern of results was slightly different, this time, between-prime targets produced no larger synchrony priming effects than on-prime targets.

Taken together, these pattern of results suggest that a dynamic ‘prime field’ is generated by the two synchronous primes. A possible form for such a prime field could exhibit a ‘Gaussian-type’ shape. That is, the field strength is maximal in the center position between the two primes and decreases with distance from the center. The results of Experiment 3 support this view, but also Experiments 2 and 4. The latter experiments showed that, if a target appeared on a prime separated from the second by the largest distance, no priming effects were evident (for on-prime targets), which may reflect a decrease in prime field strength. The 5×5 and 6×6 displays extended about 7.3° and 8.1° of visual angle, respectively. This matches the size of receptive fields in higher visuals areas (e.g., V3 and V4). It is also consistent with the view that the integration of dual prime signals across spatial separations is accomplished via top-down projections from higher- to lower-tier visual coding mechanisms (see also Elliott & Müller, 2000).

Chapter 5. The third study examined the nature of the synchrony priming effect with respects to what kind of information is primed. Elliott and Müller (1998) argued that the synchronous prime is location-specific, because priming effects were produced only on target present trials when the target figure follows the prime at the same location. However, the question remained wether locations within the prime ‘area’, circumscribed by the prime elements in the flickering premask, are also primed, or is the priming effect dependent on the onset of a target figure following the premask.

Like in Elliott and Müllers` study (Experiment 3, 1998) in the first experiment the premask could either contain a ‘valid‘ or ‘invalid’ prime or consisted of a random arrangement of premask elements (random baseline condition) and was split up in two major conditions. The first condition should replicate the ‘standard’ synchrony priming effect with the ‘standard’ target display, the second condition presented, instead of a Kanisza-type target figure, a figurally ‘neutral’ target dot in the middle of a matrix quadrant. By this it was possible to test wether the detection of a non-figural target within the area of prime elements is also facilitated by a synchronous prime. The results for figural targets (Kanisza-type squares) showed consistent patterns to those found by Elliott and Müller. In addition, a differential effect was found when the prime and the subsequent target figure were mislocated relative to each other. When this condition was split up in the three possible kinds of mislocation (i.e., vertical, horizontal, diagonal) the vertical-mislocated prime produced nearly equally large priming effects as in the target on-prime condition. This pattern provides perhaps more insight into possible underlying neural mechanisms. The priming seems to be dependent on the intra- and inter-hemispheric spatial relation of the target relative to the prime, which is suggestive of time-consuming synchronization processes across the corpus callosum (e.g., Engel, König, Kreiter, & Singer, 1991). In the non-figural conditions no priming effects occurred, that means the synchronous prime produced no facilitatory effects for targets appearing within the area circumscribed by the prime elements. This suggests that the priming effect is indeed dependent of the onset of a target with figural properties. However, it may be that the adequate ‘task set’ is crucial for synchrony priming to occur (e.g., Kingstone, 1992).

That means observers may need to expect a target ‘square’ to profit from a facilitatory effect at a primed location. Experiment 2 adressed this issue by introducing a dot-probe technique (e.g., Kim & Cave, 1995). Here, dot-probes, which the observers had to detect, could appear at different SOAs during premask presentation, in a secondary task participants had to discern a Kanisza-type square in a (immediately after premask offset) briefly flashed target display. By this it was also possible to test wether the priming may arise already during premask presentation. The results could show no synchrony priming effects for any dot-probe condition. This suggests that the task set may not play a crucial role for prime generation.

Experiment 3 examined whether non-figural (dot) target detection may benefit from synchrony priming if the targets positions were aligned according to the Gestalt principle of good continuation (i.e., collinearity). The results of this experiment were consistent with the first experiments and showed no evidence for synchrony priming effects when dot targets appeared between two preceding collinear prime elements.

In Experiment 4, the dot target could appear in the middle of a matrix quadrant or at collinear positions, in addition, a spatial cueing procedure (acoustic peripheral cues) was introduced to examine wether the results of the previous experiments were not simply due to a ‘ceiling effect’, that is, near-optimal task performance that is no longer modulable by experimental manipulations. The results showed indeed cueing effects for valid-cue trials, but no reliable synchrony priming effects.

A possible explanation for the latter findings is that the two or four prime elements are encoded by cells with small receptive fields, which produce ‘focal’ activity that converges only in higher areas of the visual system. This has several implications for the mechanisms generating the prime information. If higher visual areas with cells that have larger receptive fields receive the spatio-temporal structure of the flickering premask and induce coherent oscillations at lower levels of the visual system by backwards propagation (e.g., Gilbert, 1993), how can the spatial area of facilitatory activation be so location-specific? An explanation may be a process of phase shifting generated by the interaction of the bottom-up 10-Hz rhythm of synchronous premask re-presentation with the top-down 40-Hz rhythm (see Elliott & Müller, 2001). In this way, the synchronous prime will take on a 40-Hz pattern, while at the same time being temporally segmented from the non-prime premask elements.

Conclusions. The examinations of this thesis showed that synchrony priming may be a largely independent process from spatial attention. Nevertheless, it can also become an effective ‘cue’ for reorienting attention rapidly to a primed position when the attentional focus is not at the (task-) relevant location. Evidence was found that multiple synchronous primes can form a spatio-dynamic ‘prime field’ which may exhibit a ‘Gaussian-type’ shape with a maximal field strength at the center between two primes. The latter results were also consistent with a proposed recurrent model of prime generation (Elliott & Müller, 2004), in that the integration of dual prime signals across spatial separations is accomplished via top-down projections from higher- to lower-tier visual coding mechanisms. There was also some evidence that suggests priming may be dependent on the intra- and inter-hemispheric spatial relation of the target relative to the prime. Furthermore, it was found that single synchronous primes have no facilitatory effect at positions within their circumscribed area and that synchrony priming may indeed depend largely on target figure information presented after premask offset which subsequent coding is consequently expedited as already suggested by Elliott & Müller (1998).

Chapter 3: Attentional Modulation of Synchrony Priming?

Abstract

Within a 3×3 matrix of 90º corner junctions, detection of a Kanizsa-type square is facilitated when the target display is preceded by a 40-Hz flickering premask of 3×3 crosses, with four crosses synchronously oscillating at the subsequent target location. To examine whether this '*synchrony-priming*' effect is influenced by visuo-spatial attention, a spatial-cueing manipulation was introduced. Observers were presented with a cue (symbolic or direct) to indicate the likely target quadrant. Symbolic cues (long cue-target SOA) had no effect on the synchrony priming effect, suggesting the priming occurs at a stage not influenced by spatial attention. With direct cues (short cue-target SOA) the synchrony priming effect was larger for non-cued compared with cued locations. This suggests that, when the system is in a reflexive mode of spatial orienting, either the synchronous premask itself or the expedited formation of the target acts as effective 'cue' for the rapid reorientation of attention.

Theoretical Background

One of the central problems to be solved by the (visual) brain is the integration of separately coded object features into coherent object representations. This set of questions is referred to as the ‘binding problem’. There have been various approaches in Experimental Psychology that have attempted to address how this problem is solved, in particular: examination of Gestalt principles of perceptual organization, of the relationship of grouping and binding processes to mechanisms of visual attention, and of the way in which these principles and processes are implemented in the feature-object coding system. A newer development is the examination of temporal factors for grouping and binding via psychophysical methods.

In the first decades of the last century, the Gestalt psychologists (Wertheimer, 1912, 1923; Köhler, 1924; Koffka, 1935) investigated the principles that underlie perceptual organization, including grouping and figure-ground segregation (e.g., Rubin, 1915). Amongst the ‘laws’ of perceptual organisation described by the Gestalt school are grouping on basis of proximity, good continuation (e.g., collinearity), similarity, and common fate (motion). Recently, psychologists working in Gestalt tradition formulated additional laws, for example, uniform connectedness and common region (Palmer, 1992; Palmer & Rock, 1994; Palmer, 1999). There were early attempts to determine the brain mechanisms that underlie perceptual organization (e.g., Köhler, Held, & O’Connell, 1952), but these were limited by the (insufficient) knowledge about functioning of the (visual) brain available at that time. Importantly, though, the Gestalt psychologists proposed that perceptual organisation and figure-ground coding are based on hard-wired, pre-attentive brain mechanisms.

However, later theories developed within the information-processing approach argued that the formation of (correct) feature-object ‘conjunctions’ requires attention (e.g. Treisman & Gelade, 1980). According to the theory of attentional binding, a first stage of feature coding, which operates in parallel across the whole visual field and in multiple feature dimensions, is followed by the serial inspection of selected display locations a mechanism of ‘focal attention’. If attention is focussed on a cluster of features, they are temporarily ‘bound’ into a coherent object representation (see also Crick, 1984). In contrast, alternative theories of pre-attentive feature-conjunctions (e.g., Duncan & Humphreys, 1989) proposed that at least some forms of feature bindings occur at the parallel stage of visual coding, and that the resulting feature-ensembles compete with each other for access to a capacity-limited object-recognition stage. Evidence for the latter theory was provided by visual search experiments which suggested, for example, that Kanizsa figures defined by virtual (illusory) contours of good continuation could be detected in parallel (e.g., Davis & Driver, 1994; but see Gurnsey, Poirier, & Gascon, 1996; Conci, Elliott, & Müller, 2005).

Further psychological investigations were inspired by single-cell studies which pointed to role of synchronized visuo-cortical cell-oscillations for feature-object binding (‘temporal binding’). If feature elements were presented simultaneously and their spatial arrangement satisfied a Gestalt principle (such as collinearity), cells in the visual cortex which responded to those elements were found to adjust their firing behavior and oscillate in synchrony, without a shift in phase (e.g., Gray, König, Engel, & Singer, 1989). These findings were taken to indicate the critical neurophysiological correlates of perceptual grouping consist of synchronized oscillatory activity patterns which are phase-locked across (different) groups of feature-coding neurons. Several attempts were made to examine the hypothesis of ‘temporal binding’ (Milner, 1974; von der Malsburg, 1981) psychophysically, for example, by examining whether the presentation of (synchronized) target elements presented asynchronized relative to the presentation of (synchronized) background elements facilitates target coding at particular stimulus presentation frequencies (Fahle & Koch, 1995; Leonards, Singer, & Fahle, 1996; Blake & Yang, 1997; Kiper, Gegenfurtner, & Movshon, 1996). The results of these studies revealed no consistent picture of 'temporal binding' effects. However, several new experimental paradigms were devised subsequently, the results of which support the notion that feature-object binding and perceptual grouping may involve temporal coding (Elliott & Müller, 1998; Usher & Donnelly, 1998). That is, the evidence obtained in these studies points to the possibility that perceptual organization is based on early, probably pre-attentive, stages of visual processing and that temporal coding can play a role in these organization processes.

Scope of the study

The experiments presented here are based on the 'synchrony priming' paradigm developed by Elliott and Müller (e.g., 1998, 2000). In this paradigm, a flickering (oscillating) matrix (premask) of figurally neutral premask-elements is presented, which is replaced after a certain time by a matrix of figure and distractor elements (see Figure 3.1.). More precisely, in the original studies, the premask display consisted of a matrix of 3×3 crosses and the target display of a matrix of 3×3 90° (i.e., L-type) corner junctions. In the target display, four of the corner junctions in one matrix quadrant could form a to-be-detected target figure, a Kanizsa-type square (whereas the distractor junctions could not be grouped to form a closed figure). Elliott and Müller found that detection of the target figure was expedited when the four premask crosses in the matrix quadrant in which the target figure appeared later were repeatedly presented *synchronously* (i.e., within the same display frame), relative to a 'random' control condition in which the premask crosses in the relevant quadrant were presented *asynchronously* (i.e., in different display frames; not that the random premask display consisted also of one frame with four elements, which were, however, not presented within the same matrix quadrant). Importantly, this 'synchronicity priming' effect occurs only when the frame components of the premask matrix, including the frame with the four synchronous crosses (which hitherto will be referred to as '*synchronous prime*') are presented with a frequency of 40-Hz (as well as other 'preferred' gamma-band frequencies, e.g., 33, 46, 53, 59, and 66 Hz; see Elliott & Müller, 1999, 2004).

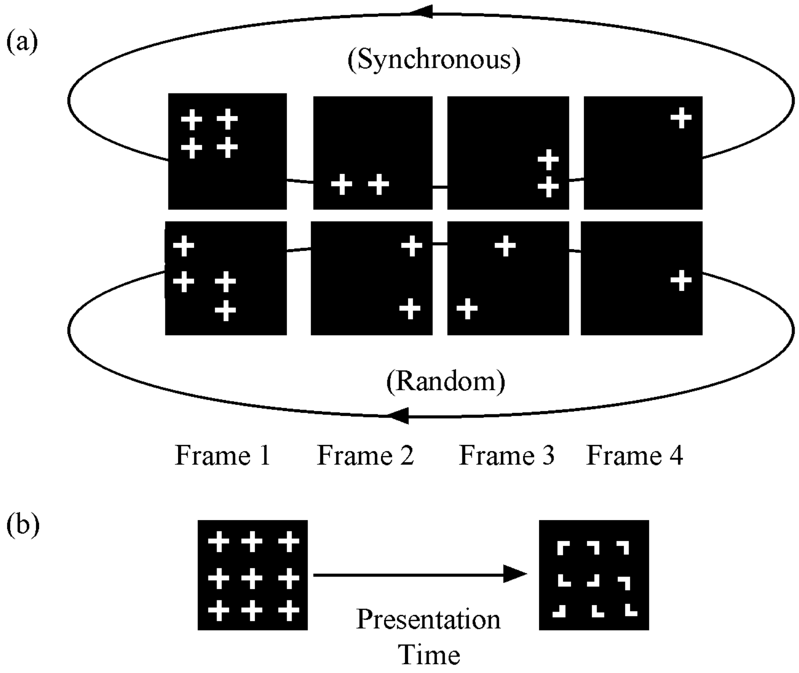

Figure 3.1: (a) Example sequence of the four premask frames in the synchronous and random conditions. The premask oscillation frequency was defined as the frequency of premask frames per second. For example, at 40-Hz, the four premask frames were presented 10 times per 1000 milliseconds, with a constant frame exposition duration of 25 ms and an inter-frame intervall of < 1ms. (b) The premask sequence was continuously repeated until the target display was presented, this induced the impression of a stochastically flickering display of nine crosses.

Two further findings of Elliott and Müller (1998) are important for the present work. (1) At a presentation frequency of 40-Hz, the synchronous prime stimulus was not explicitly perceptible by the observers, that is, premask displays containing a synchronous prime could not be discriminated above chance from ‘random’ premask displays that did not contain a synchronous prime (Elliott & Müller, 1998, Experiment 2). (2) There was some evidence that the synchronous premask stimulus does not act as a spatial-attention cue (Elliott & Müller, 1998, Experiment 3). However, this evidence was only indirect, namely: relative to the random control condition, there were no ‘costs’ (in terms of the response latencies to the target) when the target figure appeared in another matrix quadrant to that of the (preceding) synchronous prime. Such costs would be expected, under certain assumptions, if the synchronous prime stimulus attracts spatial attention to its location within the display matrix. That is: If the synchronous prime acts as a spatial-attention cue, it would be expected to attract spatial attention to the subsequent target location in the ‘valid’-cue condition (the only condition examined in Experiment 1 of Elliott & Müller, 1998), but to a non-target location in the ‘invalid’-cue condition (a condition also examined in Elliott & Müller’s Experiment 3). Now, assuming that the synchronicity priming effect results from the prior allocation of attention to the validly ‘cued’ target location, costs should be observed in the invalid-cue condition in which spatial attention is mis-directed to a non-target location, relative to the random, ‘neutral’-cue condition in which attention is assumed to be non-specifically distributed across the whole display matrix. Such costs were not observed, however.

With regard to the results of Elliott and Müller’s (1998) Experiment 3, the question remains how ‘neutral’ the random condition actually is in terms of spatial-attentional allocation. Is attention, in the random premask condition, really equally distributed across whole display? Or, alternatively, is attention attracted to the ‘gravitational’ center of the largest (i.e., 4-element) premask frame and thus systematically attracted away (at least partially) from the subsequent target location, similar to the 'invalid'-cue condition? In the latter case, no costs would be expected for the invalid condition relative to the random condition.

Experiment 3 of Elliott and Müller (1998) does not provide an answer to this question. Therefore, it cannot be ruled out that the synchronicity priming effect is attentionally mediated (whether by conscious or non-conscious attention), or at least that it is modulated by attention – which would run counter to the hypothesis of the pre-attentive nature of temporal binding processes. Indeed, theoretical considerations (e.g., Crick, 1984) as well as recent neurophysiological findings (Fries, Reynolds, Rorie, & Desimone, 2001; Engel, Fries, & Singer, 2001) point to the possibility of attentional mediation, or modulation, of temporal binding processes.

On this background, the present study was designed to address this question directly, by introducing methods of visual-attention research, in particular, '*spatial cueing*' (e.g., Posner, 1980; Müller & Rabbitt, 1989), into the synchronicity-priming paradigm. To examine whether, and to what extent, spatial attention influences synchronicity priming, the quadrant of the synchronous premask and/or the subsequent target was directly indicated by a spatial attentional cue. Either central (symbolic) cues (voluntary orienting of attention) or direct peripheral cues at the relevant display quadrant (reflexive orienting) were presented, and the cue validity – that is, the probability of a cue correctly indicating the location of the synchronous prime and/or the subsequent target – was varied systematically. By this means, it was possible to test (1) whether the synchronous prime becomes perceptible within the apparently stochastically flickering premask when spatial attention is deployed to its quadrant, and (2) whether the synchronicity priming effect is 'influenced' by the orientation of attention.

Concerning the form of such an influence, several outcomes are possible: First, there may be no influence of spatial cueing on synchronicity priming, that is, the priming effect would be as large for invalid-cue trials (target at non-cued location) as for valid-cue trials (target at cued locations). This would argue in favor of the (hypothesized) preattentive nature of temporal binding mechanisms. Second, spatial cueing may modulate the synchronicity priming effect, that is, the priming effect would be enhanced on valid- compared to invalid-cue trials, arguing in favor of an attentional influence of relatively 'automatic' binding processes (nearly all processes, which are assumed to be 'automatic', e.g., those lead to target 'pop-out' in visual feature search, are subject to such modulatory influences). Third, synchrony priming may be observed only for valid-cue trials, in which case one would conclude that the synchronous prime acts indeed as a spatial-attention cue. There would then be two theoretical alternatives: Temporal binding processes, or at least the synchronicity priming effect, could either be attentionally 'mediated' (e.g., Crick, 1984), or the synchrony priming effect could be an artefact of the prior orientation of spatial attention to the target location.

These alternatives outcomes of spatial cueing were examined in a series of five experiments.

General Method

For all five experiments, the experimental set-up and design were nearly identical; any relevant differences are reported in the corresponding method sections.

Participants. In all experiments, ten observers took part (fourteen in Experiment 4), all having normal or corrected-to-normal visual acuity. Observers were naïve as to the purpose of the experiments, and were paid at a rate of € (Euro) 8.00 per hour. The same ten observers took part in Experiments 1 and 2.

Apparatus. Event timing, data collection, and stimulus generation were controlled by a PC-compatible computer, which also controlled oscilloscopic image presentation through an Interactive Electronics Systems point plotter buffer with 8 MB frame store memory (Finley, 1985). Stimuli were presented on a 6” Tektronix 608-oscilloscope monitor equipped with a very fast-decay P15 phosphor. The use of a P15 phosphor ensured that on-screen image persistence reduced to 10% of normal image intensity within 2.8µs of image termination (Bell, 1970). The Interactive Electronics Systems point plotter buffer allowed pixels to be plotted at a rate of one pixel every microsecond. The presentation frequency of frames across the entire premask display was kept constant at 40-Hz, while the entire premask matrix, consisting of a sequence of four separate frames, was recycled at a rate of 10 repeats per second (i.e., each premask frame repeated at 10 Hz). Frames had a constant exposure duration of 25 ms and an inter-frame interval of less than 1 ms (see Figure 3.1). The continual recycling of the premask frame sequence produced the phenomenal experience of a flickering display of nine crosses, within which observers were unable to discern the structure of a given frame. Both the individual premask frames and the target display frames were presented semi-static at a fixed, 1 kHz refresh frequency.

Stimuli. In all experiments observers viewed the monitor at a distance of 57 cm (maintained via a chin rest). The experiments were conducted under controlled lighting conditions (mean screen surround luminance 0.078 cd/m^2), with stimulus luminance maintained at 0.3 cd/m^2 upon a background field of 0.075 cd/m^2. Display elements were arranged around the center of the monitor screen (see Figure 3.1). Premask crosses subtended 98′ of visual angle and exhibited horizontal and vertical separations of 2° 39′. The total 3×3 premask display matrix subtended 4° 80′ × 4° 80′ of visual angle. Premask frames could consist of 1, 2, 3, or 4 crosses presented simultaneously (Figure 3.1). Junction elements in the target display subtended 54′ of visual angle and were separated horizontally and vertically by 2° 39′. The target display subtended 4° 80′ × 4° 80′ of visual angle.

Design. In Experiments 1–4, there were three cueing conditions: neutral cues (*neutral-cue condition*), valid cues (*valid-cue condition*), and invalid cues (*invalid-cue condition*). The flickering premask matrix could either consist of one (amongst four repeated) display frame(s) with four crosses in one matrix quadrant (*synchronous premask/prime*), or the premask crosses were arranged (pseudo-) randomly across the four quadrants (with the constraint that there could not be a frame with four crosses in one quandrant; *random premask*). The target matrix could contain four junctions elements in one quadrant that formed a Kanizsa-type square (*target present*), or the junction elements were arranged such that they did not form a square (*target absent*). The target could appear in any of the four matrix quadrants. (Experiment 5 had a different design, which is described below.)

The experiments consisted of either one (Experiments 1–4) or three sessions (Experiment 5). Each session lasted about 50 minutes and was divided into 8–10 blocks trials. Each block started with 3 (unrecorded) warming-up trials, followed by the presentation of the experimental trials. The blocks were separated by short breaks. Prior to each experiment, observers were familiarized with the task in one practice block of trials (data not recorded).

Experiment 1

Experiment 1 was designed to examine the influence of visuo-spatial attention on synchronicity priming. Prior to the premask and target displays, observers were presented with a central (‘endogenous’) arrow cue which pointed to one of the four possible quadrants in which the synchronous prime and, subsequently, the target were likely to presented later (see Figure 3.2). The validity of the cue was 80%, with validity referring jointly to the target and the prime location (even though observers have no conscious perception of the prime under with the 40-Hz premask presentation frequency; Elliott & Müller, 1998). That is, on valid- and invalid-cue trials, the cue was valid and, respectively, invalid for both the prime and the target location (primes and targets were always presented at the same location). In the neutral-cue condition, observers were presented with a fixation cross (instead of the central arrow cue), which provided no information as to where the prime and the target were likely to appear. If the spatial cueing procedure is effective, one would expect the classical pattern of spatial cueing effects: ‘benefits’ for valid-cue trials and ‘costs’ for invalid-cue trials relative to the neutral-cue baseline (e.g., Posner, 1980), to be replicated. Furthermore, and most importantly, if visuo-spatial attention has an influence on synchronicity priming, one would expect detection of a Kanizsa-type target square to be expedited (i.e., the synchronicity priming effect to be enhanced) on valid-cue trials relative to the neutral cueing condition. The relevant finding would become manifest in terms of an interaction between premask condition (synchronous vs. random) and cueing condition (valid vs. neutral). This would be consistent with studies (Fries et al., 2001; Engel et al., 2001) which have shown that visuo-spatial attention can influence the synchronous firing of neuronal assemblies, which is thought to mediate the binding of object features.

Method

Stimuli. The endogenous cues were realized as follows (see Figure 3.2): the neutral cue was a fixations cross presented in the center of the screen (*neutral-cue condition*), a valid cue was an central arrow pointing to the quadrant in which the prime and the target were likely to appear (*valid-cue condition*), and an invalid cue was an central arrow pointing to a quadrant in which the prime and the target did not appear later (*invalid cue condition*).

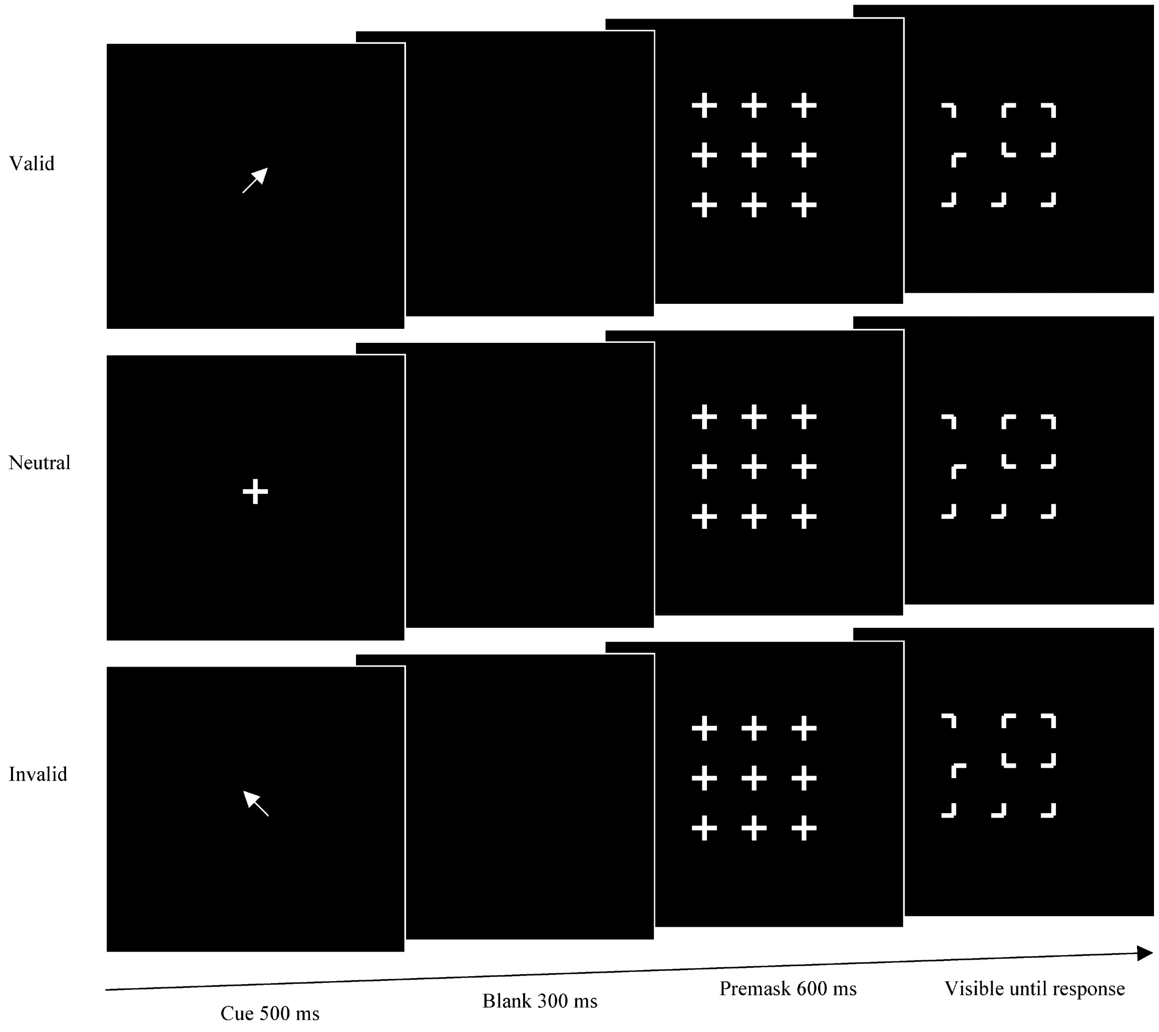

Figure 3.2: Example trials of Experiment 1. The upper row shows a valid-cue trial, the middle row a neutral-cue trials, and the lower row a invalid-cue trial.

Procedure. At the beginning of each trial, a fixation cross (neutral-cue condition) or an arrow pointing to one of the four quadrants (valid- and invalid-cue conditions) was presented in the center of the screen for 500 ms. Then, after a 300-ms blank-screen interval, the flickering matrix of premask crosses was presented for 600 ms. Directly following the offset of the premask matrix, the target display matrix of 90° corner junctions was presented – and observers had to discern, as rapidly and accurately as possible, the presence or absence of a target Kanizsa-type square within this matrix (pressing one of two buttons with their right or the left index finger to indicate target presence or absence, respectively). The target display remained in view until the response had been made. The response was followed by a blank screen for 1000 ms, after which the next trial display was presented. Observers were told to fixate the center of the display and avoid eye movements during premask display presentation. In case of an erroneous response, feedback was provided in the form of a (300-ms) 400-Hz computer-generated tone.

The experiment consisted of 900 experimental trials, of which 544 were target-present trials (60% of the trials) and 356 target-absent trials (40% of the trials). The target-present trials consisted of 272 trials with a synchronous-premask and 272 trials with a random-premask display. Each of the premask conditions was subdivided into 130 trials for the neutral-cue condition, 112 trials for the valid-cue condition, and 30 trials for the invalid-cue condition. All these different types of trial were presented in randomized order within blocks of trials.

Results

RT analysis. RTs on trials on which a response error was made (3.23% of all trials), extreme RTs (< 150 ms and > 1500 ms), and RTs 2.5 standard deviations above or below the mean for each individual observer (2.38% of all trials) were removed from the data prior to RT analysis. Figure 3.3 presents the correct mean RTs (and their associated standard errors [SE mean]) as a function of Cueing (neutral, valid, invalid) x Synchrony (random, synchronous) x Target (present, absent) condition. The data were examined in two stages: by a two-way repeated-measures ANOVA of the target-present RTs only, with main terms of Cueing and Synchrony, and a three-way repeated-measures ANOVA of both the target-present and the target-absent data, with an additional main term for Target, but excluding the invalid-cue condition. Note that, by definition, there was neither a valid- nor an invalid-cue condition for target-absent trials. For the sake of analysis, target-absent trials preceded by an arrow cue were classified as 'valid-cue' trials (since most 'cued' target-present trials were of the valid-cue type).

Target-present RTs were faster for valid-cue relative to neutral-cue trials, and slower for invalid-cued trials (RTs and associated standard errors [SE mean]: 490 [25] vs. 535 [24] vs. 572 [28] ms), F(1.023, 9.205) = 16.314, $p < .01$ (Greenhouse-Geisser corrected degrees of freedom [G-G]). There was also a main effect for Synchrony: under all cueing conditions, target present RTs were significantly enhanced on synchronous-premask relative to random premask trials (mean enhancement of 19 [3] ms for valid-cue trials, 16 [3] ms for neutral-cue trials, and 20 [5] ms for invalid-cue trials), F(1, 9) = 57.772, $p < .001$. However, the Cue x Synchrony interaction was not significant, F(2, 18) = 0.299.

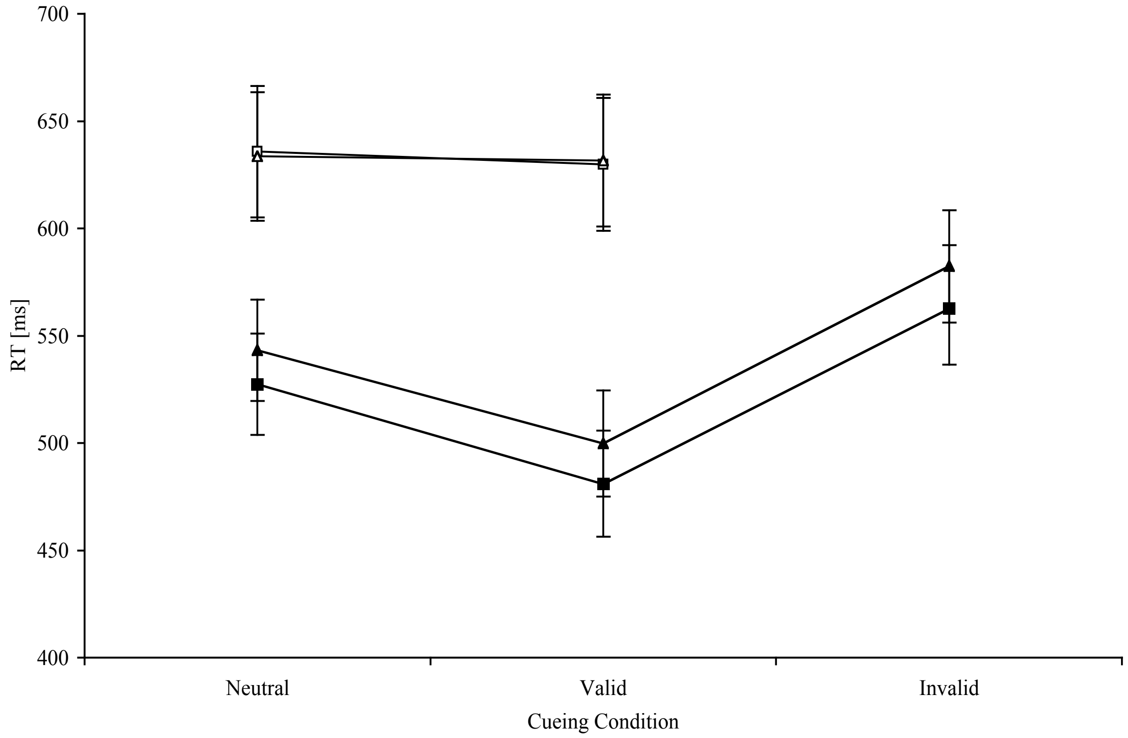

Figure 3.3: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Cueing (neutral, valid, invalid) x Synchrony (random, synchronous premask) x Target (present, absent) condition. Squares represent synchronous-premask, triangles random-premask trials. Filled symbols show target-present, open symbols target-absent RTs.

The second ANOVA, with the additional term Target, revealed main effects for Cueing, F(1, 9) = 9,49, p < .02, and Synchrony, F(1, 9) = 24.951, p < .01. Target-absent RTs were slower than target-present RTs (632 [30] vs. 512 [24] ms), F(1, 9) = 171.870, p < .001, consistent with the task involving a component of visual search. In agreement with Elliott and Müller (1998, Experiments 1 and 3), the ANOVA revealed a significant synchronicity priming effect solely for target-present trials (mean enhancement of 17 [2] ms for target-present trials, as compared to –0.04 [2] ms for target-absent trials), Synchrony x Target interaction, F(1, 9) = 77.872, p < .001. The Cueing x Target interaction was also significant, F(1, 9) = 36.194, p < .001, indicating that there was a cueing effect only for target-present trials (mean cueing effect for valid-cue trials of 45 [11] ms for target-present trials, as compared to 4 [6] ms for target-absent trials). The

Cueing x Synchrony and Cueing x Synchrony x Target interaction was not significant, F(1, 9) = 0.711 and F(1, 9) = 0.090, respectively. Figure 3.4 shows the mean priming effects in milliseconds (and their associated standard errors [SE mean]) for target-present and target-absent trials, as a function of the cueing condition.

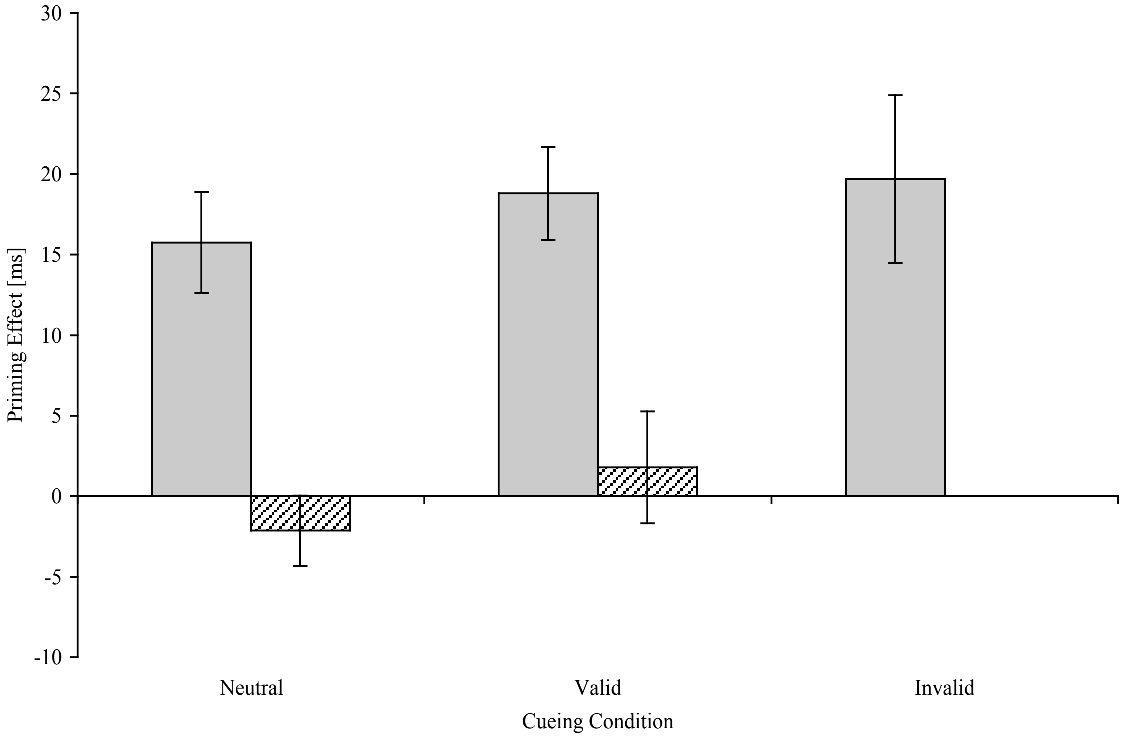

Figure 3.4: Mean priming effects (and their associated standard errors [SE mean]). Grey bars show effects for target-resent trials, shaded bars for target-sent trials.

Error analysis. The error scores are presented in Figure 3.5. The overall error rates were 1.97% misses (target-present trials) and 1.27% false alarms (target-absent trials). The arc-sine transformed error data were analysed by two ANOVAs, with the same terms as for the ANOVAs of the RT data. There was no significant effect for Synchrony, F(1, 9) = 1.530, but a significant main effect for Cueing, F(1.165, 10.486) = 8.414, $p < .02$ (G-G). The Cueing x Synchrony interaction was not significant, F(2, 18) = 0.563. Multiple comparisons for the factor Cueing revealed that more errors were made in the invalid condition relative to the two other cueing conditions (9.50 [3.4]% vs. 3.19 [0.7]% vs. 1.65 [0.7]%, for invalid, neutral, and valid conditions, respectively [p < .05, Bonferroni adjusted]).

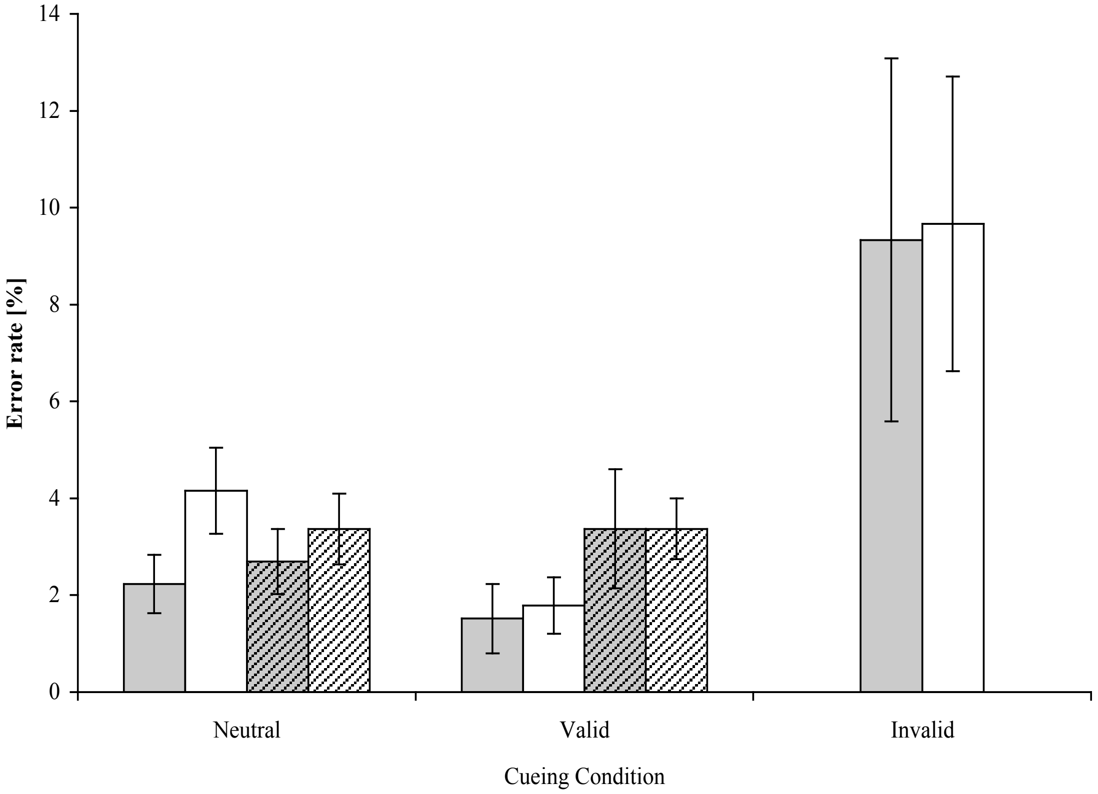

Figure 3.5: Mean error rates (and their associated standard errors [SE mean]) for target-present (non-shaded bars) and target-absent trials (shaded bars). Grey bars show error rates for synchronous-premask trials, white bars for random-premask trials, separately for the various cueing conditions (neutral, valid, invalid).

The second ANOVA with the additional term Target revealed no significant effect for Cueing, F(1, 9) = 2.224 (as the invalid-cue condition in which most errors were made was excluded from this analysis). However, there were significant main effects for Synchrony, F(1, 9) = 9.807, p < .02, indicating that fewer errors were made in the synchronous-, relative to the random-, premask condition (2.45 [0.8]% vs. 3.17 [0.7]%), and for Target, F(1, 9) = 6.292, p < .04, indicating that observers produced more false alarms (target-absent trials) than misses (target-present trials) (2.42 [0.7]% vs. 3.20 [0.82]%). The Cueing x Synchrony, Cueing x Target, Synchrony x Target, and Cueing x Synchrony x Target interactions were not significant, F(1, 9) = 1.460, F(1, 9) = 2.164, F(1, 9) = 0.483, and F(1, 9) = 0.750, respectively.

Discussion

By introducing a central spatial cue, an arrow that pointed to one of the four possible quadrants in which the Kanizsa-type target square could appear, the influence of endogenous spatial-attentional orienting on synchronicity priming was examined. If the endogenous orientation of spatial attention had an effect on the priming, one would have expected an interaction between Cueing (valid, neutral, invalid conditions) and Synchrony (random, synchronous-premask conditions). However, the results clearly showed an additive pattern of Cueing and Synchrony effects: the priming (i.e., the facilitation for targets presented at the location of a synchronous prime, relative to the random condition) was evident and of equivalent magnitude in all cueing conditions. This was the case despite the fact that the spatial-cueing procedure was effective: target detection RTs were fastest in the valid-cue condition, intermediate in the neutral-cue condition, and slowest in the invalid-cue condition. This pattern of effects could be taken to indicate that, although visuo-spatial attention was directed to the indicated quadrant, it had no effect on synchronicity priming – that is, the priming effect is pre-attentive, independent of the deployment of spatial attention.

However, when attention is directed endogenously to a particular location (at which the target is likely to appear), it may be hard to reject an invalidly cued location as not containing a target, because of a top-down bias which ‘expects’ the target at the cued location; that is, there may be a tendency to mistake a part-figure presented at the cued location for the target, and it consequently becomes harder to exclude the partial figure at this location from the competition for target selection (see, e.g., Müller & Humphreys, 1991, who found differential signal detection 'bias' effects between central and peripheral spatial cues). The higher error (i.e., miss) rates on invalid trials are consistent with this interpretation, namely, that the spatial cueing had an effect on observers' expectations not just about the likely target location, but also the target figure at this location. Nevertheless, a target at an invalidly cued location was selected faster when it was preceded by a synchronous prime than when it was not. This indicates that, although top-down spatial and figural biases may be confounding any differential synchronicity priming effects between validly and invalidly cued targets, there is priming for non-cued locations – which argues that priming is not strictly 'mediated' by spatial attention. In fact, assuming that, with endogenous cues, detection of an invalidly cued target is delayed due to focal attention remaining engaged at the cued location due to a figural bias for the target appearing there, Experiment 1 may have actually underestimated the 'true' priming effect for invalidly cued locations unconfounded by such biases (i.e., the true priming effect may be greater for invalidly than for validly cued locations).

On the other hand, the cue in Experiment 1 was presented for 500 ms, followed by a cue–premask interval of 300 ms and, subsequently, the presentation of the premask display for 600 ms, so that observers had more than enough time to direct attention to the indicated quadrant. It can not be excluded, therefore, that the priming effect achievable for the cued location was limited by a ceiling effect, that is, target detection could not be expedited beyond the limit reached in the valid-cue condition (in this scenario, the true priming effect may be larger for validly than for invalidly cued locations, indicative of a 'modulation' of priming by spatial attention). Such a scenario may be even more likely if the synchronous prime becomes explicitly visible to the observers when the prime quadrant is cued in advance (valid-cue trials in Experiment 1). To rule out the latter possibility, a signal detection experiment was conducted, similar to Experiment 2 of Elliott and Müller (1998), which was designed to examine whether the prime would become discernible when spatial attention is deployed to its location within the premask matrix.

Experiment 2

Experiment 2 used a signal-detection approach to examine whether the synchronous prime becomes consciously perceptible for observers when they are presented with a central arrow cue pointing to the prime location (which could, in turn, reinforce the building up of a top-down expectation about both the target location and the target figure). The stimuli were identical to those in Experiment 1 (see Figure 3.2 above). The difference was that, instead of a target-present/absent response, observers had to indicate, by pressing one of four possible keyboard buttons, whether they did or did not 'see' a synchronous prime within the premask matrix. One of two buttons were to be pressed if they saw the prime ('certain yes', 'uncertain yes'), and one of two different buttons if they did not see a prime ('uncertain no', 'certain no'). In case one of the prime-present buttons was pressed, observers needed to press again one of the four buttons to indicate in which quadrant they had seen the prime. This was to examine whether observers were able not simply to detect, but also to correctly localise the prime (see, e.g., Müller & Findlay, 1987, for the logic of this approach).

Method

Procedure. Half the observers performed Experiment 2 prior to Experiment 1, and half after Experiment 1. The stimuli were the same as in Experiment 1; however, there was never a target in the (‘target’) display of 90° corner junctions that replaced the premask matrix of crosses. The premask display contained a synchronous prime (i.e., four crosses synchronously presented within the same matrix quadrant) on about 50% of the trials. Observers were told to fixate the display center and avoid eye movements during premask display presentation. Upon termination of the premask matrix and the onset of the ‘target’ display, observers were asked to produce a 4-alternative forced-choice response. They had to press one of the following keys on the keyboard: F, V, J, or N. They were instructed to press the F key when they were certain they had seen a prime in the premask matrix and the V key when they were uncertain, but had a feeling that had been prime in the matrix. Further, they were to press the J and N key for certain- and uncertain-absent responses, respectively. In case observers pressed one of the positive-response keys (F or V), they were instructed to again press one of four keys to indicate in which quadrant they a seen the prime (the layout of the four keys on the keyboard matches the topography of the four display quadrants: F=upper left, V=lower left, J=upper right, N=lower right). The ‘target’ display remained in view until the response(s) had been made. Note that observers were instructed to respond as accurately as possible, without any speed pressure. No feedback was provided in case of an erroneous response. After the response(s), there was an interval of 1000 ms, until the start of the next trial.

552 experimental trials were presented in Experiment 2. The neutral-cue condition consisted of 138 trials with a random-premask display and 120 with a synchronous-premask display; the arrow cue condition consisted of 138 random-premask trials, 120 valid-cue synchronous-premask trials, and 36 invalid-cue synchronous-premask trials

(note that, here, cue validity refers to the location of the synchronous prime only). Thus, overall, there were 276 synchronous-premask trials and 276 random-premask trials. All types of trial were presented in randomized order within blocks of trials.

Results

For all cueing conditions, the signal detection sensitivity parameter A_z was derived from the detection and localization judgments, using the maximum-likelihood (ML) estimation procedure for rating method data developed by Dorfman and Alf (1969). The A_z value is an estimate of the area under the Receiver Operating Characteristic (ROC) curve, based on the ML fit of the curvilinear function through the points of the empirical ROC curve. This area ranges from 0.5 (signal is indistinguishable from noise) to 1.0 (signal is always detected). The analysis of the signal detection data was conducted in two stages. First, the localization responses were ignored; that is, detection responses were accepted as hits if the prime present-absent responses were correct. In the second stage, detection responses were accepted as hits only if both the detection and the localization responses were correct.

Tables 3.1, 3.2, and 3.3 present the A_z values for the detection data (D) and for the detection-plus-localization data (D-L) for each observer, separately for each cueing condition (neutral, valid, invalid). For all three cueing conditions, the average A_z scores for detection responses were tested against random-guessing level (i.e., $A_z = 0.5$) (Table 3.4). The planned t-tests revealed the mean sensitivity to be slightly above chance level for neutral-cue trials ($A_z = 0.537$, SE mean = 0.0128), $t(9) = 2.919$, $p < .05$, and for valid-cue trials ($A_z = 0.539$, SE mean = 0.0143), $t(9) = 2.750$, $p < .05$. For invalid-cue trials, sensitivity was at chance ($A_z = 0.501$, SE mean = 0.0521). However, one-way repeated-measures ANOVA failed to reveal a significant effect, $F(1.152, 10.370) = 0.498$ (G-G), so that there are no reliable differences between the three cueing conditions. To test sensitivity on an individual basis, the 95% confidence intervals were calculated for each individual observer score (based on the ML variability estimates) for detection responses. None of the observers' scores were significantly different from chance.

The analysis of the detection-plus-localization data revealed a slightly different picture: here, to planned t-tests failed to reveal above-chance sensitivity for any of the three cueing conditions (A_z = 0.447 [SE mean = 0.0300], A_z = 0.483 [SE mean = 0.0225], A_z = 0.453 [SE mean = 0.0519] for neutral, valid, and invalid conditions, respectively; t(9) = -1.751, t(9) = -0.763, and t(9) = -.903, respectively. Again, a one-way repeated-measures ANOVA failed to reveal any reliable difference among the three cueing conditions, F(1.255, 11.291) = 0.492 (G-G). Examined on an individual basis, only one observer showed a detection-plus-localization performance that was significantly below chance, namely, for invalid-cue trials (Observer 1, A_z = 0.071, SE mean = 0,0074, $p < 0.05$); however, this observers showed a very low performance in all cueing condition.

Table 3.1: Detection and joint Detection-plus-Localization Sensitivity: A_z values for each observer under neutral cueing conditions.

Neutral Cueing Condition				
	Detection		Detection + Localization	
Observer	A_z	SE mean	A_z	SE mean
1	0.493	0.0050	0.271	0.0153
2	0.474	0.0019	0.378	0.0081
3	0.518	0.0013	0.353	0.0068
4	0.507	0.0005	0.557	0.0042
5	0.521	0.0011	0.444	0.0033
6	0.582	0.0055	0.556	0.0037
7	0.588	0.0050	0.500	0.0001
8	0.579	0.0046	0.498	0.0001
9	0.567	0.0044	0.400	0.0067
10	0.545	0.0017	0.515	0.0008

Table 3.2: Detection and joint Detection-plus-Localization Sensitivity: A_z values for each observer under valid cueing conditions.

Valid Cueing Condition				
	Detection		Detection + Localization	
Observer	A_z	SE mean	A_z	SE mean
1	0.532	0.0025	0.357	0.0095
2	0.496	0.0003	0.449	0.0038
3	0.547	0.0043	0.518	0.0015
4	0.507	0.0008	0.489	0.0008
5	0.574	0.0045	0.560	0.0037
6	0.600	0.0071	0.525	0.0017
7	0.467	0.0020	0.386	0.0073
8	0.596	0.0062	0.543	0.0032
9	0.505	0.0004	0.445	0.0040
10	0.570	0.0039	0.556	0.0032

Table 3.3: Detection and joint Detection-plus-Localization Sensitivity: A_z values for each observer under invalid cueing conditions. A_z values significantly above chance are marked by * for $p < .05$.

Invalid Cueing Condition				
	Detection		Detection + Localization	
Observer	A_z	SE mean	A_z	SE mean
1	0.173	0.0130	0.071*	0.0074
2	0.551	0.0062	0.500	0.0001
3	0.308	0.0185	0.347	0.0173
4	0.685	0.0186	0.685	0.0140
5	0.409	0.0079	0.416	0.0057
6	0.583	0.0075	0.527	0.0037
7	0.474	0.0023	0.592	0.0066
8	0.556	0.0053	0.457	0.0051
9	0.572	0.0067	0.501	0.0001
10	0.700	0.0114	0.435	0.0077

Table 3.4: Detection and joint Detection-plus-Localization: Mean Sensitivity (A_z values) each cueing condition (neutral, valid, invalid). A_z values significantly above chance are marked by * for $p < .05$.

	Detection		Detection + Localization	
Neutral	0.537*	0.1281	0.447	0.3005
Valid	0.539*	0.1433	0.483	0.0225
Invalid	0.501	0.0521	0.453	0.0519

Discussion

The results of Experiment 2 suggest that the observers were unable to explicitly discern the presence of synchronous prime in the premask display matrix. Although some of the detection-only scores tended to be slightly above chance, this 'sensitivity' vanished when the localization perfomance was taken into account. Thus, although observers may have shown some, albeit severely limited, sensitivity in terms of detecting the presence of a synchronous prime (at validly and neutrally cued locations) in the display, their sensitivity in identifying the precise prime location was a chance levels, even for valid cues. [The decrease in sensitivity from detection to detection-plus-localization performance was due to observers displaying a tendency to falsely 'see' a prime at the cued location; i.e., the detection 'sensitivity' measure is confounded by a bias effect (see Müller & Findlay, 1987, and Müller & Humphreys, 1991).] With regard to the outcome of Experiment 1, this implies that the presentation of an endogenous spatial cue prior to the premask display, indicating the possible quadrant of the synchronous prime, did not lead to the conscious perception of the embedded stimulus. This finding of zero detection-plus-localization sensitivity replicates the results of Elliott and Müller (1998, Experiment 2), whose observers were unable to detect the synchronous prime in a non-cueing experiment (also with 40-Hz premask presentation frequency). The detection-plus-localization performance suggests that, in case of a correct prime-present response, observers could not reliably discern the quadrant of the prime. In other words, the arrow cue led observers to build up a top-down bias ('expectancy') such that they tended to judge the presence of a prime more liberally for the cued location. Because observers in Experiment 1 only responded to the presence of a target (as rapidly as possible), it cannot be ruled out that a similar top-down bias influenced the pattern of RT effects.

Experiment 3

The results of Experiment 1 suggest that endogenous cues do not have a differential effect on synchronicity priming for valid-cue relative to neutral- and invalid-cue conditions. However, with the results of Experiment 2 in mind, the lack of an interaction between spatial cueing and synchrony priming may be due to a top-down bias (or ‘expectation’) that makes the system tend to mistake a non- or part-figure at the cued location for a target (recall the increased miss rates for invalidly cued targets in Experiment 1). Such a bias may well have concealed a ‘true’ interaction between spatial cueing and synchrony priming. However, such biases may be more likely with endogenous (symbolic, central) than with exogenous (direct, peripheral) cues (e.g., see Müller & Humphreys, 1991, who found differential bias effects between these two types of cue). This leaves the possibility an interaction between spatial cueing and synchrony priming is revealed when spatial-attentional orienting is triggered by exogenous cues. Consequently, Experiment 3 was designed to examine the influence of exogenous cues on synchrony priming. Further, in order to minimize the development of explicit target ‘expectations’ on a trial, the stimulus onset asynchrony (SOA) between the exogenous cue and the target (display) was set to 100 ms (compared to an SOA of 1800 ms in Experiment 1). In more detail, the exogenous cue was presented immediately after the offset of the premask matrix of flickering crosses (Figure 3.6), which did or did not contain a synchronous prime. On valid- and invalid-cue trials, the cue consisted of a brief (25-ms) presentation of four bright crosses within the quadrant where a Kanizsa-type square was likely to appear in the target display matrix (which was presented 75 ms post cue offset). On neutral-cue trials, the cue consisted of four crosses at the corners of the display matrix.

Note that, in contrast to endogenous cues (‘voluntary orienting’ of attention), exogenous cues develop their effect faster, within 100 ms of their onset, and cannot be easily ignored (‘reflexive orienting’; e.g., Cheal & Lyon, 1991; Jonides, 1981; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Weichselgartner & Sperling, 1987). In addition, with short cue–target SOAs (100 ms in Experiment 3), overt eye movements to the cued location can be minimized. [Saccadic eye movements, or even slow drifts of fixation (Müller & Findlay, 1987; Rolfs, Engbert, & Kliegl, 2005; Laubrock, Engbert, & Kliegl, 2005), to the cued location prior to the presentation of the target display could have been a problem in Experiment 1, in which there was a temporal gap of 900 ms between cue offset and target display onset.] Finally, as already stated, with short cue-target SOAs, observers are unlikely to have the time for developing explicit target ‘expectations’ prior to target display onset. For these reasons, exogenous cueing and a 100-ms cue–target SOA were used in Experiment 3.

Note that the cues in Experiment 3 were presented after premask matrix offset (rather than before premask matrix onset, as in Experiment 1). This means that there was a (100-ms) gap between the offset of the premask display (the first 25 ms of which were occupied by the cue) and the onset of the target display. This was not considered a problem because Elliott and Müller (2000) had shown that, once entrained, the synchronous prime has a lifetime (‘peristence’) of about 150 ms beyond premask offset. Finally, by presenting the cue after premask matrix offset, it became possible to look for any interactions between spatial cueing and synchronicity priming unconfounded by spatial-attentional processing of the premask display.

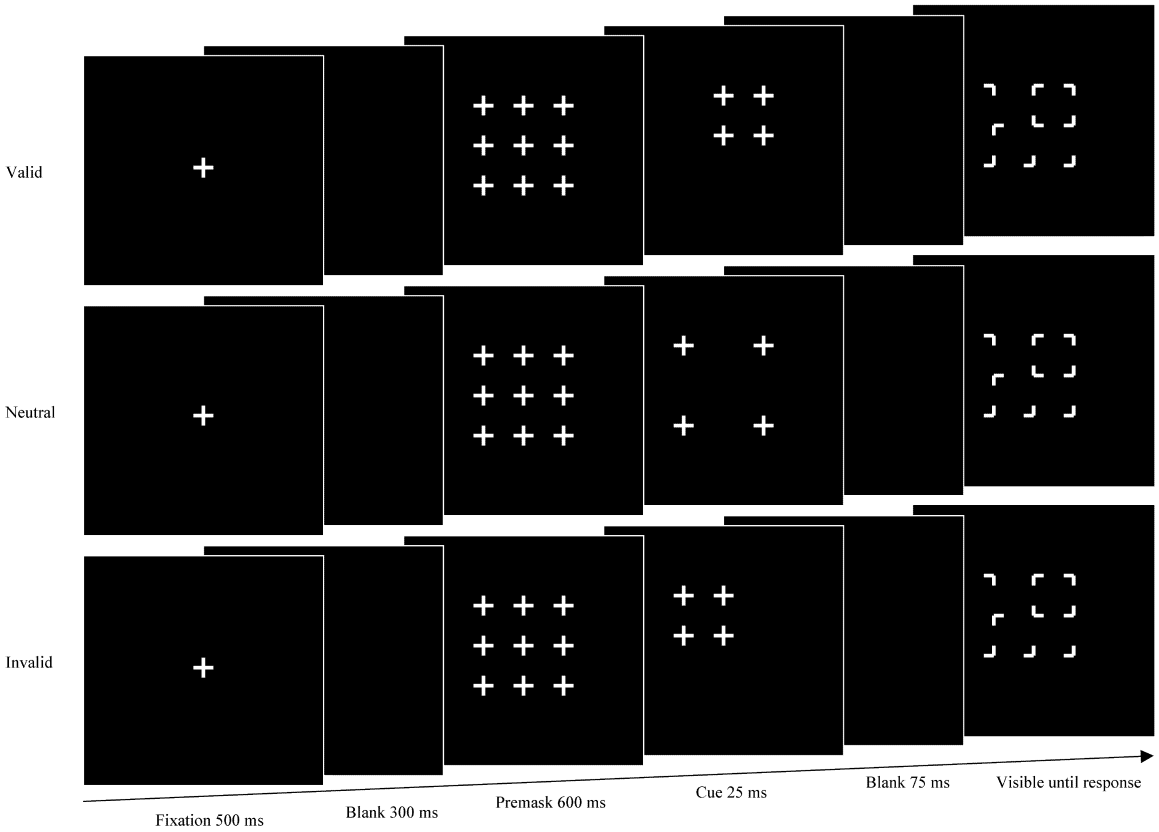

Figure 3.6: Example trials of Experiment 3. The upper row shows a valid-cue trial, the middle row a neutral-cue trials, and the lower row a invalid-cue trial.In this Experiment a peripheral visual cue flashed up for 25 ms.

Method

Stimuli. The stimuli were the same as in Experiments 1 and 2, with the difference that direct/exogenous (instead of symbolic/endogenous) cues were presented after the offset (rather than prior to the onset) of the premask matrix. Valid and invalid cues consisted of four ‘premask’ crosses presented briefly in one of the (at that time empty) matrix quadrants (Figure 3.6); that is, effectively a ‘brightening’ of the four points marking the quadrant where the following target was likely to appear. In the neutral-cue condition, the four crosses at the corners of the premask matrix were briefly brightened, providing observers with no information as to the likely target quadrant. The four cue crosses were presented for 25 ms (i.e., the same same duration as one premask frame), with luminance increased by 50% (~ 4.5 cd/m^2) to ensure that observers consciously perceived the cue.

Procedure. See Figure 3.6. At the beginning of each trial, a fixation cross was presented in the center of the screen for 500 ms. After a 300-ms blank screen, the flickering matrix of premask crosses was presented for 600 ms. Immediately following the offset of the premask display, the cue (four crosses) was displayed for 25 ms. Then, 100 ms after premask offset (or, respectively, cue onset), the target display matrix (of 90° corner junctions) appeared – and observers had to detect, as rapidly and accurately as possible, the presence or absence of a target Kanizsa-type square within this matrix. As in Experiment 1, observers were told to fixate the center of the display and avoid eye movements during premask display presentation. (All other procedural details were as in Experiment 1.)

Experiment 3 consisted of 900 experimental trials, 544 target-present and 356 target-absent trials (60% and 40% of the trials, respectively). Target-present trials consisted of 272 trials with a synchronous premask and 272 trials with a random premask. Each of the premask conditions was subdivided into 130 neutral-cue trials, 112 valid-cue trials, and 30 invalid-cue trials (giving a cue validity of 80%). All types of trials were presented in randomised order within trial blocks.

Results

RT analysis. RTs on trials on which a response error was made (2.99% of all trials), extreme RTs (< 150 ms and > 1500 ms), and RTs 2.5 standard deviations above or below the mean for each individual observer (3.44% of all trials) were removed from the data prior to RT analysis. Figure 3.7 presents the correct mean RTs (and their associated standard errors [SE mean]) as a function of Cueing (neutral, valid, invalid) x Synchrony (random, synchronous premask) x Target (present, absent) condition. The data were examined in two stages: by a two-way ANOVA of the target-present data only, with main terms of Cueing and Synchrony; followed by a three-way ANOVA of corresponding target-present and target-absent data, with an additional main term for Target, and excluding the invalid-cue condition (see Experiment 1 above for the rationale of this procedure).

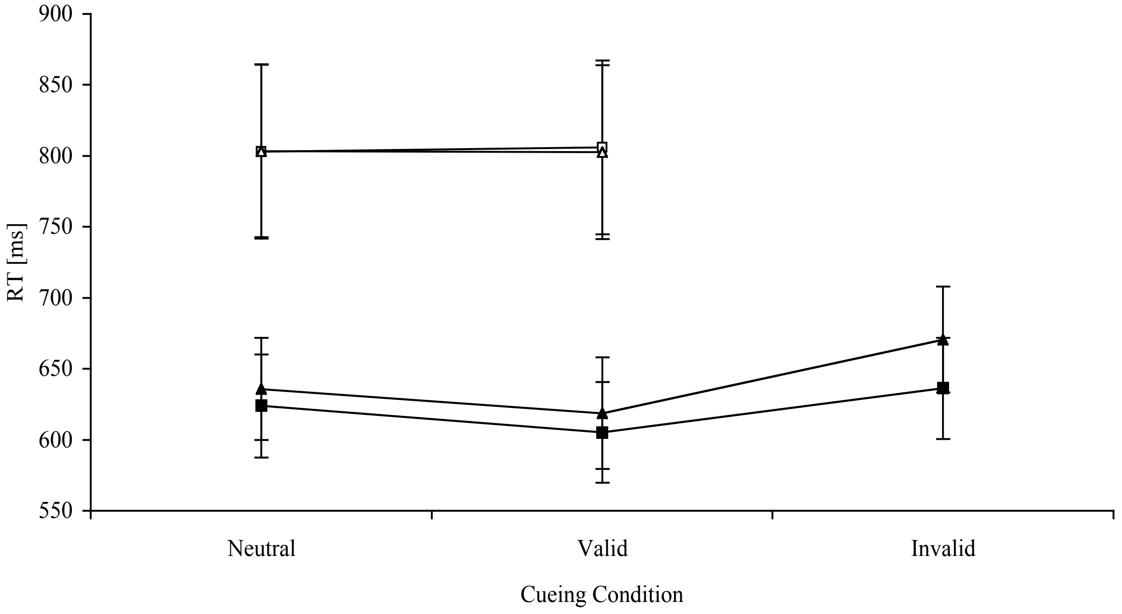

Figure 3.7: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Cueing (neutral, valid, invalid) x Synchrony (random, synchronous premask) x Target (present, absent) condition. Squares represent synchronous-premask, triangles random-premask trials. Filled symbols show target-present, open symbols target-absent RTs.

RTs were faster for valid-cue trials relative to neutral-cue trials, and slower for invalid-cued trials (RTs and their associated standard errors [SE mean]: 612 [37] vs. 629 [36] vs. 653 [36] ms, respectively), F(1.188, 10.694) = 10.090, p < .01 (G-G). The main effect for Synchrony was significant (642 [37] vs. 622 [35] ms, for random and synchronous premask conditions, respectively), F(1, 9) = 27.411, p < .01. This time (in contrast to Experiment 1), the Cueing x Synchrony interaction was also significant, F(2,

18) = 4.593, p < .05. Follow-up t-tests (Bonferroni adjusted) revealed that synchronicity priming expedited RTs significantly only for invalid-cue trials, but not (or only borderline) significantly for neutral and valid-cue trials (priming effects and their associated standard errors [SE mean]: 12 [3] vs. 13 [7] vs. 34 [7] ms for neutral, valid, and invalid conditions; t(9) = 3.592, n.s., t(9) = 1.972, n.s., and t(9) = 4.670, p < .002, respectively; see Figure 3.8).

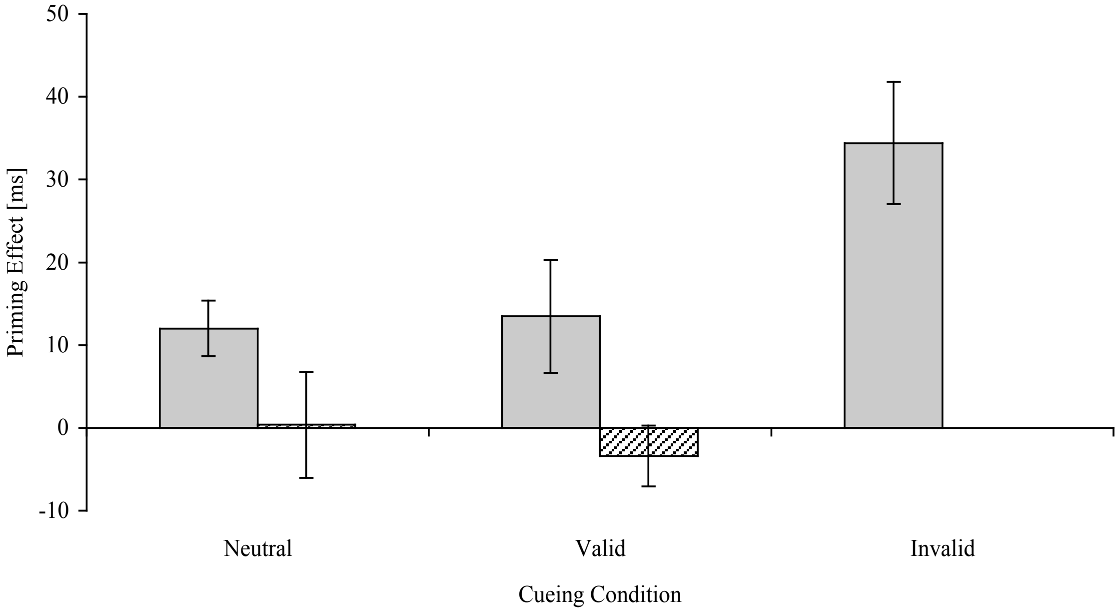

Figure 3.8: Mean priming effects (and their associated standard errors [SE mean]). Grey bars represent effects for target-present trials, shaded bars for target-absent trials.

The ANOVA with the additional term Target revealed no main effect for Cueing, F(1, 9) = 2.72, and no significant main effect for Synchrony, F(1, 9) = 4.087. Target-absent RTs were slower than target-present RTs (804 [61] vs. 621 [36] ms), F(1, 9) = 46.591, p < .001. The Synchrony x Target interaction was significant, F(1, 9) = 6.869, p < .05, indicating that synchronicity priming effects were confined to target-present trials. The Cueing x Target, Cueing x Synchrony, and Cueing x Synchrony x Target interactions were not significant, F(1, 9) = 4.229, F(1, 9) = 0.039, and F(1, 9) = 0.399, respectively.

Error analysis. The error data are presented in Figure 3.9. The overall error rates were 1.99% misses (target-present trials) and 1.00% false alarms (target-absent trials). The arc-sine transformed error data were examined in two ANOVAs analogous to those of the RT data. The first (Cueing x Synchrony) revealed none of the main effects nor the interaction to be significant. The second ANOVA, with the additional term Target, revealed a significant Cueing x Target interaction, F(1, 9) = 9.914, p < .02, all other main effects or interactions remained not significant. Observers produced slightly more misses than false alarms on valid-cue trials (error rates and their associated standard errors [SE mean]: 2.81 [0.99]% vs. 3.39 [0.74]%), and more false alarms than misses on neutral-cue trials (3.35 [0.9] % vs. 2.65 [0.91] %).

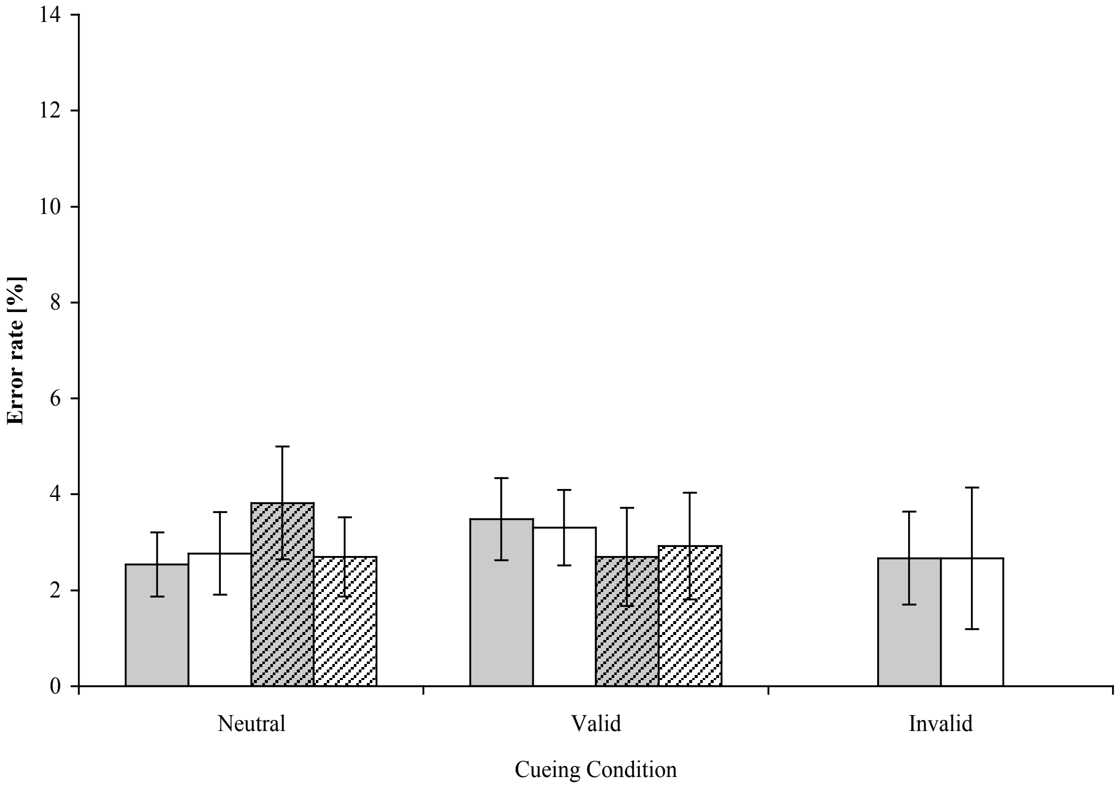

Figure 3.9: Mean error rates (and their associated standard errors [SE mean]) on target-present (non-shaded bars) and target-absent trials (shaded bars). Grey bars show error rates on synchronous-premask trials, white bars on random-premask trials, separately for each cueing condition (neutral, valid, invalid).

Discussion

A visual direct (exogenous) spatial cue was introduced in Experiment 3 to trigger reflexive orienting of attention to the cued location. This was done to examine whether exogenous cues would produce a differential effect of attentional orienting on synchronicity priming, in contrast to endogenous cues (see Experiment 1). Consistent with Experiment 1, there was a Cueing effect (for target-present trials only), with benefits for valid-cue trials and costs for invalid-cue trials relative to the neutral-cue baseline. Concerning the Synchrony effects, for the neutral- and valid-cue conditions, the data display the same pattern as in Experiment 1, that is: an additive effect of spatial cueing and synchrony priming. In contrast, for the invalid-cue condition, the data reveal a pattern that seems somewhat counter-intuitive. Whereas the magnitude of the synchronicity priming effect was the same for the neutral- and valid-cue conditions (12–13 ms), it was two to three times as large (34 ms) for the invalid-cue condition.

An explanation of this pattern of could be as follows: When spatial attention is allocated to the cued quadrant, but the target appears at a non-cued location, the cued quadrant needs to be ‘rejected’ as containing the target and attention needs to ‘disengaged’ from there in order to find and select the target location. In this situation, the synchronous prime would serve as a ‘second-order’ cue, in that it represents a ‘saliency signal’ on the overall-saliency map (e.g., Wolfe, 1994) of the display matrix. [This signal may be generated directly by the synchronous prime, that is, prior to the presentation of the target display; or it may be generated by the prime expediting target figure coding, that is, only after presentation of the target display.] This signal permits the attentional system to select the correct target location with great efficiency (after rapid ‘rejection’ of the cued location) .

If this were true, a question would arise, namely: why does this interaction become manifest only on invalid-cue trials, but not on neutral-cue trials? This could be because, on neutral-cue trials, none of the four possible display quadrants can be effectively excluded from the search. With spatial attention equally distributed across the target display, the rate of information accumulation would be slowed compared to when attention is focused on one location; as a result, it would take relatively longer for a signal to emerge that triggers the focussing (i.e., ‘zooming in’) of attention on the target location. In this situation, the synchronous prime can provide some ‘guidance’ for target search (by either directly representing a saliency signal or by expediting the emergence such a signal), resulting in a (weak) synchronicity priming effect.

As in Experiment 1, on valid-cue trials, there was also a synchronicity priming effect, but no further facilitation as a result of the direct cue (over and above that achieved in the neutral-cue condition). This finding, together with the results of Experiment 1, suggests that, in the valid-cue condition, the system may be operating near its upper limit. That is, given the (attentionally) expedited coding of the target figure at the location of the exogenous cue, the synchronous prime has a limited potential to (additionally) enhance the cue effect (focussing attention more narrowly at the cued location) and/or figural coding processes at this location.

Experiment 4

However, there is a potential problem with this interpretation (i.e., the assumption that the gains to be achieved by a synchronous prime at the cued location are limited by a ceiling effect): The visual exogenous cue in Experiment 3, a brief, bright transient signal presented directly at the cued location, may have actually visually interfered with the effect of a synchronous prime presented at that location (but not synchronous primes presented at non-cued locations). Therefore, Experiment 4 was designed to re-examine the effect of exogenous cues uncontaminated by visual interference – namely: by presenting observers with direct auditory (rather than visual) cues to indicate the likely target location.

Auditory cues do have another advantage: they are non-figural in nature. The visual cues used in Experiment 3 were formed, in some sense, a square ‘figure’ (of crosses), potentially giving rise to specific figural priming processes that subdue the enhancement to be gained from the synchronous prime. This could be another reason for the reduced synchronicity priming effect for validly cued targets (i.e., the ceiling effect referred to above).

The auditory cues introduced in Experiment 4 therefore permitted examination for a possible interaction between spatial cueing and synchronicity priming unconfounded by both visual and figure-based interference of the cue with the prime effect.

In Experiment 4, spatial-attentional deployment was manipulated by acoustically attracting attention to one or another display quadrant (see Figure 3.10). Studies of attentional cueing have shown that visual as well as auditory cues can be used to reflexively orient spatial attention (Spence & Driver, 1997, but see Ward, McDonald, & Lin, 2000), and that there is a intermodal exchange between visual and acoustical spatial information (e.g., Driver & Spence, 1998, Eimer & Schröger, 1998). Given this, auditory spatial cueing of attention could also lead to interactions with synchronicity priming. If the priming is indeed modulated by spatial attention and if figural information is not the reason for the modulation revealed in Experiment 3, then reflexive orientation of spatial attention by an auditory cue should lead to the same pattern of results as observed with visual exogenous cues in Experiment 3.

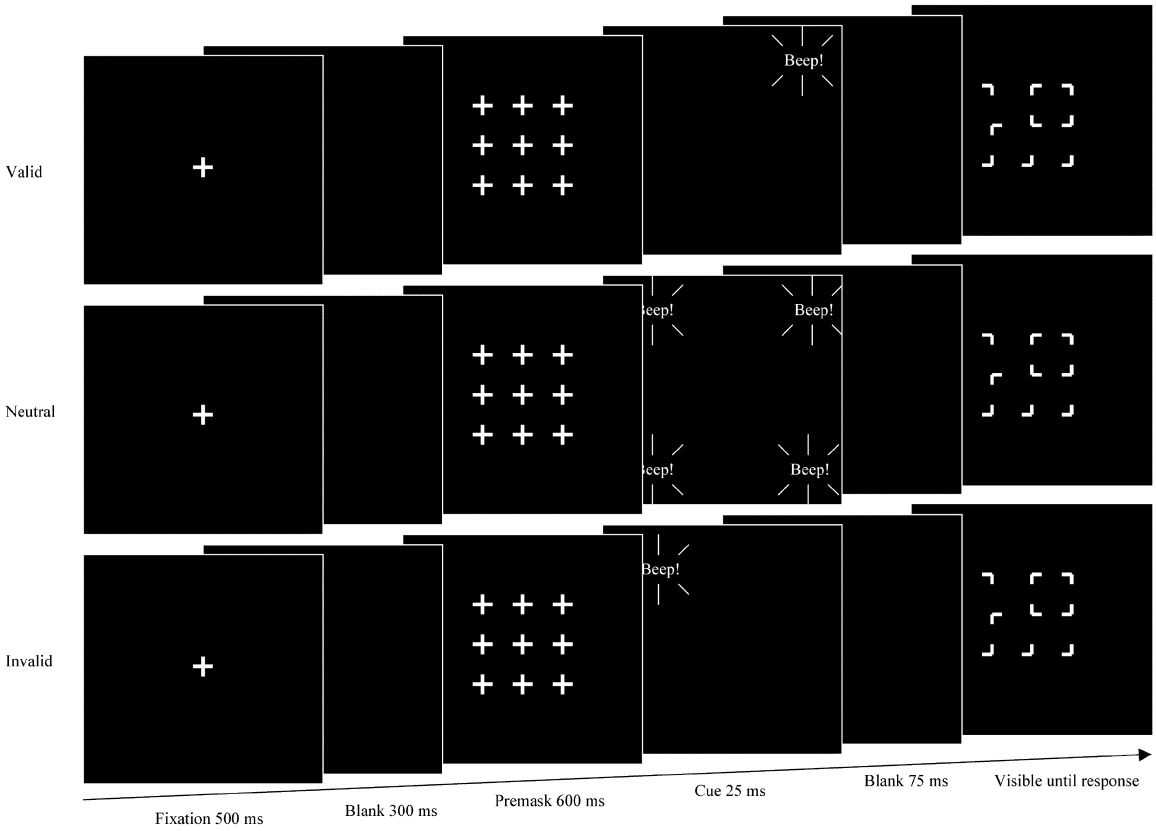

Figure 3.10: Example trials of Experiment 3. The upper row shows a valid-cue trial, the middle row a neutral-cue trials, and the lower row a invalid-cue trial.In this Experiment a peripheral acoustical cue flashed up for 25 ms.

Method

Apparatus. The auditory peripheral cue was provided through a custom-made device, via four speakers (30 mm diameter, 8 Ω impedance, 1300 - 8000 Hz) placed at a distance of about 8 cm relative to the four matrix quadrants presented on the oscilloscopic screen. The device had its own energy supply and was controlled through the parallel port of the same computer that controlled the point-plotter buffer and recorded the data.

Stimuli. The stimuli were the same as in Experiments 3, the only difference being that exogenous auditory cues (rather than exogenous visual cues) were presented after the premask offset. Valid and invalid cues consisted of a 25-ms ‘beep’ (i.e., a beep of the same duration as a single premask frame, 1500 Hz) produced by a speaker at one of the four corners of the display screen. In the neutral-cue condition, the four speakers beeped simultaneously, which led to the impression that the beep came from the middle of the screen, rather than indicating a particular display quadrant (Figure 3.10).

Design and Procedure. The design and procedural details were identical to those in Experiment 3.

Results

RT analysis. RTs on trials on which a response error was made (3.67 % of all trials), extreme RTs (< 150 ms and > 1500 ms), and RTs 2.5 standard deviations above or below the mean for each individual observer (2.27 % of all trials) were removed from the data prior to RT analysis. Figure 3.11 presents the correct mean RTs (and their associated standard errors [SE mean]) as a function of Cueing (neutral, valid, invalid) x Synchrony (random, synchronous premask) x Target (present, absent) condition. As before, the data were examined in two stages: two-way ANOVA of target-present data only, with main terms for Cueing and Synchrony; and three-way ANOVA of corresponding target-present and target-absent data, with an additional main term for Target, and excluding the invalid cueing condition.

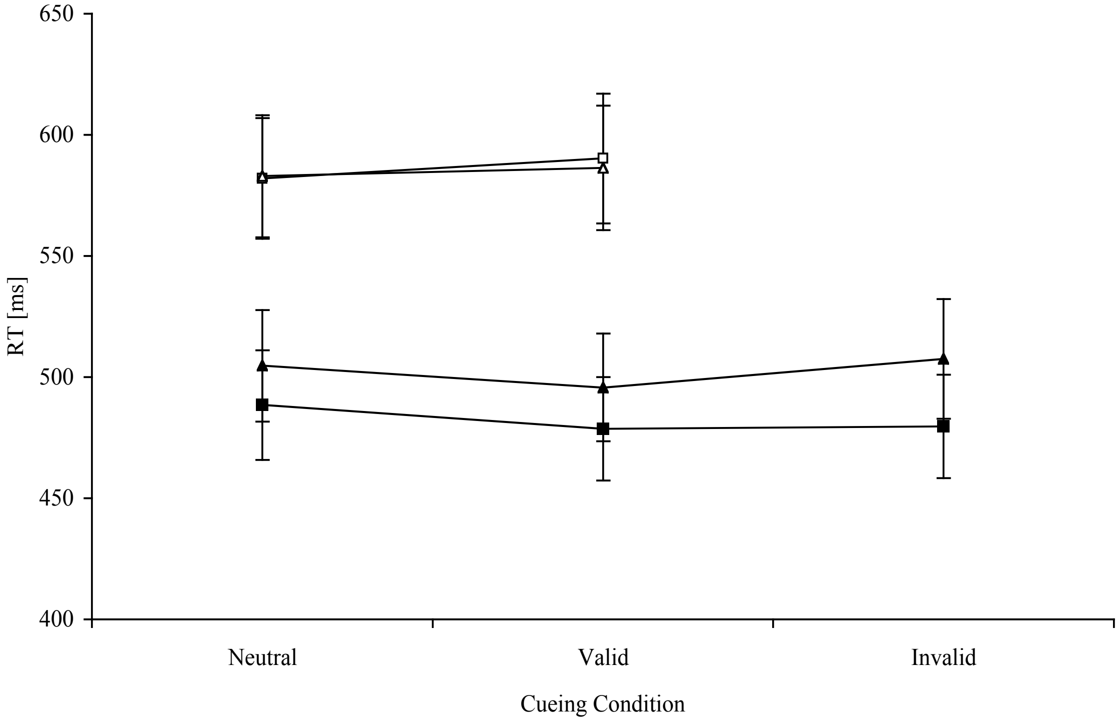

Figure 3.11: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Cueing (neutral, valid, invalid) x Synchrony (random, synchronous premask) x Target (present, absent) condition. Squares represent synchronous-premask, triangles random-premask trials. Filled symbols show target-present, open symbols target-absent RTs.

The first ANOVA revealed no significant main effect for Cueing (RTs and their associated standard errors [SE mean]: 496 [23] vs. 487 [22] vs. 493 [23] ms, for neutral, valid, and invalid trials, respectively), F(2, 20) = 3.193, though the effect approached significance, p = .058. Planned (one-tailed) t-tests revealed a significant difference between neutral and valid trials, t(13) = 2.251, p < .05, and between valid and invalid trials, t(13) = -1.828, p = 0.09. The main effect of Synchrony was significant (503 [23] vs. 482 [22] ms for random and synchronous premasks), F(1, 13) = 41.523, p < .001, as was the Cueing x Synchrony interaction, F(2, 26) = 8.329, p < .01; follow-up pairwise comparisons (Bonferroni adjusted) revealed synchrony priming to be evident in every cueing condition (priming effects and their associated standard errors [SE mean]: 16 [3] vs. 17 [4] vs. 28 [4] ms for neutral, valid, and invalid conditions), t(13) = 5.976, p < .001, t(13) = 4.711, p < .001, and t(13) = 6.265, p < .001, respectively. As can be seen from the priming gains depicted in Figure 3.12, the Cueing x Synchrony interaction was due to a larger synchronicity priming on invalid-cue trials relative top both neutral- and, importantly, valid-cue trials.

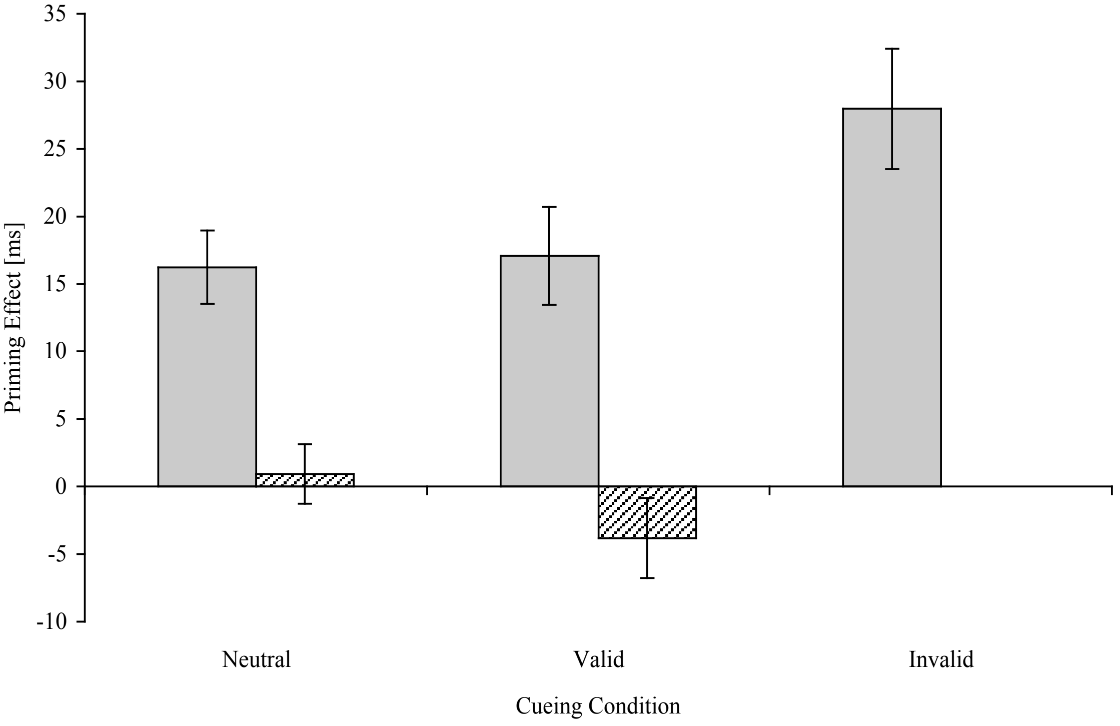

Figure 3.12: Mean priming effects (and their associated standard errors [SE mean]). Grey bars show the effects for target-present trials, shaded bars for target-absent trials.

The second ANOVA with the additional term Target revealed no main effect for Cueing, F(1, 13) = 1.187, but main effects for Synchrony, F(1, 13) = 22.224, p < .001, and Target, F(1, 13) = 81.516, p < .001, with slower target-absent than target-present RTs (585 [25] vs. 492 [22] ms). Neither the Cueing x Synchrony interaction nor the Cueing x Target interaction were significant, F(1, 13) = 0.667 and F(1, 13) = 3.711, respectively. However, as expected, the Synchrony x Target interaction was significant, F(1, 13) = 23.506, p < .001, with synchronicity priming effects evident only for target-present trials. [The Cueing x Synchrony x Target interaction was non-significant, F(1, 13) = 1.935, which could be expected because the invalid-cue condition, that had given rise to the relevant interaction in the first ANOVA, was excluded from the analysis.]

Error analysis. The error data are presented in Figure 3.13. The overall error rates were 2.17% misses (target-present trials) and 1.50% false alarms (target-absent trials). The arc-sine transformed error rates were examined by two analogous ANOVAs to those conducted for the RT data. The first ANOVA (of target misses only) revealed no significant main effect for Cueing, F(2, 26) = 2.467, but a significant effect for Synchrony, F(1, 13) = 40.023, p < .001. The Cueing x Synchrony interaction was not significant, F(2, 26) = 2.704.

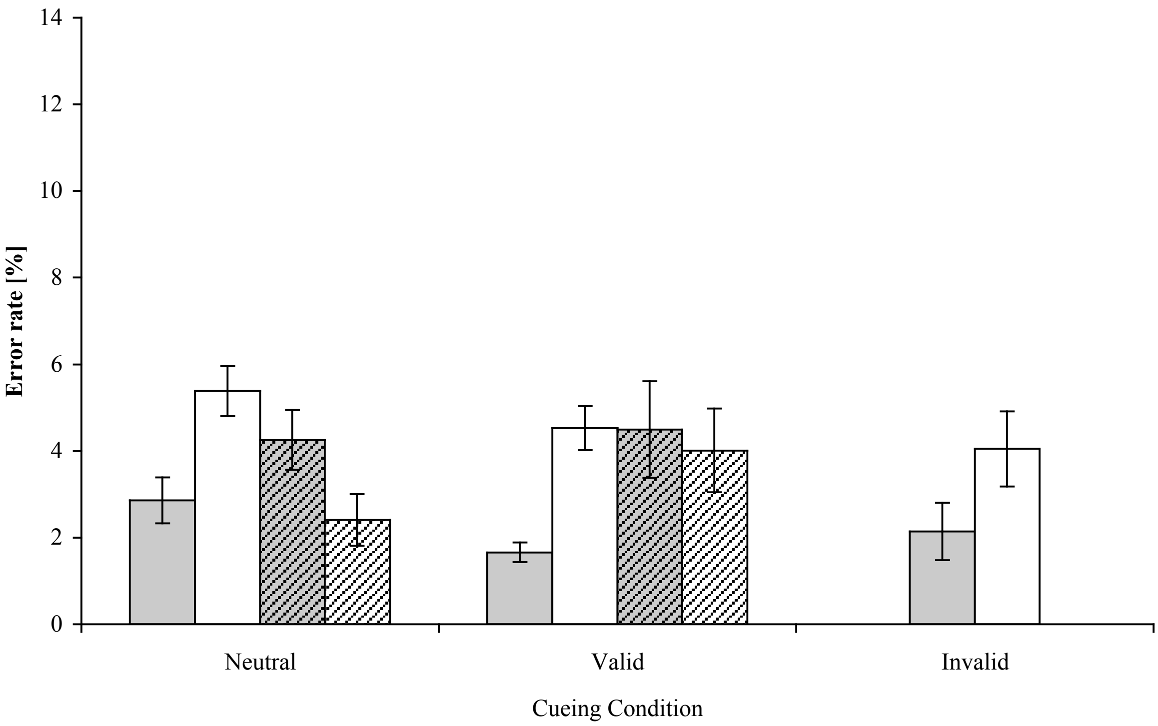

Figure 3.13: Mean error rates (and their associated standard errors [SE mean]) for target-present (non-shaded bars) and target-absent trials (shaded bars). Grey bars show error rates for synchronous-premask trials, white bars for random-premask trials, separately for each cueing condition (neutral, valid, invalid).

The second ANOVA with the additional term Target also revealed no significant effect for Cueing, F(1, 13) = 0.215), but again a significant effect for Synchrony, F(1, 13) = 18.677, $p < 0.01$. The main effect for Target was non-significant, F(1, 13) = 0.009. Of the interactions, only that between Synchrony x Target was significant, F(1, 13) = 48.008, $p < .001$, indicating that observers produced less misses (target present trials) were made only on synchronous premask conditions. (Cueing x Target, F(1, 13) = 3.820; Cueing x Synchrony, F(1, 13) = 1.598; Cueing x Synchrony x Target, F(1, 13) = 0.845).

Discussion

The results of Experiment 4 show that the interaction of spatial cueing with synchronicity priming observed with exogenous visual cues (Experiment 3) is also obtained with exogenous auditory cues. There may be one problem with the experimental set-up, namely: on neutral-cue trials, observers reported hearing the cue beep to come from the middle of the screen (a ‘neutral’ location with respect to the target quadrant), but they perceived it as less loud, that is, less salient, than valid or invalid cues. This could be the reason why the classical pattern of cueing effects, including costs for invalidly cued targets against the neutral baseline, was not observed in Experiment 4 (see also Jonides & Mack, 1984). However, the main interest was in the effects of auditory spatial cueing on synchronicity priming for valid- as compared to invalid-cue conditions (with the neutral-cue condition serving as a baseline for the average synchronicity priming effect). Importantly, valid cues still led to faster RTs than invalid cues (i.e., there were significant costs-plus-benefits in terms of Jonides and Mack [1984]), confirming that the exogenous auditory cues were effective in directing spatial attention to the cued location. Furthermore, the synchronicity priming effect was dependent on cue validity: it was larger for invalidly than for validly cued targets, in line with Experiment 3 in which spatial attention exogenous visual cues were presented to guide spatial attention to the cued location. This suggests that the modulation of synchronicity priming in Experiment 3 (in particular, the reduced priming for targets at the cued location) was not due to visual interference of the transient visual cue with target coding or, respectively, the figural information provided by the visual cue at its location. Instead, the fact that the interaction was observed with purely auditory cues may be taken to suggest that, some time after cue onset, a synchronous prime at a non-cued location competes with the spatial cue signal (more effectively once the cued location is rejected as containing the target), attracting spatial attention away from the cued to the primed (target) location. That is, the information provided by the synchronous prime (either directly or in terms of its effect on target coding) must be available for interaction with (cue) signals from the visual and other modalities. One mechanism mediating such an interaction could be an overall-saliency map of the (visual) field, as suggested, for example, by Wolfe (1994; Driver & Spence, 1998).

Experiment 5

In Experiment 3 of Elliott and Müller (1998), a, relative to the target location, ‘mislocated’ synchronous prime was introduced to examine whether the prime attracts spatial attention. The results showed no RT costs associated with mis-located primes compared to the random-premask condition. Elliott and Müller took this to mean that the facilitatory effect of synchronicity priming is not based on the engagement of spatial attention, but rather on enhanced object coding. However, as the results of the present Experiments 3 and 4 show, mis-guiding spatial attention by exogenous cues leads to larger priming effects for invalidly cued targets. Thus, in the absence of directed spatial-attentional orienting, mis-located (i.e., in relation to the target location ‘invalid’) synchronous primes do appear to give rise to processing costs (Elliott & Müller, 1988, Experiment 3), while, on the other hand, invalid spatial cues produced larger priming effects (present Experiments 3 and 4). The latter findings suggest a competitive relationship between the synchronous prime and the spatial cue.

Experiment 5 was designed to examine whether the prime and the cue do indeed compete for spatial attention. To test this ‘competition hypothesis’, the neutral-, valid-, and invalid-cue conditions were systematically varied by introducing, besides the standard random- and synchronous-‘*valid*’-premask conditions, a new condition with synchronous-‘*invalid*’ premasks. Note that, in these condition labels, the terms valid and invalid refer to the location of the target relative to that of the synchronous prime. That is, in the standard synchronous-*valid*-premask condition (already used in the previous experiments), the target always appeared at the location of the synchronous prime. In contrast, in the new, synchronous-‘*invalid*’-premask condition, the target appeared at a location other than that of the synchronous prime.

If the cue and the prime signals compete with each other, reduced cueing benefits would be expected on valid-cue trials with a synchronous-invalid prime (i.e., a prime appearing at a different location to that of the cue), compared to valid-cue trials with a random premask. Furthermore, increased costs on invalid-cue trials would be expected on trials with a synchronous-invalid prime (i.e., when the synchronous prime 'indicates' a non-cued location, but the target appears at another non-cued location), compared to invalid-cue trials with a random premask.

Method

Stimuli, design, and procedure. In Experiment 5, on trials with a synchronous premask, the target could appear either in the same quadrant where the prime had been located during premask presentation (*synchronous-valid premask*; the 'standard' condition also realized in the previous experiments) or in a different quadrant (*synchronous-invalid premask*; a new condition); on the remaining trials, the premask crosses were pseudo-randomly distributed across the four premask matrix quadrants and frames (*random premask*; the 'standard' random-premask condition). The cues were exogenous visual signals, the same as in Experiment 3. All cueing (neutral, valid, invalid) and priming conditions (random, synchronous-valid, synchronous-invalid) were combined. Thus, for target-present trials, there were nine different cue–prime pairings plus one extraordinary condition in which an invalid spatial cue and a synchronous-invalid prime pointed to different locations, but the target appeared at a third, non-cued location. – Henceforth, conditions in which the cue and the prime (if presented) 'indicated' the same location or different locations will be referred to as *SL* or *DL* conditions, respectively (see Figure 3.14).

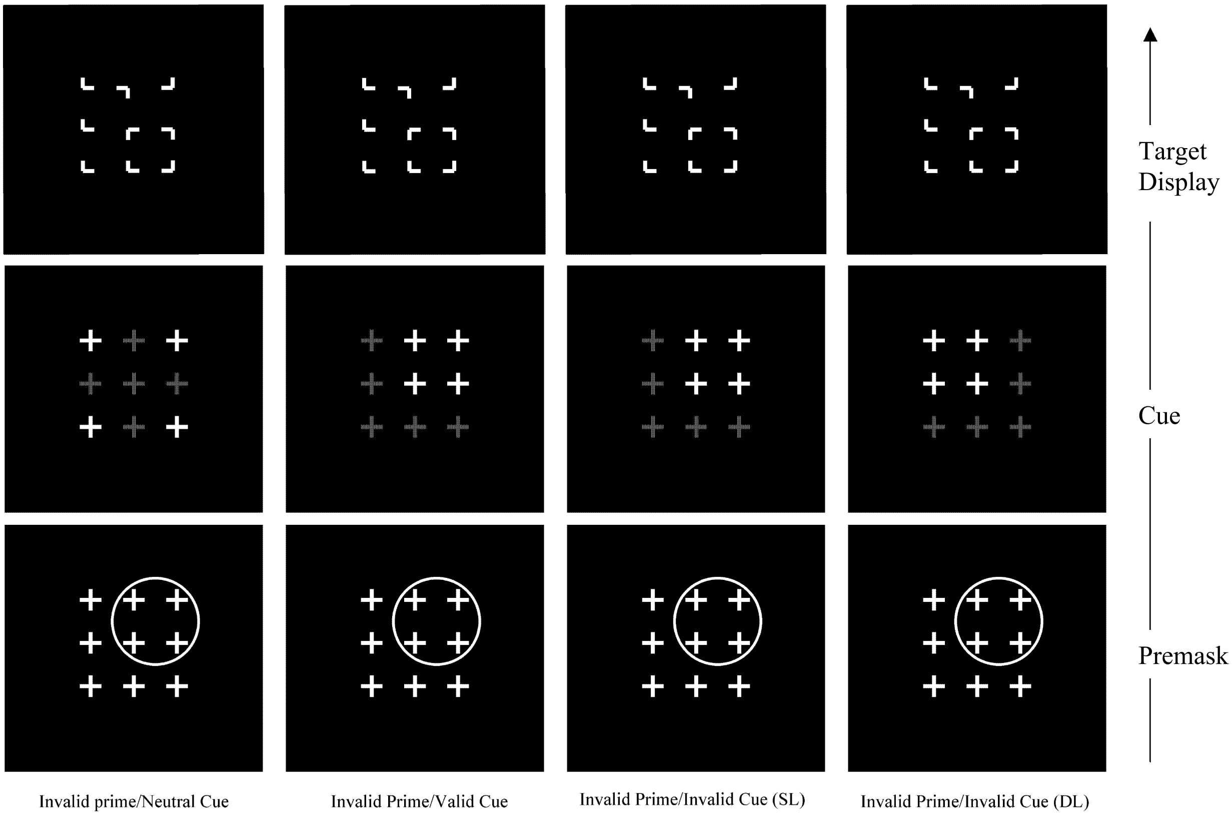

Figure 3.14: Each column stands for a new condition. These are no example trials, but descriptions of Prime/Cue combinations. Prime location is symbolized by the circle, cue location by the white crosses (grey crosses are only for orientation and were not presented in the experiment). From left to right: Invalid Prime/Neutral Cue, Invalid Prime/Valid Cue, Invalid Prime/Invalid Cue (pointing to the same location [SL]), Invalid Prime/Invalid Cue (pointing to different locations [DL] with the target appearing in a third location.

Experiment 5 consisted of a total of 3000 experimental trials, 1800 target-present trials (60% of the trials) and 1200 target-absent trials (40% of the trials). In each premask condition, 50% of the trials presented a neutral cue, 40% a valid cue, and 10% an invalid cue (i.e., the cue validity was 80%). For target-present trials, there were 900 trials with a random premask, 300 trials with a synchronous-valid premask, and 600 trials with a synchronous-invalid premask (i.e., 300 neutral cue, 240 valid cue, 30 invalid cue [SL], and 30 invalid cue [DL]). All combinations of experimental conditions were presented in randomised order within blocks of trials. Observers performed the 3000 experimental trials over the course of three separate sessions.

In all other respects, the method of Experiment 5 was the same as that in Experiment 3.

Results

RT analysis. [Due to unduely high error rates, the data of one observer were excluded from analysis.] RTs on trials on which a response error was made (4.16% of all trials), extreme RTs (< 150 ms and > 1500 ms), and RTs 2.5 standard deviations above or below the mean for each individual observer (2.26% of all trials) were removed from the data prior to RT analysis. RT data were examined in three stages: a three-way ANOVA with main terms Target, Cueing, and Synchrony, excluding the invalid-cue and invalid-synchronous prime conditions (these conditions logically were not possible for target absent trials); a two-way ANOVA with main terms Cueing and Synchrony, excluding the 'invalid-cue, synchronous-invalid prime (DL) condition (because this condition had no logic equivalent on neutral- or valid-cue conditions); and an one-way ANOVA for the invalid-cue condition data with the main term Synchrony to compare all premask conditions (inclusive the 'invalid-cue, synchronous-invalid prime (DL) condition).

Figure 3.15 presents the correct mean RTs (and their associated standard errors [SE mean]) as a function of Target (present, absent) x Cueing (neutral, valid) x Synchrony (random, synchronous-valid [with respects to target present trials] premask). There was a significant main effect for Target (616 [28] vs. 493 [16] ms for target-absent, target-present trials, respectively), F(1, 8) = 64.392, p < .001. The Target x Synchrony interaction approached significance, F(1, 8) = 4.859, p = .059, pointing to the direction that synchronicity priming occurred on target present trials. None of the other effects was significant (Cue F(1, 8) = 2.192, Synchrony F(1, 8) = 2.082, Target x Cue F(1, 8) = 0.031, Cue x Synchrony F(1, 8) = 0.274, Target x Cue x Synchrony F(1, 8) = 0.042).

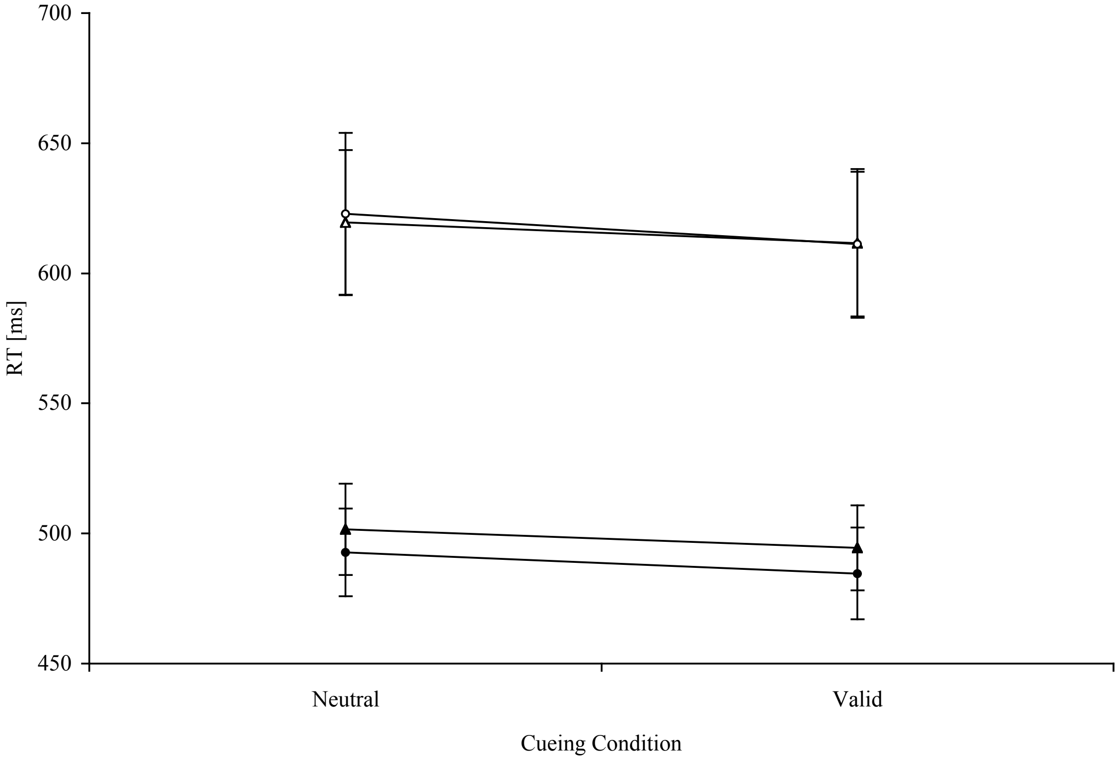

Figure 3.15: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Target (present, absent) x Cueing (neutral, valid) x Synchrony (random, synchronous-valid). Filled symbols represent target-present, open symbols target-absent trials. Circles refer to synchronous, triangles to random premask conditions.

Figure 3.16 presents the correct mean target-present RTs (and their associated standard errors [SE mean]) as a function of Cueing (neutral, valid, invalid) x Synchrony (random, synchronous-valid, synchronous-invalid [SL] premask) condition, and Figure 3.17 presents the corresponding synchrony priming effects (to aid comparison, the ‘invalid-cue, synchronous-invalid premask, DL’ condition was added to the figure, even though it was excluded from the ANOVA below). The second ANOVA of the corresponding target-present RT data, with main terms for Cueing and Synchrony (but excluding the ‘invalid-cue, synchronous-invalid premask, DL’ condition), revealed a significant main effect for Cueing (498 [17] vs. 490 [17] vs. 517 [22] ms for neutral, valid, and invalid conditions, respectively), F(2, 16) = 4.098, p < .05. Planned (one-tailed) t-tests showed that this effect was due to significantly slower RTs on invalid-cue than on neutral- and valid-cue conditions, t(9) = 2.829, p < .05 and t(9) = 2.428, p < .05, respectively). There was a significant main effect for Synchrony (507 [18] vs. 494 [18] vs. 505 [18] ms for random, synchronous-valid, and synchronous-invalid [SL] conditions, respectively), F(1.208, 9.660) = 18.762, p < 0.01 (G-G). Multiple comparisons (Bonferroni adjusted) showed that the synchronous-valid condition differed significantly from random (p < .001) and synchronous-invalid conditions (p < .05), while the two latter did not differ from each other. The Cueing x Synchrony interaction was border-line significant, F(4, 32) = 2.787, p < .05, due to a greater advantage for the synchronous-valid relative to the random and synchronous invalid [SL] premask conditions with invalid spatial cues. Pair-wise comparisons (Bonferroni adjusted) revealed that random and synchronous invalid [SL] premask trials differed reliably from synchronous valid premask trials (21 [14] ms, p < .002 and 21 [15] ms, p < .003, respectively) (see Figure 3.17).

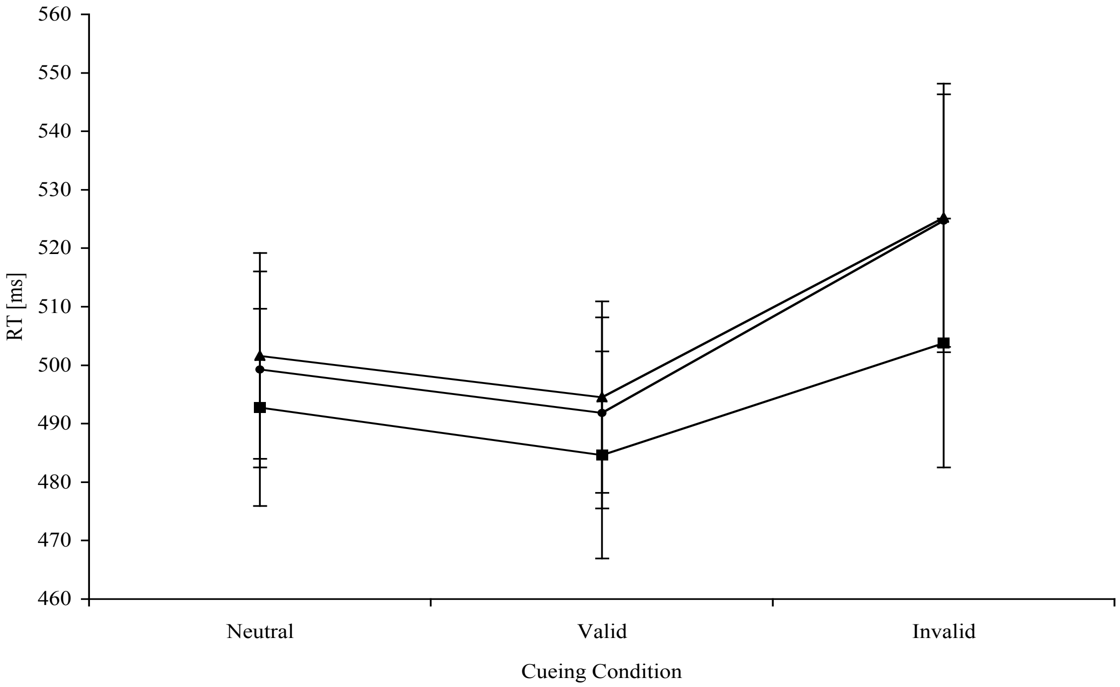

Figure 3.16: Mean correct target-present RTs (and their associated standard errors [SE mean]) as a function of Cueing (neutral, valid, invalid) x Synchrony (random, synchronous-valid, synchronous-invalid [SL] premask). Squares represent RTs for synchronous-valid, circles for synchronous-invalid, and triangles for random-premask trials.

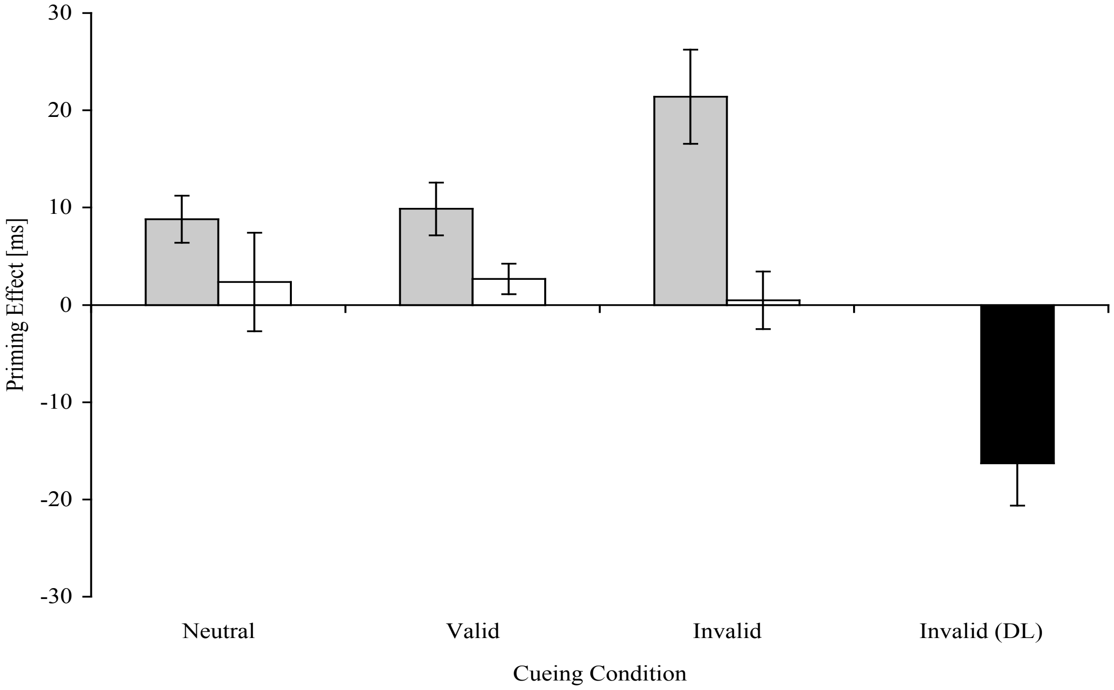

Figure 3.17: Mean priming effects (and their associated standard errors [SE mean]) for target-present trials as a function of Cueing (neutral, valid, invalid, invalid (DL)). Grey bars show the effects for trials with synchronous-valid primes, white bars for trials with synchronous-invalid primes. The black bar (DL) shows the effect for trials with incongruent cue and prime locations.

Figure 3.18 presents the correct mean target-present RTs on invalid-cue conditions (and their associated standard errors [SE mean]) as a function of Synchrony (random, synchronous-valid, synchronous-invalid [SL], synchronous-invalid [DL]), as a comparison aid all priming effects are shown in Figure 3.17 (the black bar represents the synchronous-invalid [DL] condition). Only the invalid-cue condition data was examined, because this was the only cueing condition in which all synchronous-invalid premask conditions were realized. As can be seen from Figure 3.18, relative to the random-premask baseline, RTs were faster for synchronous-valid premask trials, that is, when the target appeared at the synchronous-prime location (RT [SE means]: 504 [21] vs. 524 [23] ms); RTs on synchronous-invalid premask trials on which the cue and the prime indicated the same location [SL] were equally fast to the random-premask RTs (525 [22] vs. 524 [23] ms); and for synchronous-invalid premask trials on which the cue and the prime indicated different loactions [DL] and the target appeared at a non-primed non-cued location, RTs were slower relative to the random-premask baseline (541 [25] vs. 524 [23] ms). The one-way ANOVA of the corresponding RT data, with the single main term Synchrony, revealed the main effect to be significant, F(3, 24) = 24.496, $p < .001$. Pair-wise comparisons revealed the RT advantage for the synchronous-valid premask condition relative to the random-premask baseline to be significant ('positive' synchronicity priming effect) as well as the RT disadvantage for the synchronous-invalid premask (DL) condition ('negative' priming effect) ($p < .001$ and $p < .05$, respectively [Bonferroni adjusted]).

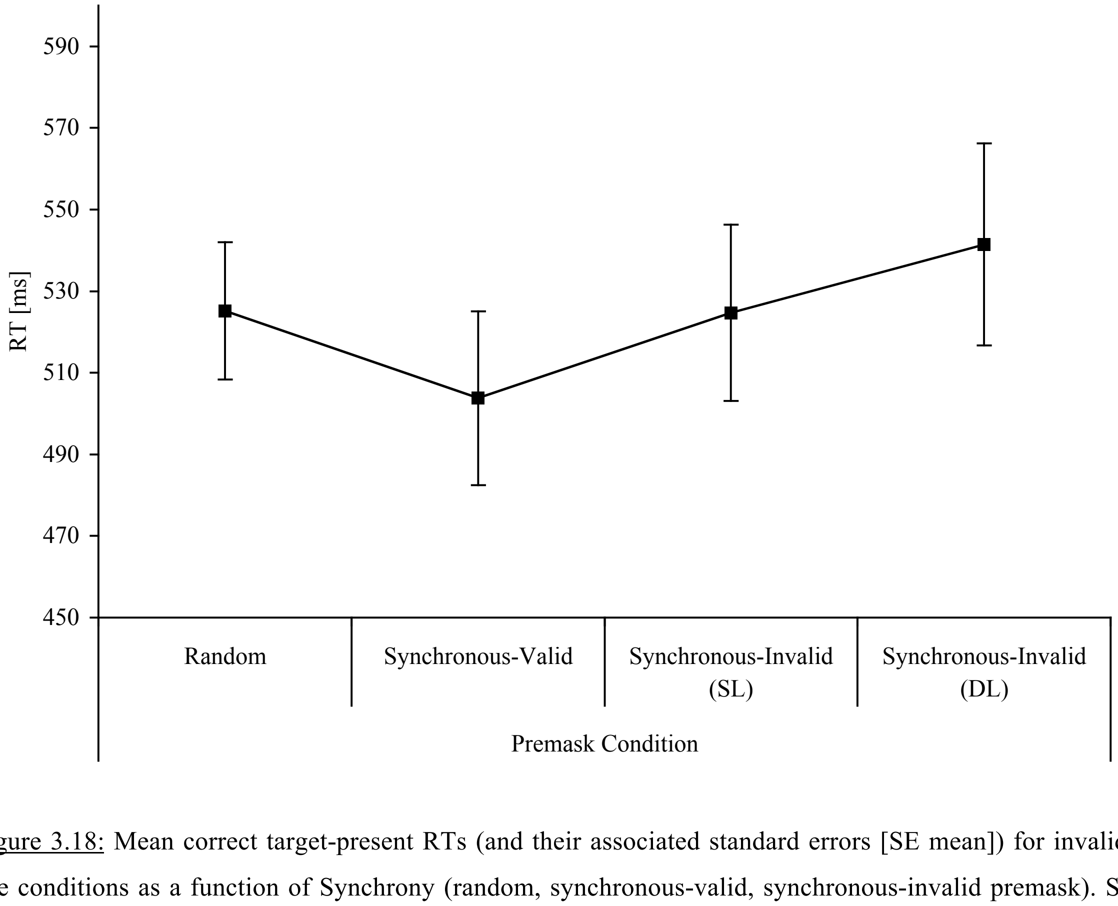

Figure 3.18: Mean correct target-present RTs (and their associated standard errors [SE mean]) for invalid-cue conditions as a function of Synchrony (random, synchronous-valid, synchronous-invalid premask). SL (same location) refers to congruent locations of cue and prime, DL (different locations) incongruent locations.

Error analysis. The error rates are presented in Figure 3.19 for target-present trials, and in Figure 3.20 for target-absent trials. The overall error rates were 2.26% misses (target-present trials) and 1.90% false alarms (target-absent trials). The arc-sine transformed error data were examined in several ANOVAs, with the same main terms as the corresponding ANOVAs of the RT data. None of these ANOVAs revealed any significant effects (the only exception was the miss-rate ANOVA with main term for Cueing and Synchrony, which revealed a borderline-significant main effect for Cueing, F(2, 16) = 4.375, p = .063, indicating that more misses (target present trials) were made on invalid-cue conditions..

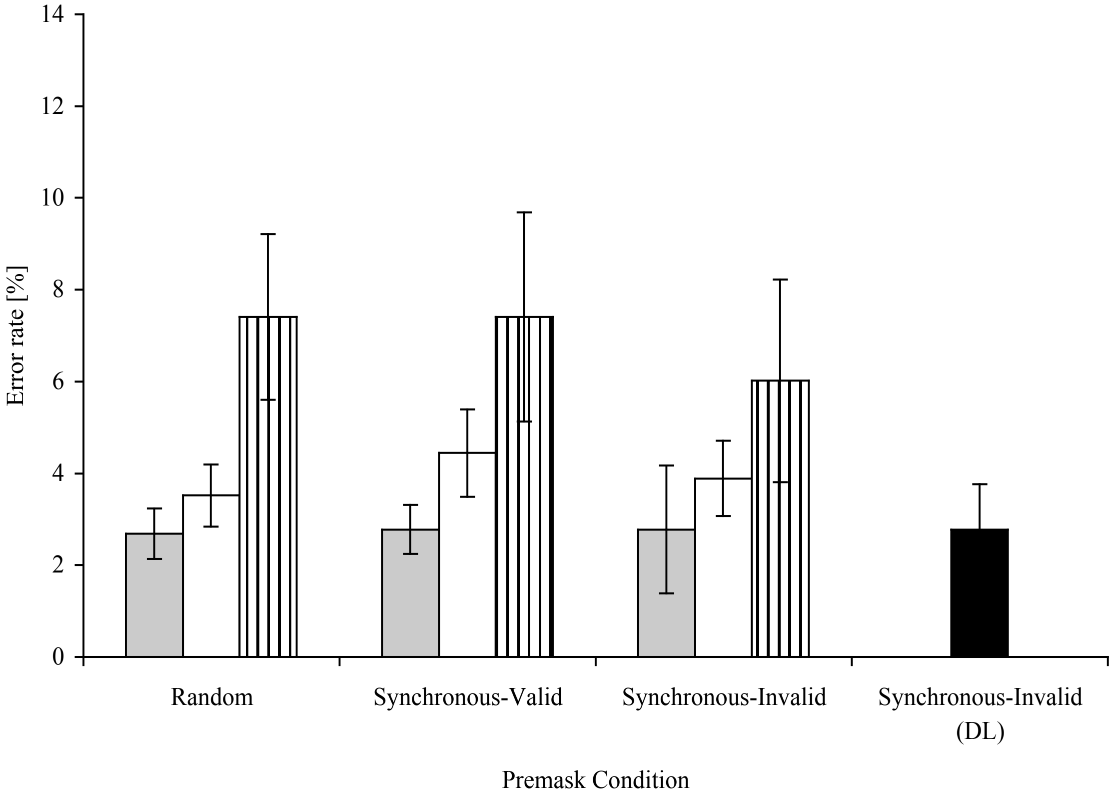

Figure 3.19: Mean error rates (and their associated standard errors [SE mean]) on target-present trials as a function of Synchrony (random, synchronous-valid, synchronous-invalid, synchronous-invalid [DL] premask). Grey bars show effects for neutral-cue trials, white bars for valid-cue trial, and striped bars for invalid-cue trials. The black bar (DL) shows the error rate on trials with incongruent cue and prime locations.

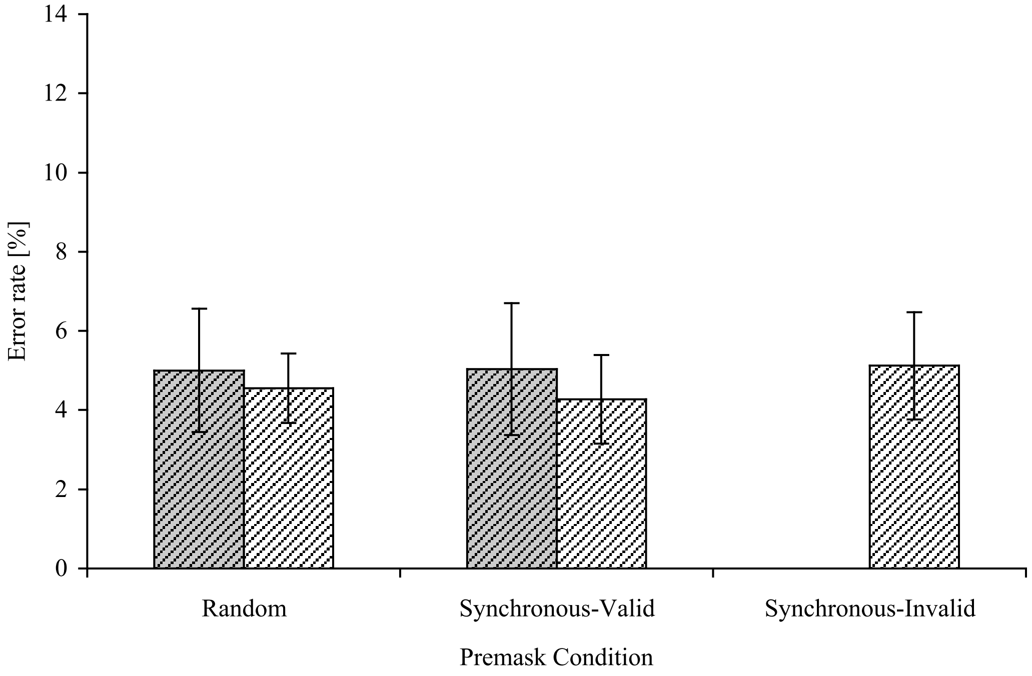

Figure 3.20: Mean error rates (and their associated standard errors [SE mean]) on target-absent trials as a function of Synchrony (random, synchronous-valid, synchronous-invalid premask).

Discussion

Consistent with findings of Elliott and Müller (Experiment 3, 1998), the results of Experiment 5 show that, on neutral-cue trials, an invalid synchronous prime (i.e., a prime presented at a location different to that of the subsequent target) does not produce costs relative to the random-premask condition. Furthermore, in line with the previous Experiments 3 and 4, the synchronous prime had its largest (synchronicity) enhancement effect on invalid-cue valid-prime trials, that is, when the target that appeared at a non-cued, but primed location. New findings were as follows: No synchronicity priming effect was evident when the synchronous prime was invalid, that is, when it appeared at a non-target location, whether the cue was neutral, valid, or invalid (though in the latter case, only when the cue and prime locations were congruent). This argues that synchronicity priming effects are spatially specific, confined to targets appearing at the prime location (consistent with Elliott & Müller, 1998, who had argued that the priming effects are target-specific in the sense that they do not occur on target-absent trials). Furthermore, as hypothesized, in case of incongruent cue and prime locations, the synchronous prime actually increased the RT costs for invalid-cue trials on which the target was presented at a non-primed (non-cued) location. However, RTs on valid-cue trials were not slowed relative to the random premask condition when the synchronous prime was presented at a non-cued location, that is, potentially 'competitive' synchronous primes do not reduce the beneficial effect produced by valid cues. Had this been the case, this would have provided direct evidence that the synchronous prime directly competes with spatial-attentional orienting to the cue. Thus, the present findings suggest that there is no direct competition between the cue and the prime for spatial attention, while, on the other hand, the synchronous prime produces the largest (priming) effect when spatial attention is cued to another location. On invalid-cue trials with valid primes (i.e., when the target was presented at a noncued, but primed location), the priming effect was larger relative to neutral- or valid-cue conditions. But on invalid-cue trials with invalid primes, with cues and primes presented at different locations (i.e., when the target appeared at a noncued and non-primed location), the synchronous prime actually produced costs compared to the random premask condition. This pattern of effects suggests a clear order of search priorities for the cued (searched first), the non-cued primed (searched next), and the non-cued non-primed locations (searched last), that is: After the (invalidly) cued location is rejected as not containing the target, attention is attracted to the (invalid) synchronous-prime location (either because the prime itself or a part-figure at its location gains saliency), and this location has to be rejected in turn before attention is directed to the target location.

General Discussion

To examine the relationship between synchrony priming and spatial attention, the present study combined the synchronicity-priming paradigm of Elliott and Müller (e.g., 1998, 2000, 2001) with a spatial-cueing paradigm (e.g., Posner, 1978, 1980; Müller & Rabbitt, 1989). Either symbolic central cues (endogenous attention) (Experiments 1–2) or direct peripheral cues at the relevant display quadrant (exogenous attention) were presented (Experiments 3–5), and the validity of the cue in predicting the target location was systematically varied (neutral, valid, invalid). In Experiments 1, 3, and 4, the target invariably appeared at the location of the synchronous prime (if on synchronous-premask trials), that is, the prime was valid with regard to the target location. In contrast, in Experiment 5, the prime could be invalid as well as valid.

With endogenous cues and long cue–target SOAs (Experiment 1), only additive effects of Cueing and Synchrony were found. That is, the synchronicity priming was equally large for all (neutral, valid, and invalid) cueing conditions, lending support to the notion of the pre-attentive nature of temporal binding mechanisms. However, such a conclusion would be problematic based on Experiment 1's data, as the error data suggested that observers were biased to (mistakenly) accept target presence at the cued location. Also, for valid-cue trials, on which targets were detected fastest overall, there may have been a ceiling effect such that the prime could have added only little to enhance performance (given that the system was operating near its spatial-attentionally determined optimum). However, in Experiments 3 and 4, there was never a larger priming effect on valid-cue trials relative to neutral-cue trials, even though the neutral-trial RTs were slower than the valid-trial RTs – casting doubt on the idea that the priming effects on valid-cue trials were limited by a ceiling effect. Experiment 2 ruled out that the synchronicity priming effects were mediated by explicit perception of the location of the prime: discrimination of the prime (location) was at chance, even when the prime was presented at the cued location.

The following experiments (3, 4, and 5) were conducted to examine whether a Cueing x Synchrony interaction would be observed when visuo-spatial attention is directed to the cued location by an exogenous signal, either a visual cue (Experiments 3 and 5) or an acoustical cue. In these experiments, the cues were presented after the flickering premask display, which could contain a synchronous prime (however, as Experiment 2 had shown, observers were unable to discern prime presence), and the cue–target SOA was short (100 ms). These parameters were chosen so as to avoid the response biases that were evident with endogenous cues. Experiments 3, 4, and 5 indeed revealed an interaction between Cueing and Synchrony, suggesting that visuo-spatial attention does indeed modulate the synchronicity priming effect. However, the pattern of this modulation was somewhat counter-intuitive: the facilitatory effect of the synchronous prime was actually larger for targets at invalidly cued (relative to validly and neutrally cued) locations. This pattern of effects is not easily consistent with the idea that visuo-spatial attention influences a relatively ‘automatic’ binding process (similar to other processes that are assumed to be pre-attentive in nature, such as target pop-out in visual search; e.g., Treisman & Gelade, 1980).

A more likely explanation is that cueing and synchrony priming involve largely independent processes and that their beneficial ‘outputs’ are (non-additively) combined when they point in the same (target) direction, but, on the other hand, if spatial attention is displaced, the prime can act on full strength and compensate some of the costs produced by invalid cueing.

Interestingly, this works only in the described direction. If the synchronous prime is invalid, there is no larger cueing effect on valid cue trials (Experiment 5), although the priming effect is, temporally, prior to the spatial cue. The possibility that synchrony priming is purely mediated by attention through the deployment of spatial attention on the display looses ground on the present results. Even if spatial attention is equally distributed over the whole display in neutral cueing conditions and by this mediates the priming, it could not explain how a bigger priming effect can arise when spatial attention is not equally distributed.

Another, more likely possibility is that expedited target figure formation by synchrony priming at a non-indicated position helps to rapidly reorient attention to the primed (target) position (Elliott & Müller, 1998), provided that the cued (non-target) location can be efficiently rejected as containing the target (as a result of spatial attention being deployed there in response to the cue). In this situation, the target figure itself could become an effective ‘cue’ for reorienting attention.

But how could this explain the reduced priming effect on neutral- relative to invalid-cue trials? A possible explanation is that, on neutral-cue trials, attention is either distributed widely across the display matrix (direct visual cues) or concentrated on the central point of the matrix (acoustic cues). Consequently, what would be required in this situation is not simply a shift of spatial attention towards the target figure, but also a ‘zooming’ operation (i.e., narrowing or broadening of the attentional focus), which is more time-consuming than a shift alone (see Stoffer, 1993). This could account for the reduced priming effect on neutral- relative to invalid-cue trials (on the latter, only a shift operation would be required). An alternative (though not necessarily incompatible) explanation (to that above) could be that, on neutral-cue trials, there is increased competition of randomly formed part-figures in non-target display quadrants, because these receive a relatively greater amount of ‘attentional processing’ than part-figures at non-cued locations on (valid- and) invalid-cue trials. To resolve this increased competition for attentional selection would take longer (compared to invalid trials on which the cued location can be rapidly rejected and the primed target needs to win only against two competing part-figures), thereby reducing the facilitation to be derived from the prime.

Another issue to be discussed concerns why symbolic cues (or, respectively, long cue–target SOAs) do not lead to differential (greater) synchronicity priming for invalid- compared to valid-cue trials. One reason for this could be that endogenous (voluntary) orienting of visuo-spatial attention involves other mechanisms than exogenous (reflexive) orienting. In particular, under endogenous orienting conditions, it could be harder to reject a invalidly indicated position as not containing a target, because of a top-down bias that ‘expects’ the target at the cued location and therefore makes the system prone to accept a part-figure at the cued location for the target (see, e.g., Müller & Humphreys, 1991; see also Kingstone’s, 1992, work on combined spatial and target expectancies). Such a ‘target’ bias would make it harder to exclude the cued position from the competition for selection, delaying the disengagement of attention from the indicated location. Consequently, a target figure at an invalid (non-cued) location would loose some of its synchronity priming advantage (the longer attention is focused on the cued location, the more figure formation catches up at a non-cued locations or, respectively, on random- relative synchronous-premask trials). Another possibility is that endogenous attentional orienting gives rise to a (general) suppression of coding processes outside of the attentional focus (i.e., to inhibition for non-cued locations as well as facilitation for the cued location; e.g., Posner & Snyder, 1975). Such a suppression would also reduce the advantage to be gained from synchronicity priming for a target figure at a non-cued location.

Taken together, the results of the cueing experiments suggest that, in cueing conditions where top-down expectancies (and eye-movements) are minimized or can be ruled out, a synchronously primed target figure at a non-cued position can attract attention very efficiently, most likely due to the prime expediting target figure formation and the target, in turn, providing an effective spatial-attentional 'cue' to itself.

Concerning the latter suggestion, the critical question is at which point of time the synchronous premask (at a non-indicated location) unfolds its effect: after the onset of the target display in terms of a expedited target figure formation, so that the target can act as a cue to itself (as suggested); or already during the presentation of the premask display in terms of an 'attractor' that (relative to a spatial cue) marks another location for the prioritized allocation of attention. If the latter were true, on invalid-cue trials with a synchronous prime at a non-cued location, there should be competition between the prime 'attractor' and the spatial cue. The results of the signal detection experiment (Experiment 2) may be taken as evidence against such a competition, in that observers were unable to discern the exact position of the synchronous prime better than chance level. Nevertheless, it remains possible that the synchronous premask attractor is encoded implicitly (see, e.g., Lambert, Naikar, McLahan, & Aitken, 1999, who showed that peripheral cues that were presented below conscious threshold, could nevertheless attract attention). Thus, given that the signal detection evidence is at best indirect with respect to the question as to point in time when the priming effect arises, further work is required to settle this issue (see Chapter 5).

Chapter 4: Effects of Multiple Synchronous Primes

Abstract

Within a 3×3 matrix of 90º corner junctions, detection of a Kanizsa-type square is facilitated when the target display is preceded by a 40-Hz flickering premask of 3×3 crosses, with four crosses synchronously oscillating at the subsequent target location. To examine the spatio-dynamic structure of this ‘*synchrony-priming*’ effect the premask was extended to 5×5 or 6×6 elements and dual synchronous primes were presented with varying spatial relations relative to each other and relative to positions of the following target figure. Targets could appear either on-prime or between-prime positions. Evidence was found that multiple synchronous primes form a spatio-dynamic ‘prime field’ which may exhibit a ‘Gaussian-type’ shape with a maximal field strength at the center between two primes and decreasing strength with increasing distance to this center. The results were also consistent with a proposed recurrent model of prime generation (Elliott & Müller, 2004), in that the integration of dual prime signals across spatial separations is accomplished via top-down projections from higher- to lower-tier visual coding mechanisms.

Theoretical background

Perceiving visual objects composed of separable features coded within the same and in different processing modules requires our visual system to solve a fundamental 'binding problem' (e.g., von der Malsburg, 1981, 1995). The object's features must be bound together in order to perceive a unified whole and, in addition, the complete object must be segregated from the background in which it is embedded. Several theoretical accounts have been proposed of how the brain could solve these problems, one of them being Treisman's 'Feature Integration Theory (FIT)' (e.g., Treisman & Gelade, 1980; Wolfe, 1994). FIT assumes that focal (location-based) attention provides the 'glue' that is needed to conjoin the features of an object registered in separate dimensions (such as orientation and colour). Another influential account is based on neuro-physiological findings which suggest that neurons representing features of the same object fire in synchrony with each another, but out of synchrony with neurons representing features of different objects (e.g., Singer & Gray, 1995). According to this hypothesis of 'temporal binding', modulations of neuronal activity in the gamma-band (i.e., 30-80 Hz) is most likely to be involved in binding by synchrony (e.g., Eckhorn et al., 1988; Gray & Singer, 1989; König, Engel & Singer, 1995; Lisman, 1998).

More recently, there have also been psychophysical attempts to test the temporal-binding hypothesis, by examining whether the synchronized presentation of target elements asynchronous relative to the presentation of background elements facilitates the efficient target coding at certain stimulus presentation frequencies (Fahle & Koch, 1995; Leonards, Singer, & Fahle, 1996; Blake & Yang, 1997; Kiper, Gegenfurtner, & Movshon, 1996). However, these studies revealed no consistent picture. However, several new paradigms were recently devised, the results of which support the notion that feature-object binding can involve temporal coding (e.g., Elliott & Müller, 1998; Usher & Donnelly, 1998). One of these paradigms is the 'synchronicity priming' paradigm developed by Elliott and Müller (1998, 2000, 2001).

In this paradigm, observers are presented with a flickering matrix of figurally neutral premask elements for a certain time (typically 600 ms). Then, the premask matrix is replaced by a matrix of figure and distractor elements (see Figure 4.1), and observers have to decide, as rapidly and accurately as possible, whether this display contains a pre-defined target figure. In more detail, the premask display consisted of a matrix of 3×3 crosses and the target display of a matrix of 3×3 90° (i.e., L-type) corner junctions.

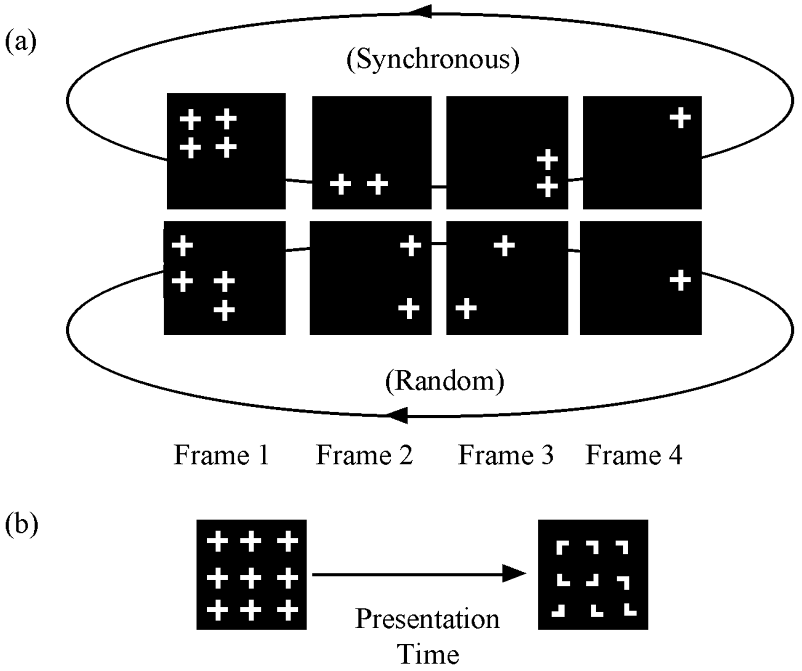

Figure 4.1: (a) Example sequence of the four premask frames in the synchronous and random conditions. The premask oscillation frequency was defined as the frequency of premask frames per second. For example, at 40-Hz, the four premask frames were presented 10 times per 1000 milliseconds, with a constant frame exposition duration of 25 ms and an inter-frame intervall of < 1ms. (b) The premask sequence was continuously repeated until the target display was presented, this induced the impression of a stochastically flickering display of nine crosses.

In the target display, four of the corner junctions in one matrix quadrant could form a to-be-detected target figure, a Kanizsa-type square (whereas the distractor junctions could not be grouped to form a closed figure). Elliott and Müller found that detection of the target figure was expedited when the four premask crosses in the matrix quadrant in which the target figure appeared later were repeatedly presented *synchronously* (i.e., within the same display frame), relative to a 'random' control condition in which the premask crosses in the relevant quadrant were presented *asynchronously* (i.e., in different display frames; not that the random premask display consisted also of one frame with four elements, which were, however, not presented within the same matrix quadrant). Importantly, this 'synchronicity priming' effect occurs only when the frame components of the premask matrix, including the frame with the four synchronous crosses (which hitherto will be referred to as '*synchronous prime*') are presented with a frequency of 40-Hz (as well as other 'preferred' gamma-band frequencies, e.g., 33, 46, 53, 59, and 66 Hz; see Elliott & Müller, 1999, 2004).

To account for the 40-Hz synchronicity priming effect demonstrated by means of this paradigm, Elliott and Müller (2004) proposed a recurrent model of synchronous-prime generation. The model assumes that the prime is generated in later stages in the visual processing hierarchy, but becomes subsequently active in earlier stages (e.g., V1) due to back-propagation of a global 40-Hz pattern. That is, neurons with larger receptive fields, which cover the whole spatial extension of the premask matrix, such as cells in inferotemporal cortex (IT), are entrained with a 40-Hz rhythm through integration of the single premask frame, that is, 10-Hz signals. Earlier neurons' activity would then come to be determined by both recurrent 40-Hz activity and the repeated presentations of (local) premask elements at 10 Hz (Elliott & Müller, 2000, 2004). There is neuro-physiological evidence in support of this view. Fries, Reynolds, Rorie, and Desimone (2001) found that the pattern of 40-Hz activity generated by an IT neurons is fed back to earlier neurons that comprise the receptive field of that IT neuron, inducing them to oscillate at 40-Hz.

Scope of the study

The present study was designed to extend the paradigm developed by Elliott and Müller (1998, 2000, 2001), in order to investigate the potential role of dynamic spatial structures of multiple (dual) synchronous primes for target detection. According to the model proposed by Elliot and Müller (2004), prime information is first generated in higher stages of the visual stream, in cortical areas with relatively large receptive fields. The inferotemporal (IT) cortex, with receptive fields greater than 20º of visual angle, is a possible region were this could occur. However, the priming effect is location-specific, which suggests that the synchronous prime becomes principally active across contributive neurons at earlier stages of visual processing, such as V1 or V4, or both, where neurons, due to their receptive field dimensions, code only smaller regions of visual space occupied by premask frame subsets, but not the entire premask display.

On this background, the present study asked: When the flickering premask contains dual primes in particular spatial relations to each one, what kinds of dynamic prime structures would be generated by such multiple primes? Does the system generate individual (i.e., spatially separate) primes or are both primes merged into a single prime field?

Four experiments were conducted to examine the effects of dual synchronous primes (or, rather, synchronous premasks), which were embedded in the same frame of a flickering premask matix. To make this possible, for the first two experiments, the 3×3 premask (standardly used by Elliott and Müller) was extended to a 5×5 and 6×6 premask matrix, respectively. By this means, it was possible to implement varying separations the two primes could have relative to each other. With 5×5 premask matrices, the two primes were either not separated by any intervening premask crosses, that is, they formed a connected rectangular region of eight crosses (distance 0), or the two primes formed two square regions separated by one row of premask crosses (distance 1). With a 6×6 premask, a third distance condition could be realized: the two primes could also be separated by two rows of premask crosses (distance 2) (see Figure 4.2).

In principle, the possible effects under dual-prime conditions may take on three forms. First, no ‘focal’ prime is generated. Second, two ‘focal’ primes are generated, which, due to inhibitory interactions, less strong than a single prime (this would be consistent with the first possibility). Third, two equally strong ‘focal’ primes are generated, of which only one attracts ‘attention’ in a competitive way (see Yantis & Johnson, 1990). The latter possibility implies that the prime itself draws attention to its location. In this case, the RTs to targets presented in-between the two primes that are maximally distant from each other, should show no synchronicity priming effect, because the target location does not overlap with any synchronously primed matrix elements (see Figure 4.2). This would also imply that the coding system is able to represent (spatially) separate objects within the same phase. The JIM model of visual binding (Hummel, 2001; Hummel & Biederman, 1992; Hummel & Stankiewicz, 1996) would not predict this. In this model the different attributes of each individual object (its features) are represented by synchronized neuronal firing, and separable objects (i.e., their feature representing cell assemblies) would fire out of phase relative to each other. Accordingly, the presentation of multiple primes within a single display frame (i.e., in phase) would lead to the integration of both prime signals.

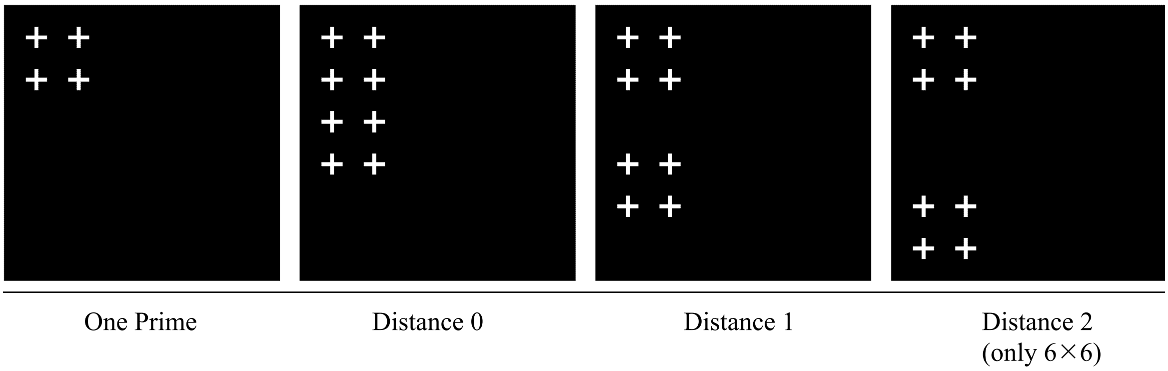

Figure 4.2: Example synchronous-prime frames, embedded within the sequence of four display frames making up the flickering premask matrix (see Figure 4.1), with either one (left-hand panels) or two (all other panels) spatially separate synchronous-premask stimuli (i.e., premask crosses arranged in the form of a square). When there were dual synchronous premasks, they were presented either directly next to each other, forming a closed rectangular region (distance 0), or they could be separated by either two (distance 1) or four (distance 2) premask crosses presented asynchronously to the prime frame (and are therefore not shown in the figure); see the 2st, 3rd , and 4th panels from the left-hand side.

General Method

The present study consisted of four experiments which used essentially the same experimental set-up and design. These are described in the General Method section; any relevant differences are reported in the method sections of the relevant experiments.

Participants. Twelve observers took part Experiment 1 and 2, thirteen in Experiment 3, and ten in Experiment 4. All had normal or corrected-to-normal visual acuity. Observers were naive as to the purpose of the experiments and were paid at a rate of € (Euro) 8.00 per hour.

Apparatus. Event timing, data collection, and stimulus generation were controlled by a PC-compatible computer, which also controlled oscilloscopic image presentation through an Interactive Electronics Systems point plotter buffer with 8 MB frame store memory (Finley, 1985). Stimuli were presented on a 6” Tektronix 608-oscilloscope monitor equipped with a very fast-decay P15 phosphor. The use of a P15 phosphor ensured that on-screen image persistence reduced to 10% of normal image intensity within 2.8μs of image termination (Bell, 1970). The Interactive Electronics Systems point plotter buffer allowed pixels to be plotted at a rate of one pixel every microsecond. The presentation frequency of frames across the entire premask display was kept constant at 40-Hz, while the entire premask matrix, consisting of a sequence of four separate frames, was recycled at a rate of 10 repeats per second (i.e., each premask frame repeated at 10 Hz). Frames had a constant exposure duration of 25 ms and an inter-frame interval of less than 1 ms (see Figure 4.1). The continual recycling of the premask frame sequence produced the phenomenal experience of a flickering display of nine crosses, within which observers were unable to discern the structure of a given frame. Both the individual premask frames and the target display frames were presented semi-static at a fixed, 1 kHz refresh frequency.

Stimuli. Observers viewed the monitor at a distance of 57 cm (maintained via a chin rest). The experiment was conducted under controlled lighting conditions (mean screen surround luminance 0.078 cd/m^2), with stimulus luminance maintained at 0.3 cd/m^2 upon a background field of 0.075 cd/m^2. Display elements were arranged around the center of the monitor screen (see Figure 4.1). Premask crosses subtended $99'$ of visual angle and exhibited horizontal and vertical separations of $1^\circ\ 70'$ for the 5×5 display matrix and $1^\circ\ 58'$ for the 6×6 matrix. The total 5×5 premask display matrix subtended $7^\circ\ 30' \times 7^\circ\ 30'$ of visual angle, and the 6×6 premask $8^\circ\ 40' \times 8^\circ\ 40'$ of visual angle. Premask frames could consist of 4, 8, 8, and 5 crosses (5×5 premask matrix) and, respectively, 4, 8, 12, and 12 crosses (6×6 matrix) presented simultaneously in a given matrix frame. Junction elements in the target display subtended $54'$ of visual angle and were separated horizontally and vertically by $1^\circ\ 70'$ (5×5 target display) and $1^\circ\ 58'$ (6×6 target display).

The target display subtended 7° 30'×7° 30' of visual angle on 5×5 matrix experiments and 8° 40'×8° 40' of visual angle on 6×6 matrix experiments.

Design and Procedure. In all experiments, there were three premask conditions: the flickering matrix could either contain a single prime at one of the possible target locations (*one-prime condition*); or the premask matrix could contain two primes (one of them being the location of a subsequent target) (*two-prime condition*), which were located either directly next to each other, forming a rectangular region (*distance 0*), or were separated by one row of (two) premask crosses (*distance 1*), or by two rows of (four) premask crosses (*distance 2*, only 6×6 matrix); see Figure 4.2. Note that, with dual primes, distance was manipulated by moving the two primes apart in either horizontal direction only (x-coordinate variable, y-coordinate constant) or vertical direction only (x-coordinate constant, y-coordinate variable). In the third condition, the premask matrix contained no prime, that is: the same amount of premask crosses were arranged randomly across locations and frames, with the constraint that they were not permitted to form a square, closed rectangular region, or any other synchronous premask constellation within a single premask frame (*random condition*). The target display, which immediately replaced the flickering premask display, either did or did not contain a target figure, a Kanisza-type square (*target-present* and *target-absent trials*, respectively). The target could appear in any one of the 16 and, respectively, 25 matrix positions (5×5 and 6×6 matrices, respectively).

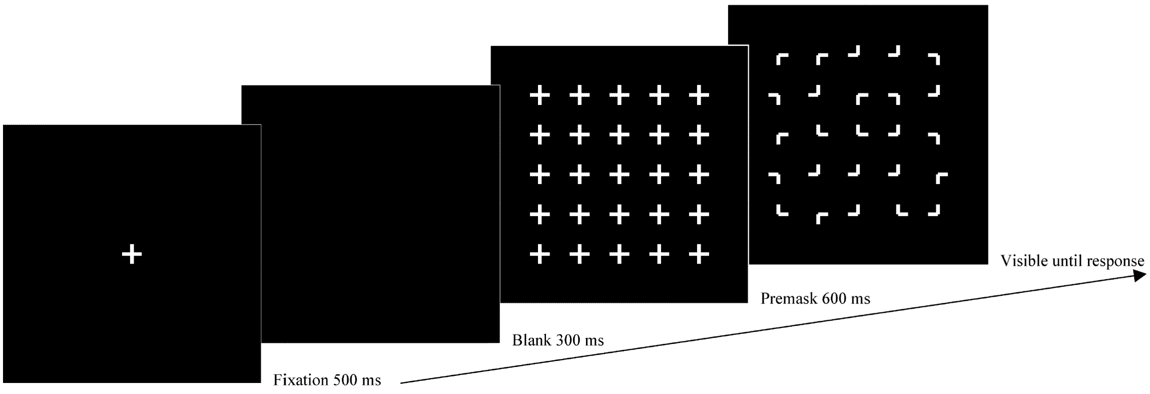

Figure 4.3: Example trial with a 5×5 matrix.

At the beginning of each trial, a fixation cross was presented in the center of the screen for 500 ms. Then, after a 300-ms blank-screen interval, the flickering matrix of premask crosses was presented for 600 ms. Directly following the offset of the premask matrix, the target display matrix of 90° corner junctions was presented – and observers had to discern, as rapidly and accurately as possible, the presence or absence of a target Kanizsa-type square within this matrix (pressing one of two buttons with their right or the left index finger to indicate target presence or absence, respectively). The target display remained in view until the response had been made (see Figure 4.3). The response was followed by a blank screen for 1000 ms, after which the next trial display was presented. Observers were told to fixate the center of the display and avoid eye movements during premask display presentation. In case of an erroneous response, feedback was provided in the form of a (300-ms) 400-Hz computer-generated tone.

The experiments were conducted over multiple sessions: two sessions for Experiments 1–3 and four sessions for Experiment 4. Each session lasted about 60 minutes, and was divided into 10 blocks with 3 (unrecorded) warming-up trials presented prior to the experimental trials. Trial blocks were separated by short breaks. Prior to each experiment, observers performed one practice block of trials (data not recorded).

Experiment 1

Experiment 1 was designed to examine the effects of dual synchronous primes, which were embedded in a premask matrix flickering at 40-Hz, on target figure detection. To permit the presentation of dual primes, a 5×5 premask matrix was introduced, which could either contain a single synchronous prime, two synchronous primes, or a random arrangement of premask crosses (baseline condition). By using this experimental set-up, it was examined whether dual primes would produce differential effects relative to the single-prime condition. For trials with a single synchronous premask, a synchronicity priming effect was expected to be observed similar to that found in previous studies (e.g., Elliott & Müller, 1998, 2000, 2001). With dual synchronous premasks, if there is no interaction between the two (single) primes and they give rise to two separate (location-specific) prime signals, one might expect no change in synchronicity priming relative to the single-prime condition. However, if there is a competitive interaction between the two prime signals (for example, because only one signal can be represented within a single frame), one would expect the synchronicity priming effects to be reduced relatively to the single-prime condition or entirely abolished.

Method

The methodology in Experiment 1 was in all respects as described in the General Method section above. On synchronous-prime trials, the target (if one was presented) appeared always exactly at a primed location. With dual primes presented directly adjacent to each other (so that they formed a closed rectangular region), the target could appear only at one or the other prime location (but not in the middle of the rectangular region).

Results

RT analysis. RTs on trials on which a response error was made (5.47 % of all trials), extreme RTs (< 150 ms and > 2500 ms), and RTs 2.5 standard deviations above or below the mean for each observer (3.24 % of all trials) were removed from the data prior to RT analysis. See Figure 4.4 for the mean correct target-present and target-absent RTs (and their associated standard errors [SE mean]), presented as a function of Premask condition (random, one prime, two primes).

The RT data were examined by a two-way repeated-measures ANOVA, with the two main terms for Premask and Target (present, absent). There was a significant main effect for Premask, $F(2, 22) = 10.923$, $p < .01$. In both one- and dual-prime conditions, observers responded faster than on random-premask trials, 828 [73] and, respectively, 834 [75] ms vs. 855 [77] ms, respectively. Further, there was a significant main effect of Target, $F(1, 11) = 5.172$, $p < .05$: target-present RTs were faster than target-absent RTs (774 [51] vs. 905 [101] ms). The Premask x Target interaction was also significant, $F(1.105, 12.151) = 8.749$, $p < .01$ (Greenhouse-Geisser corrected degrees of freedom [G-G]), reflecting the fact that synchronicity priming occurred only on target-present trials. This interaction was expected, at least for the one-prime condition (e.g., see Elliott & Müller, 1998, who observed synchronicity priming only on target-present trials, arguing that the priming is target-specific). Concerning the synchronicity priming effects, pairwise comparisons (Bonferroni adjusted) of the random-premask condition against the one- and dual-premask conditions (target-present data only) revealed the priming enhancement to be significant both for single primes (45 [13] ms) and for dual primes and (42 [8] ms), $p = .005$ and $p < .001$, respectively, and not different in magnitude between the two prime conditions, as can also be seen from Figure 4.5.

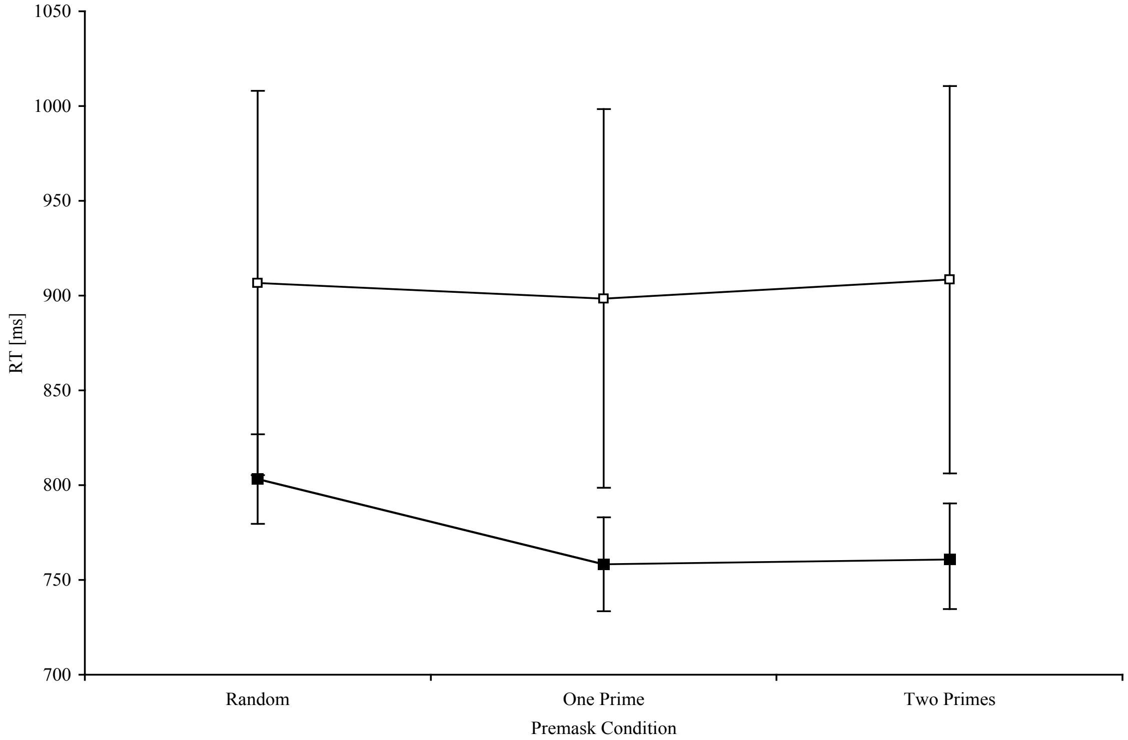

Figure 4.4: Mean correct target-present and target-absent RTs (and their associated standard errors [SE mean]) as a function of Premask condition (random, one prime, two primes). Filled squares represent target-present RTs, open squares target-absent RTs.

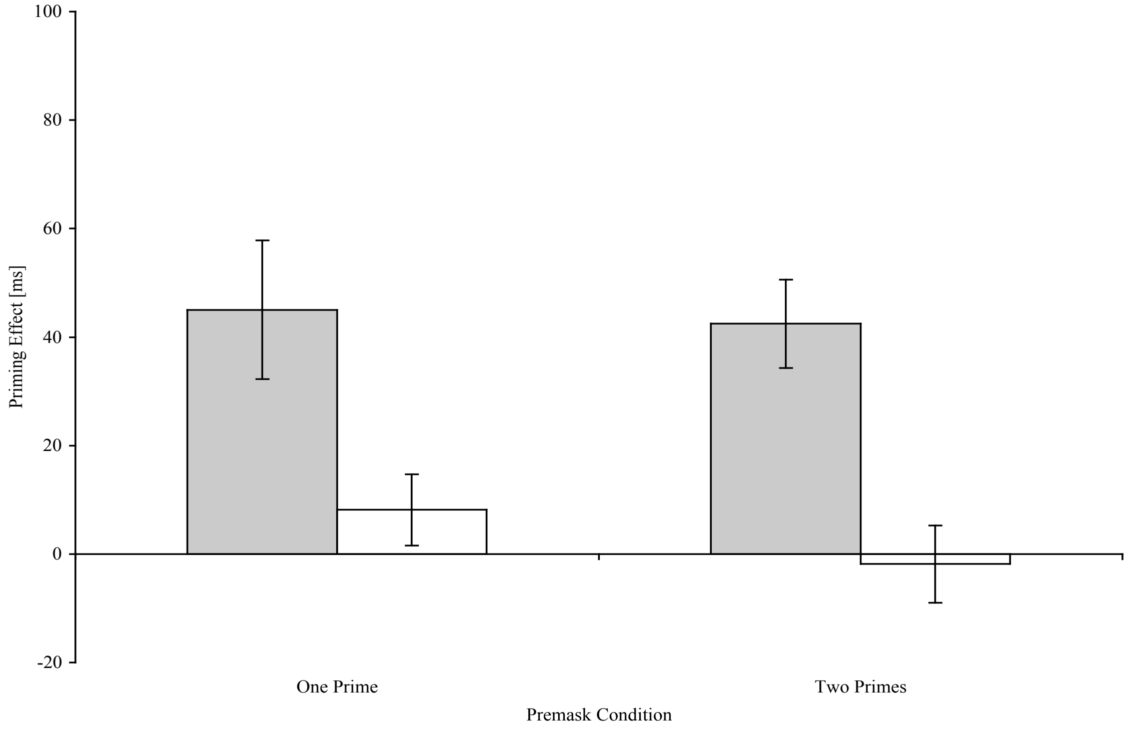

Figure 4.5: Mean priming effects (and their associated standard errors [SE mean]) for one-prime and two-prime conditions, separately for target-present (grey bars) and target-absent trials (white bars).

A further two-way (Premask x Target) ANOVA was conducted to examine the synchronicity priming effects as a function of the number of primes and the Distance between dual primes (i.e., 0 or 1 row of a asynchronously presented crosses separating the two synchronous premasks). See Figures 4.6 and 4.7 for the relevant RT data and the synchronicity priming effects, respectively. Not surprisingly (given that some of the conditions had already been examined in the first ANOVA), there was again a significant main effect for Premask, F(3, 33) = 6.879, p < .01. Target present RTs in the random-premask condition were significantly slower than in both the one-prime condition (803 [54] vs. 758 [50] ms) and the dual-prime distance-0 condition (803 [54] vs. 750 [51] ms), but not reliably slower relative to the dual-prime, distance 1 condition (803 [77] vs. 781 [51] ms). As expected, the main effect for the factor Target and the Premask x Target interaction were also significant, F(1, 11) = 5.224, p < .05 and F(2.080, 22.876) = 6.915, p < .01 (G-G); the interaction was due to the fact that there was an effect of the Premask condition only on target-present RTs, but not on the (overall slower) target-absent RTs. Pairwise comparisons (Bonferroni adjusted) of random-premask RTs with all other Premask conditions (target-present data only) revealed that the synchronicity priming effect was significant only for the one-prime and the dual-prime distance-0 conditions (p = .005 and p < .001, respectively), but not the dual-prime distance-1 condition (mean priming effects of 45 [13], 52 [8], and 22 [11] ms, respectively; see Figure 4.7).

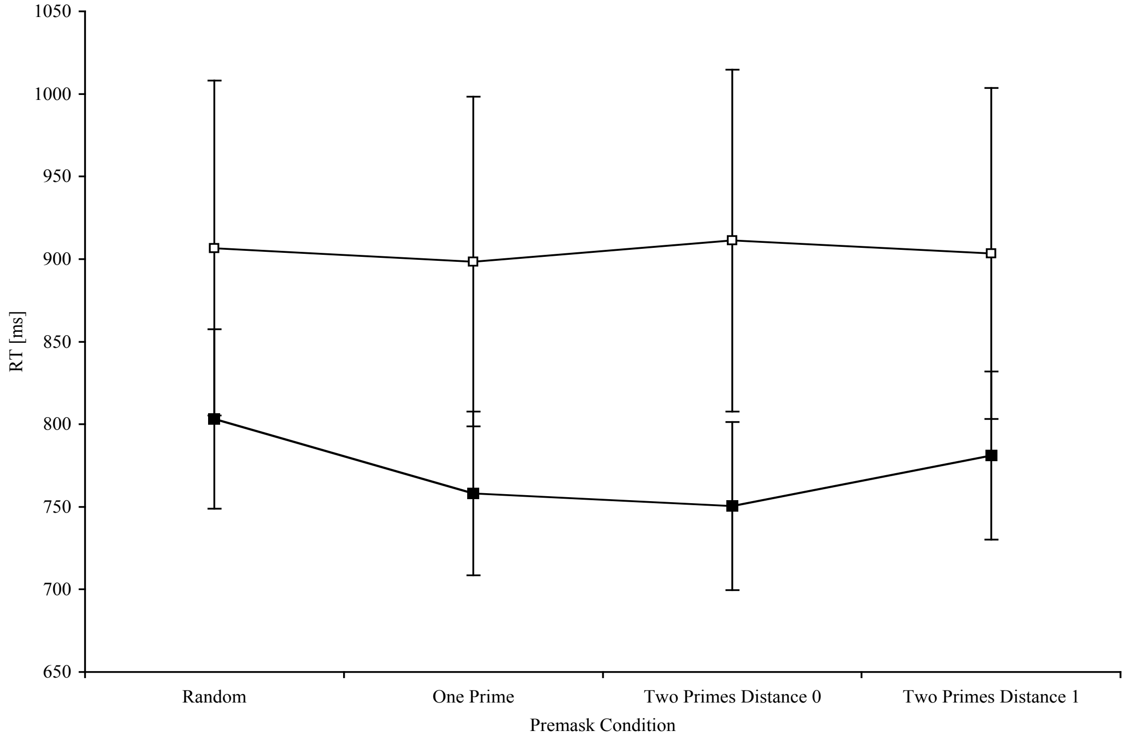

Figure 4.6: Mean correct target-present and target-absent RTs (and their associated standard errors [SE mean]) as a function of Premask condition (random, one prime, two primes distance 0, two primes distance 1). Filled squares represent target-present data, open squares target-absent data.

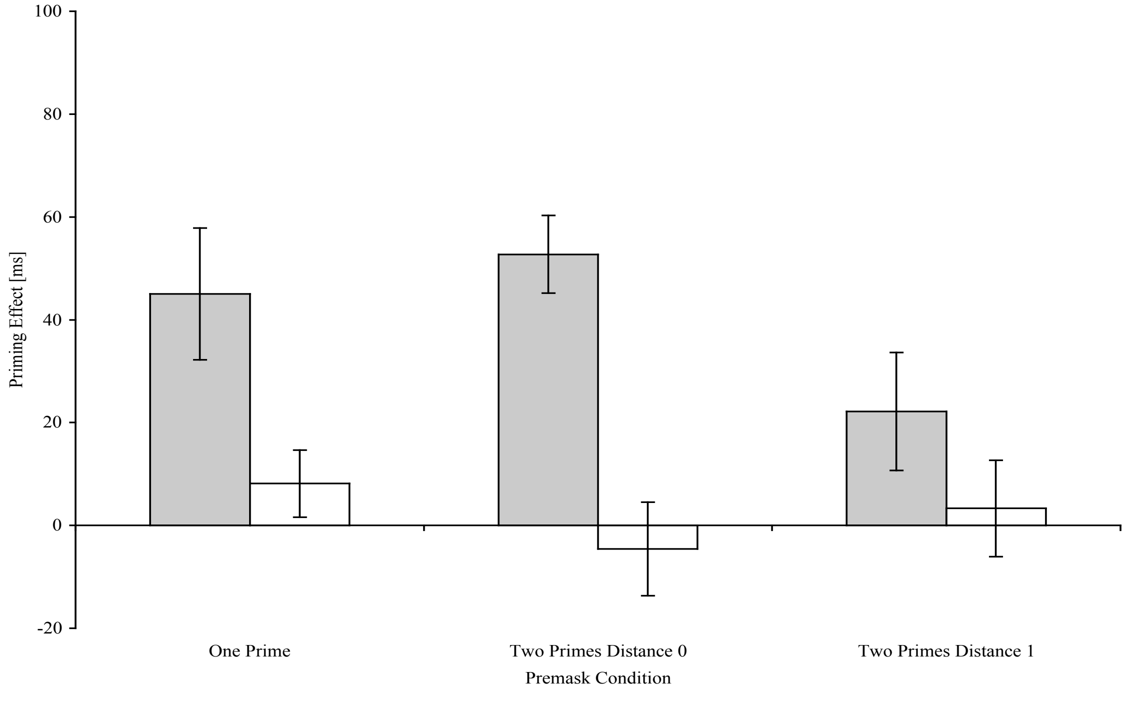

Figure 4.7: Mean priming effects (and their associated standard errors [SE mean]) as a function of Premask condition (random, one prime, two primes distance 0, two primes distance 1). Grey bars represent target-present data, white bars target-absent data.

For better comparability of the premask conditions, a third analysis was carried out that excluded the four possible target locations in the center of the 5×5 target display. These four target positions could not be realized in the two-rimes distance-1 condition; rather, in that condition, both the primes and the subsequent (on-prime) target had always to be presented at a location at the edge of the display matrix. Thus, excluding central prime and target locations in the one-prime and two-primes distance-0 conditions from the analysis was an effective means for controlling for any 'central location' effects that could have distorted the estimate of the priming effect in the two-prime distance 1 condition (relative to the other conditions). The data, depicted in Figures 4.8 (mean correct RTs) and 4.9 (mean synchronicity priming effects), were again examined by a Premask x Target ANOVA. This ANOVA again revealed a significant main effect for Premask, F(1.689, 18.575) = 9.181, p < .01 (G-G). This time, there was no significant effect for Target, F(1, 11) = 3.803, but again a significant Premask x Target interaction, (2.000, 22.002) = 5.259, p < .05 (G-G). Follow-up pairwise comparisons (target-present data only, Bonferroni adjusted) of the random-premask RTs against the three remaining conditions revealed a significant synchronicity priming effect for all these conditions: 57 [17], 49 [13], and 56 [15] ms for the one-prime, two-primes distance-0, and two-primes distance-1 conditions, respectively (p = .005, p = .003, and p = .003, respectively). There were no reliable differences among these priming effects. This pattern is different from the above analysis (of the data distorted by central location primes and targets), in that the undistorted data reveal a large and equivalent-size priming effect even for dual primes that were separated by one row of (asynchronously presented) premask crosses.

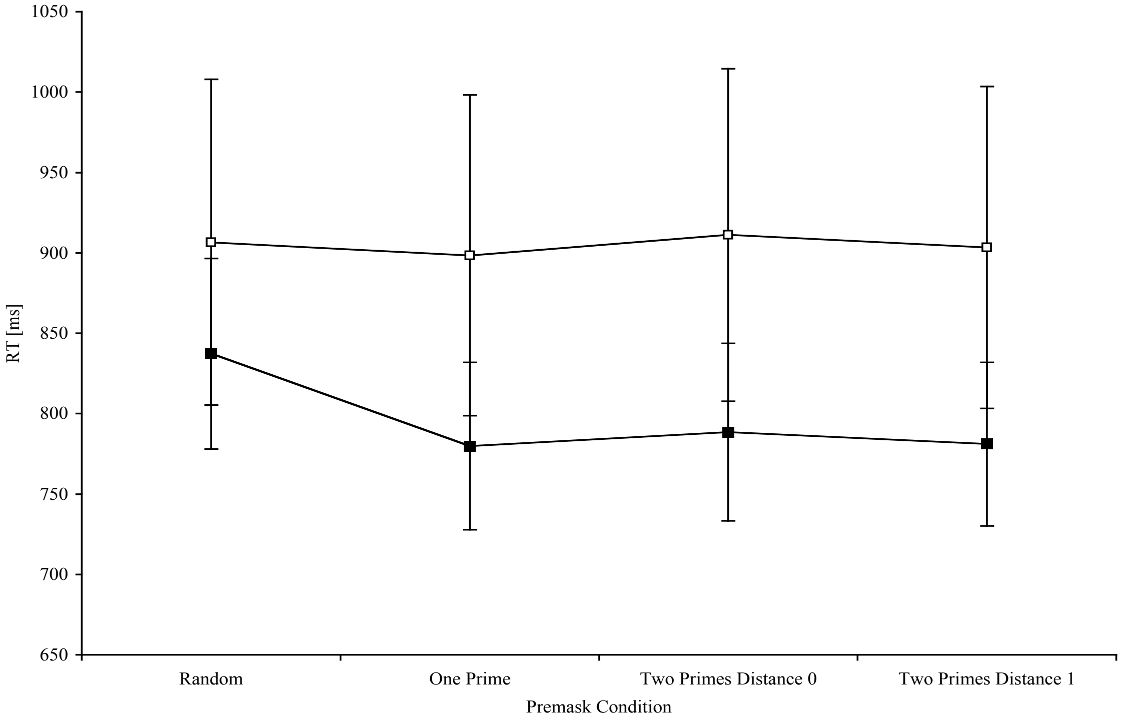

Figure 4.8: Mean correct target-present and target-absent RTs (and their associated standard errors [SE mean]) as a function of Premask condition (random, one prime, two primes distance 0, two primes distance 1). Filled squares represent target-present data, open squares target-absent data.

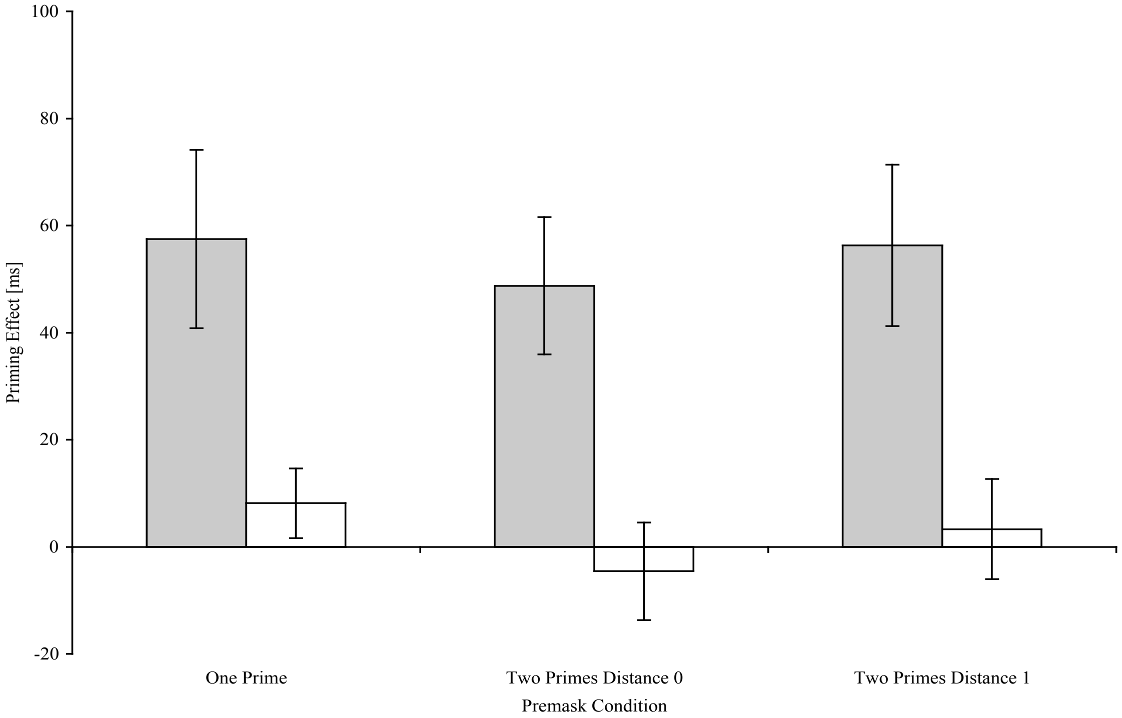

Figure 4.9: Mean priming effects (and their associated standard errors [SE mean]) as a function of Premask condition (random, one prime, two primes distance 0, two primes distance 1). Grey bars represent target-present data, white bars target-absent data.

Error analysis. The error rates are presented in Figures 4.10, 4.11,and 4.12. The overall error rates were 4.98% misses (target-present trials) and 0.49% false alarms (target-absent trials). the arc-sine transformed error data were examined by the same three ANOVAs that had been computed for the RT data. For all three analyses, the patterns of results were identical to those of the RT analyses. The overall ANOVA showed a highly significant effect for Premask, F(2, 22) = 14.180, p < .001, as well as for Target, F(1, 11) = 134.873, p < .001, and the Premask x Target interaction was significant, F(1.243, 13.677) = 16.211, p < .01 (G-G). More errors were made on target-present trials than on target-absent trials (10.07 [0.2] % vs. 0.97 [0.8] %), with a particularly high miss rate on (target-present) trials with a random premask (14.8 [1.4] %; this compares with miss rates of 7.2 [1.0] % vs. 8.2 [1.1] % in one-prime and two-primes conditions; the false alarm rates showed no such difference, 0.7 [0.2] % vs. 0.9 [0.3] % vs. 1.3 [0.4] %).

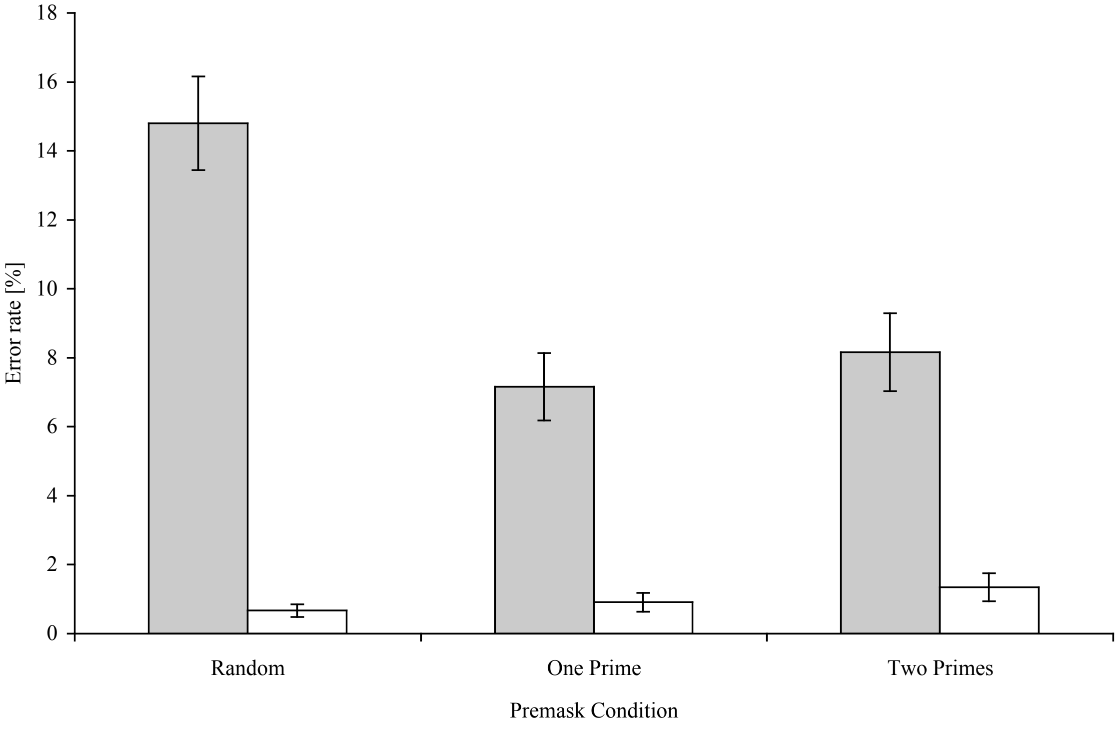

Figure 4.10: Mean error rates (and their associated standard errors [SE mean]) for target-present (grey bars) and target-absent trials (white bars).

The second analysis of the error data, with two-primes condition divided into the two-primes distance-0 and two-primes distance-1 conditions, again revealed significant main effects for both factors, F(3, 33) = 7.704, $p < .001$, for Premask and F(1, 11) = 97.994, $p < .001$, for Target. The Premask x Target interaction was also significant, F(2.042, 22.462) = 10.059, $p < .01$ (G-G). Pairwise comparisons of the target-present data revealed the miss rates for the one-prime and two-primes distance-0 conditions to differ reliably from the random condition ($p < .001$ and $p < .01$, respectively), but not the miss rate for the two-primes distance-1 conditions; 14.8 [1.4] % vs. 7.2 [1.0] %, 7.7 [1.2], and 9.1 [1.6] %, respectively; (see Figure 4.11).

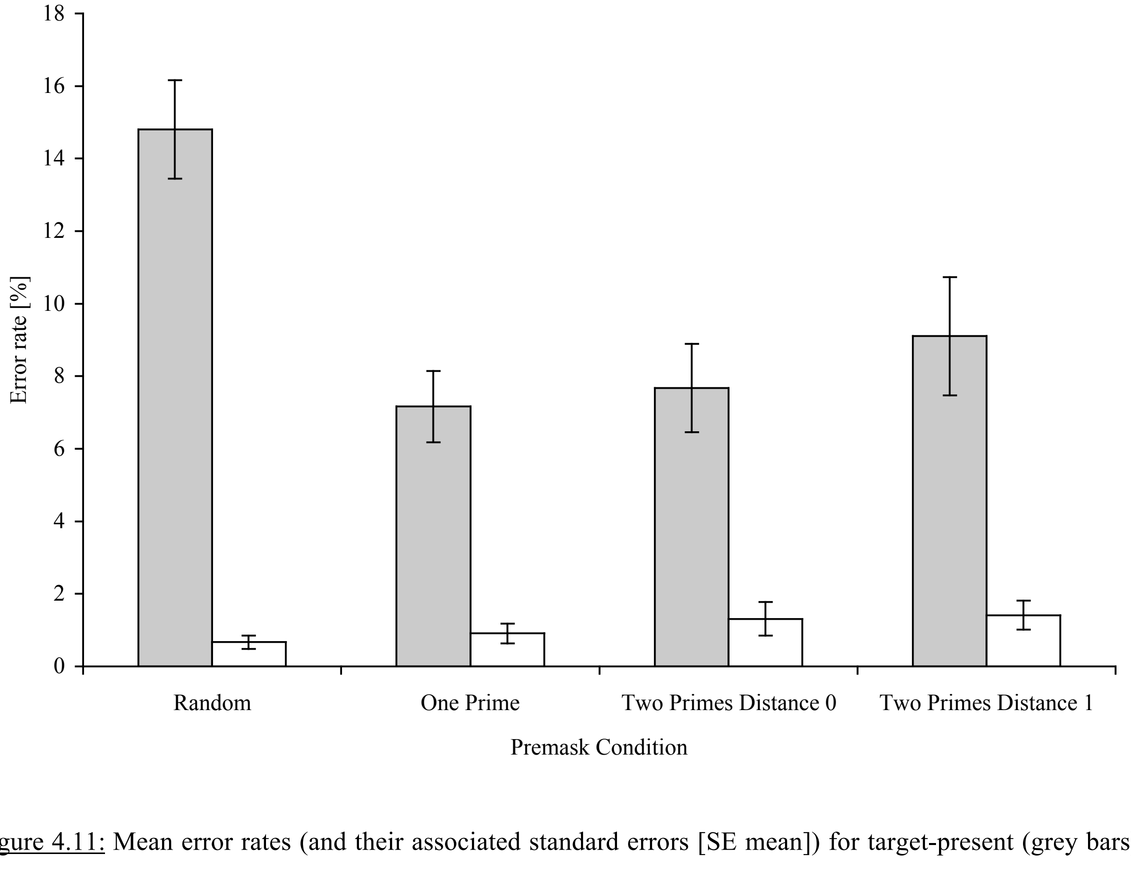

Figure 4.11: Mean error rates (and their associated standard errors [SE mean]) for target-present (grey bars) and target-absent trials (white bars).

The third analysis, performed on data with controlled prime and target locations, showed the same pattern of results as the previous analyses, F(3, 33) = 9.210, p < .001, F(1, 11) = 120.811, p < .001, and F(1.993, 21.923) = 11.808, p < .001 (G-G), for Premask, Target, and Premask x Target, respectively. Pairwise comparisons of target-present data revealed the miss rates for all synchronous prime conditions (one-prime, two-primes distance-0, two-primes distance-1) to differ reliably from the random condition (p = .001, p = .001, and p < .002, respectively); 18.3 [1.8] % vs. 8.6 [1.1] %, 10.5 [1.5] %, and 9.1 [1.6] %, respectively (see Figure 4.12).

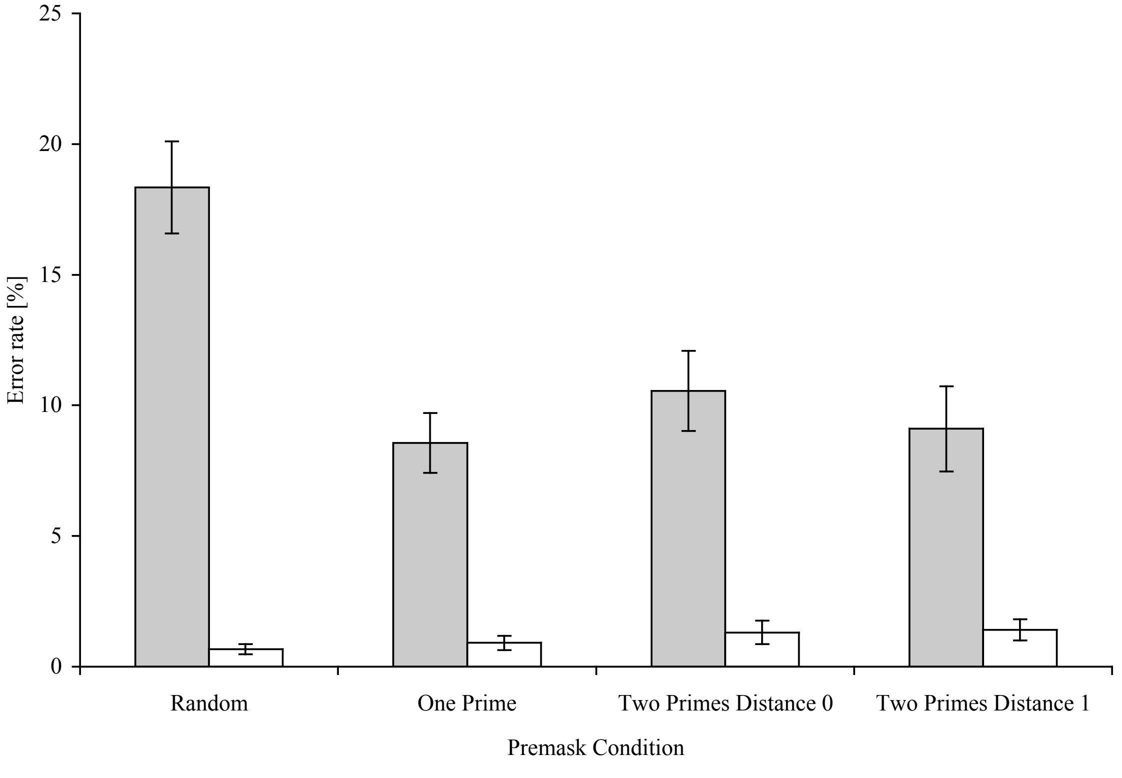

Figure 4.12: Mean error rates (and their associated standard errors [SE mean]) for target-present (grey bars) and target-absent trials (white bars).

Discussion

In this experiment a 5×5 premask was introduced, which could contain either a single prime, two primes, or a random arrangement of premask crosses. On synchronous-prime trials, the target (if one was presented) appeared always exactly at a primed location. The results showed a clear synchronicity priming effect for the single prime condition, replicating the results of the original studies (e.g., Elliott & Müller, 1998). Interestingly, priming effects were also evident in dual-prime conditions, and these were overall as large as those for the single-prime condition. Furthermore, when these effects (with dual primes) were examined as a function of the separation between the two synchronous premasks presented within the same frame, there appeared, at first, some indication of a decline in synchronicity priming when the two primes were separated by one row of (asynchronously presented) premask crosses (two-primes distance-1 condition). However, when eccentricity of prime and target locations was controlled for, this decline was no longer observed. That is, in effect dual primes produced as much synchronicity priming as single primes, and the effects with dual primes were independent of the separation between them. However, it remains unclear if, with separated dual primes (distance-1 condition), there are indeed two independent signals generated, or only one extended prime. What may be taken to argue against the notion of two independent signals is that there was no evidence of competition between the prime signals. In case of competition, one would have expected at least reduced priming effects in that condition relative to the single-prime condition.

The error analysis revealed the same pattern of effects as the RT data, ruling out speed-accuracy trade-offs. This was not necessarily expected, as, in previous studies (e.g., Elliott & Müller, 1998, 2000), the error rates displayed little difference as a function of premask condition. An explanation for the present error effects could be that is was more difficult to find the target within a 5×5 matrix, as compared to 3×3 matrices standardly used in previous studies.

Experiment 2

Experiment 2 was designed to examine whether the facilitative effect of two synchronous primes would still be observed when the separation between the primes is made larger (than the distance 1 in Experiment 1). To this end, a 6×6 matrix of premask crosses (and, subsequently, corner junction elements) was presented, permitting three distance conditions to be realized: distance 0, 1, and 2.

Method

The methodology in Experiment 2 was in all respects the same as described in the General Method section above and in Experiment 1. On synchronous-prime trials, the target (if one was presented) appeared always exactly at a primed location. With dual primes presented directly adjacent to each other (so that they formed a closed rectangular region), the target could appear only at one or the other prime location (but not in the middle of the rectangular region). When dual primes were presented at distance of 2, there were two rows of (asynchronously presented) premask crosses separating the two primes.

Results

RT analysis. Due to high error rates, the data of one observer had to be excluded from the analysis. RTs on trials on which a response error was made (7.57 % of all trials), extreme RTs (< 150 ms and > 2500 ms), and RTs 2.5 standard deviations above or below the mean for each observer (2.56 % of all trials) were removed from the data. Figure 4.13 presents the correct mean RTs (and their associated standard errors [SE mean]) as a function of Premask condition (random, one prime, two primes) x Target (present, absent) condition.

A Premask x Target ANOVA revealed significant main effects for Premask, F(2, 20) = 11.302, p < .01, and Target, F(1, 10) = 23.559, p < .01. Target present RTs were slowest for random-premask trials, fastest on one-prime trials, and intermediate on two-prime trials (RTs and associated standard errors [SE mean]: 935 [69] vs. 906 [71] vs. 921 [72] ms). Further, target-present RTs were significantly faster than target-absent RTs (921 [71] vs. 1070 [93] ms). The Premask x Target interaction was also significant, F(2, 20) = 7.997, p < .01, with only the target-present RTs exhibiting synchronicity priming effects. Pairwise comparisons (Bonferroni adjusted) of the target-present RTs, with the random-premask condition as baseline, revealed the priming to be significant both for the one-prime and the two-primes conditions (p = .002 and p = .007, respectively; priming effects and associated standard errors [SE mean]: 29 [7] vs. 14 [4] ms, respectively) (see Figure 4.14).

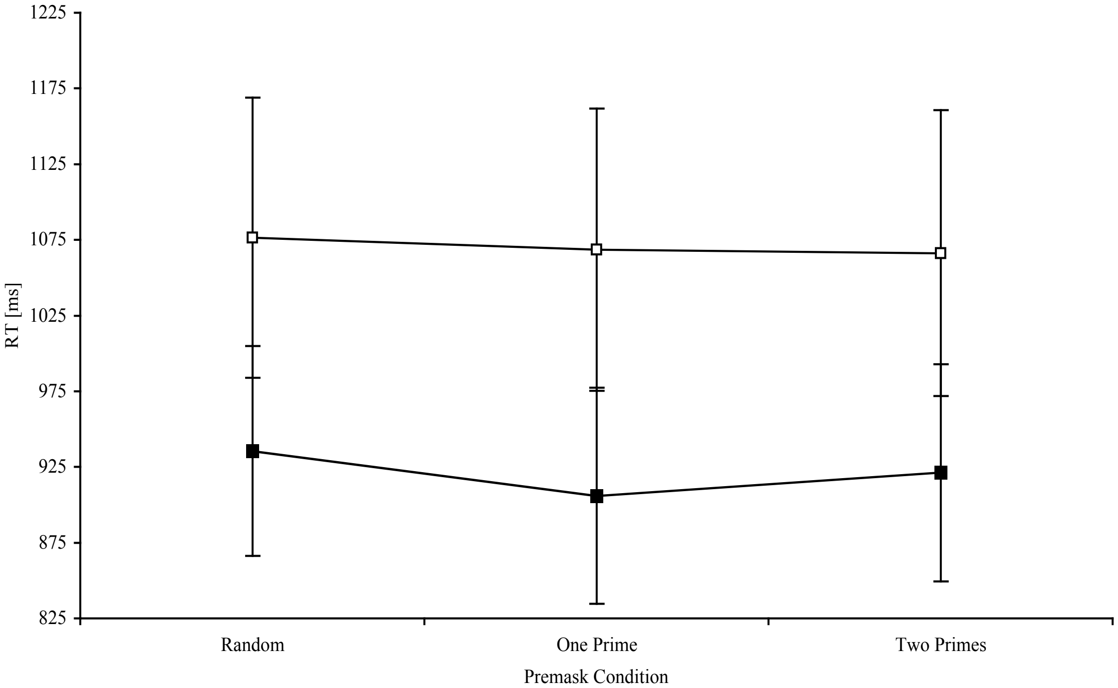

Figure 4.13: Mean correct target-present and target-absent RTs (and their associated standard errors [SE mean]) as a function of Premask condition (random, one prime, two primes). Filled squares represent target-present data, open squares target-absent data.

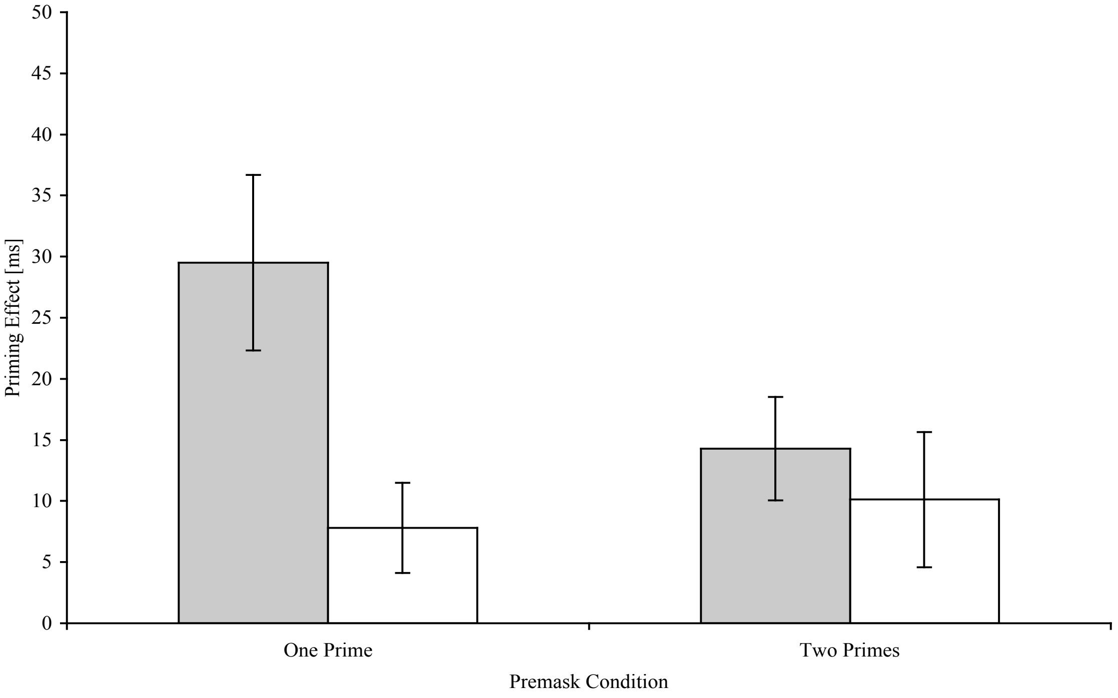

Figure 4.14: Mean priming effects (and their associated standard errors [SE mean]), separately for one-prime and two-primes conditions and for target-present (grey bars) and target-absent conditions (white bars).

In the next step, the data for the two-primes condition were further analyzed as a function of the separation between the two primes: distances 0, 1, and 2, respectively (see Figure 4.15). Again, a Premask x Target ANOVA was conducted, which revealed significant main effects for Premask, F(4, 40) = 31.699, p < .001, and Target, F(1, 10) = 22.563, p < .01. Target-present RTs were faster than target-absent RTs (923 [71] ms vs. 1069 [94] ms). Furthermore, relative to the random-premask condition (1006 [80] ms), the one-prime, two-primes distance-0, and two-primes distance-1 conditions showed an RT advantage (i.e., positive synchronicity priming; 987 [81], 978 [83], and 979 [82] ms, respectively), while the two-primes distance-2 condition showed an RT disadvantage (i.e., negative priming; 1030 [84] ms). The Premask x Target interaction was also significant, F(2.304, 23.040) = 23.498, p < .001 (G-G), due to priming being evident only for target-present trials. Pairwise comparisons (Bonferroni adjusted) of the target-present data only revealed both the random-premask and two-primes distance-2 condition to differ significantly from all other conditions (p < .002 for all tests), while one-prime, two-primes distance-0, and two-primes distance-1 conditions did not differ reliably amongst each other. That is, there was a significant and approximately equal-size synchronicity priming effect in the latter three conditions (29 [7] ms, 41 [5] ms, and 42 [9] ms respectively), but a 'cost' in the two-primes distance 2 condition relative to random-premask condition (-52 [8] ms) (Figure 4.16).

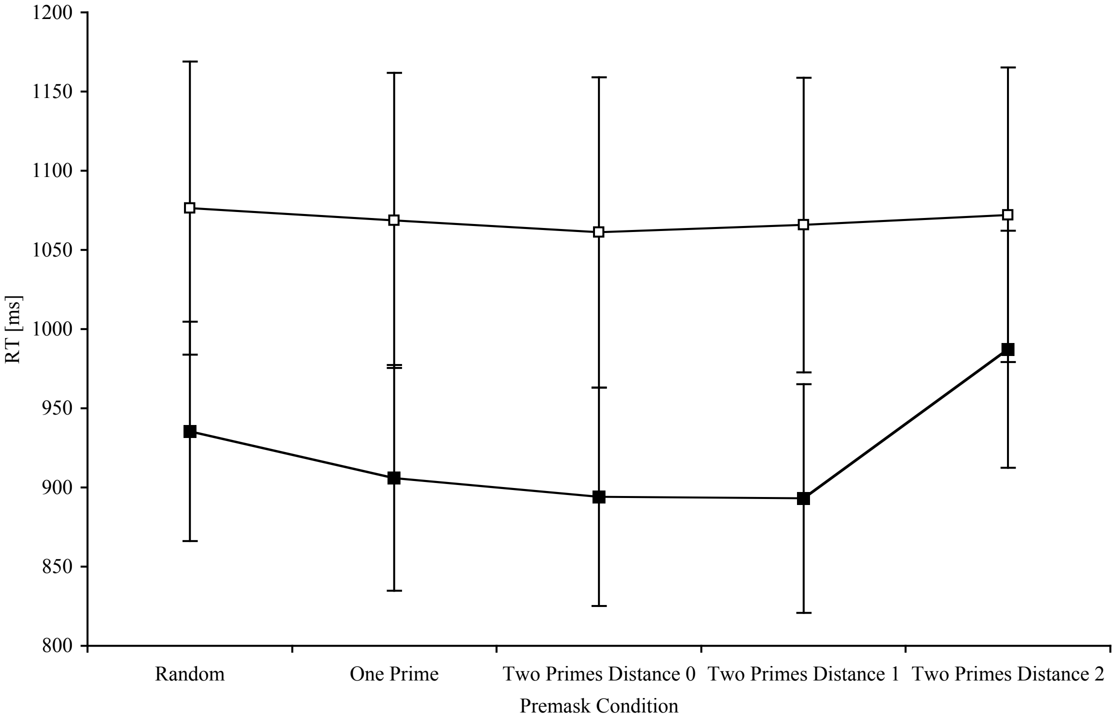

Figure 4.15: Mean correct target-present and target-absent RTs (and their associated standard errors [SE mean]) as a function of Premask condition (random, one-prime, two-primes distance-0, two-primes distance-2, two-primes distance-2). Filled squares represent target-present data, open squares target-absent data.

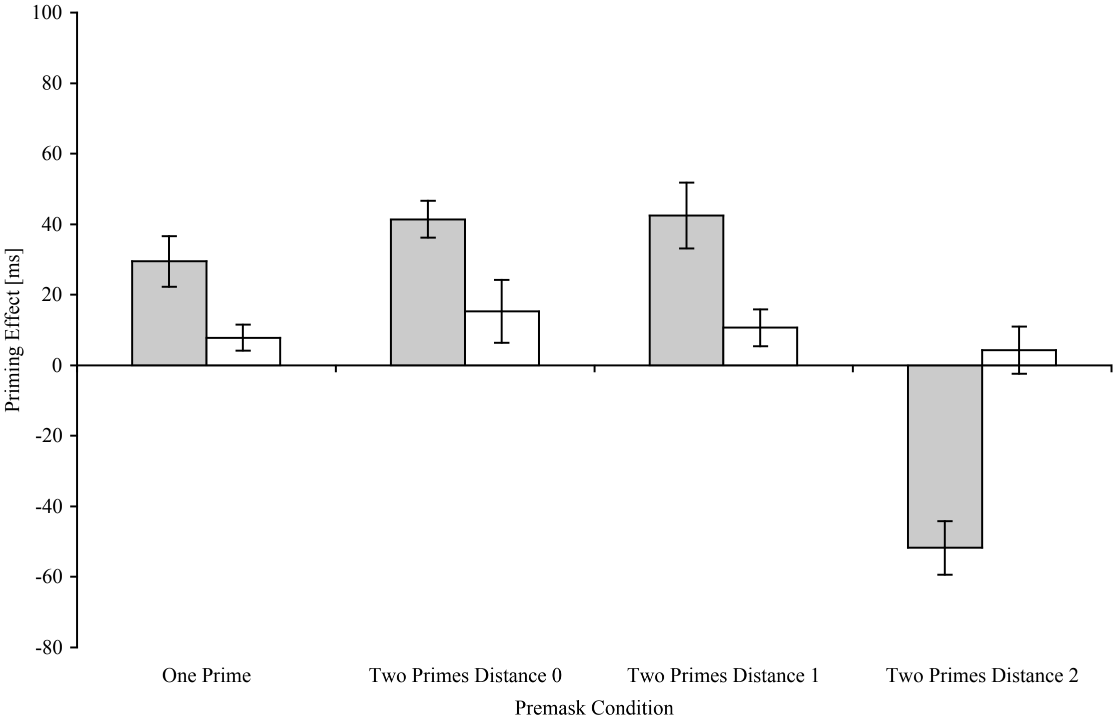

Figure 4.16: Mean priming effects (and their associated standard errors [SE mean]) as a function of premask condition (random, one-prime, two-primes distance-0, two-primes distance-1, two-primes distance-2), separately for target-present (grey bars) and target-absent trials (white bars).

For better comparability of the five matrix conditions, a third analysis was conducted that excluded the nine possible target positions in the center area the 6 × 6 display matrix. These nine target positions could not be realized in the two-primes distance-2 condition, because, in that condition, both the primes and the subsequent target were always presented at a location at the edge of the matrix. Again, a Premask x Target ANOVA was computed, which revealed a subtly different pattern of results to that in the previous analysis (see Figure 4.17). There were significant effects of Premask, F(4, 40) = 13.920, p < .001 (random, one-prime, two-primes distance-0, two-primes distance-2, two-primes distance-2 conditions: 1034 [83], 1011 [83], 1006 [86], 1008 [83], and 1030 [84] ms, respectively), , and Target, F(1, 10) = 16.515, p < .01 (target-present vs. target-absent RTs: 969 [75] vs. 1068 [94] ms), and the Premask x Target interaction was significant, F(4, 40) = 3.715, p < .05, confirming an effect of Premask to be evident only for target-present trials. Pairwise comparisons (Bonferroni adjusted) of the target-present data revealed the random-premask condition to differ significantly from the one-prime, two-primes distance-0, and two-primes distance-1 conditions (p < .002 for all tests), but not from the two-primes distance 2 condition. That is, there was significant synchronicity priming for the one-prime, two-primes distance-0, and two-primes distance-1 conditions (of 39 [8], 40 [5], and 35 [9] ms, respectively), but not for the two-primes distance 2 condition (5 [6] ms) (Figure 4.18). Recall that, in the previous analysis (of eccentricity-distorted data), the latter condition had actually exhibited a negative priming effect (of -52 [8] ms).

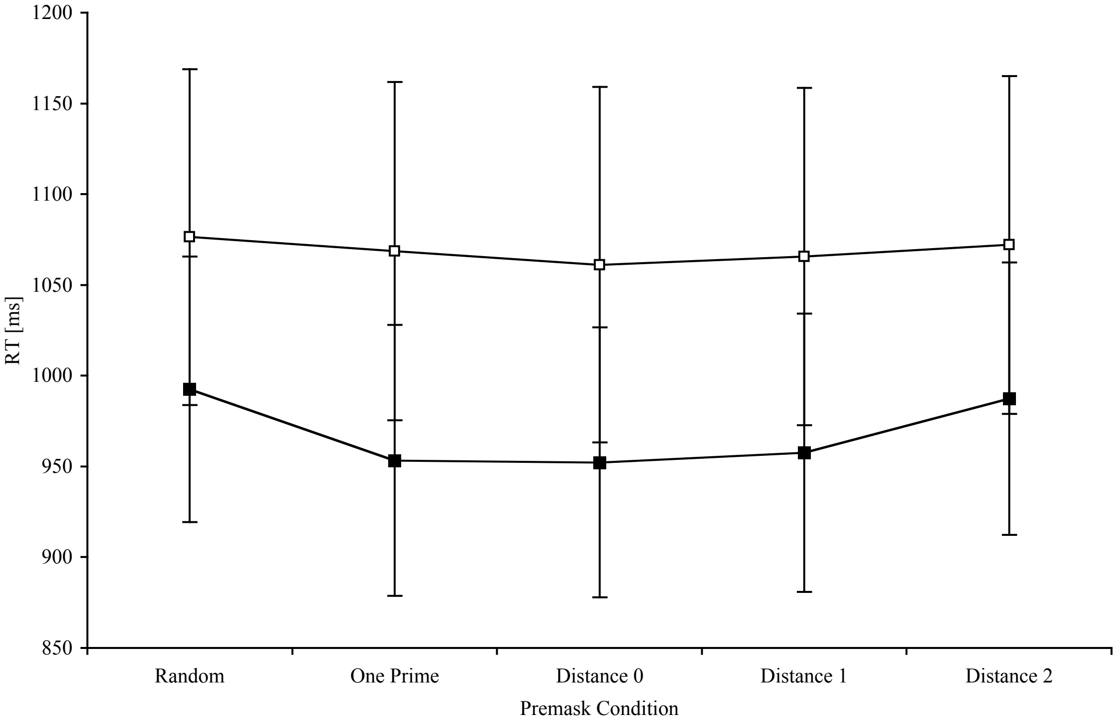

Figure 4.17: Mean correct target-present and target-absent RTs (and their associated standard errors [SE mean]) as a function of Premask condition (random, one-prime, two-primes distance-0, two-primes distance-2, two-primes distance-2). Filled squares represent target-present data, open squares target-absent data.

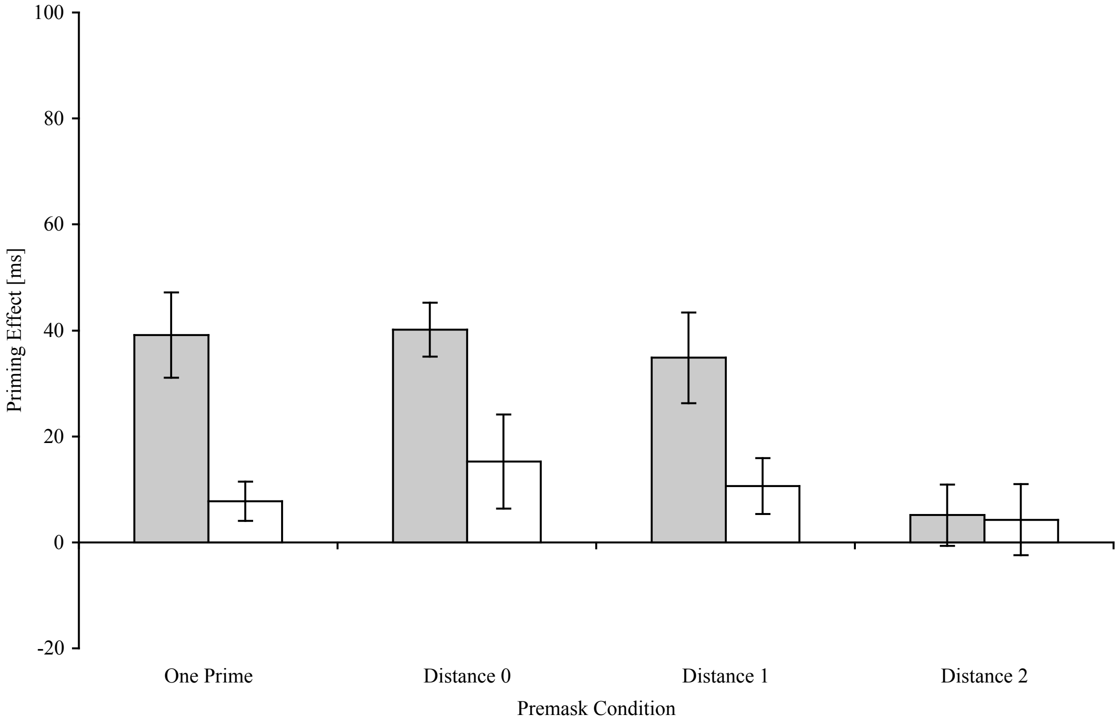

Figure 4.18: Mean priming effects (and their associated standard errors [SE mean]) as a function of premask condition (random, one-prime, two-primes distance-0, two-primes distance-1, two-primes distance-2), separately for target-present (grey bars) and target-absent trials (white bars).

Error analysis. The error data are presented in Figures 4.19 and 4.20. The overall error rates were 6.63% misses (target-present trials) and 0.98% false alarms (target-absent trials). The arc-sine transformed error data were examined in two ANOVAs with the same main terms as in the second and third ANOVAs of the RT data. There were significant effects for Premask, F(4, 40) = 17.097, p < 001, and Target, F(1, 10) = 179.599, p < .001, and the Premask x Target interaction was significant, F(4, 40) = 13.432, p < .001. Pairwise comparisons (Bonferroni adjusted) of the miss rates (target-present trials) showed that, in the random-premask and two-primes distance-2 conditions, significantly more errors were made than in the other conditions (p < .005 for all tests), which showed no differences amongst each other. The pattern of miss rate effects is consistent with the RT data. [For target-absent trials, only the two-primes distance-1 condition showed an slightly, but significantly increased miss relative to the random-premask condition.]

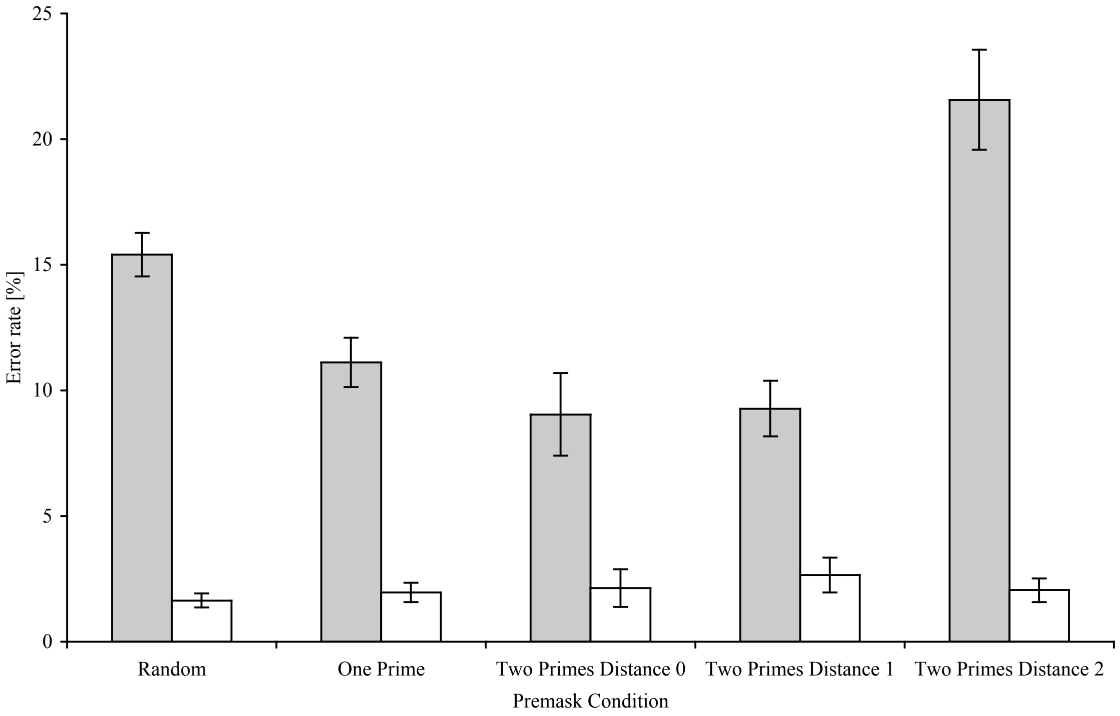

Figure 4.19: Mean error rates (and their associated standard errors [SE mean]) as a function of premask condition (random, one-prime, two-primes distance-0, two-primes distance-1, two-primes distance-2), separately for target-present (grey bars) and target-absent trials (white bars).

The error rates changed slightly when locations in the central area of the display matrix were excluded from analysis. There were 7.30% misses (target-present trials) and 1.20% false alarms (target-absent trials). The ANOVA revealed all effects to be significant: Premask, F(4, 40) = 4.605, $p < .01$, Target, F(1, 10) = 285.772, $p < .001$, and Premask x Target, F(4, 40) = 4.386, $p < .01$. While pairwise comparisons (Bonferroni adjusted) of the miss rates (target-present trials) revealed no significant differences between premask conditions (due to too much noise in the error data), the pattern apparent in Figure 4.20 again mirrors the corresponding RT data, ruling out confounding of the RT effects by speed-accuracy trade-offs.

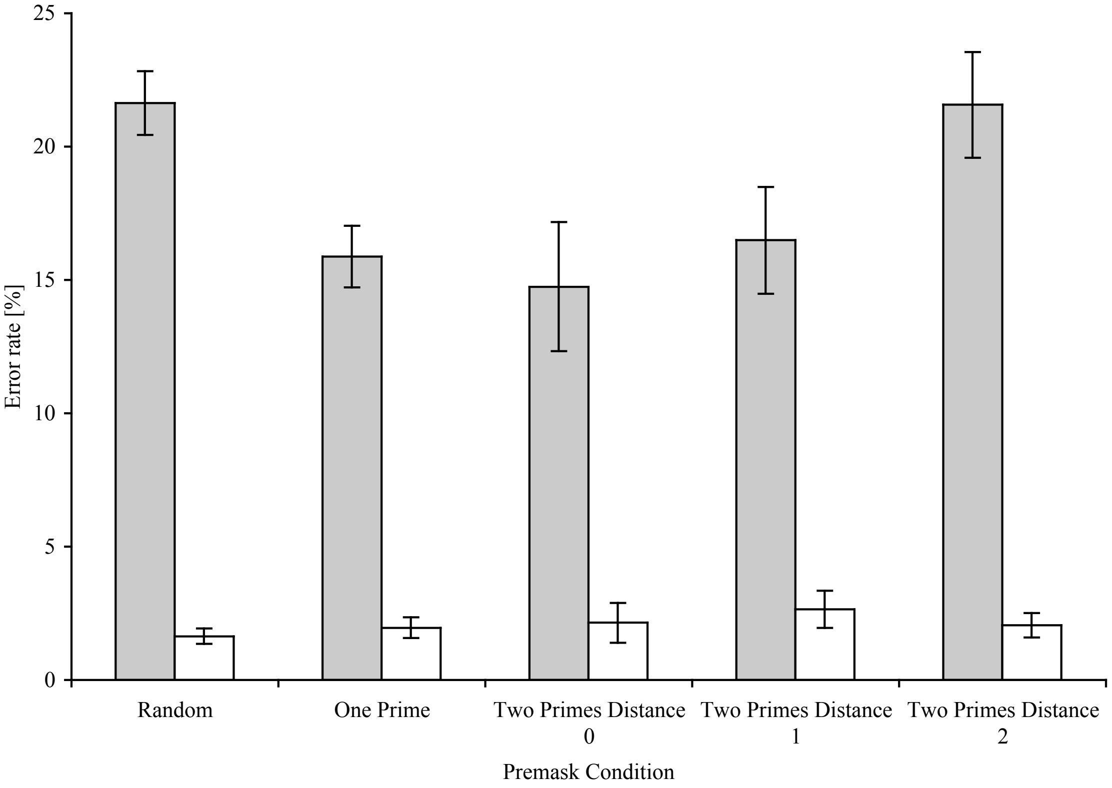

Figure 4.20: Mean error rates (and their associated standard errors [SE mean]) as a function of premask condition (random, one-prime, two-primes distance-0, two-primes distance-1, two-primes distance-2), separately for target-present (grey bars) and target-absent trials (white bars).

Discussion

A 6×6 matrix display was introduced in Experiment 2 to examine the effect of larger spatial separations between dual primes. As in Experiment 1, significant priming effects were evident in both one-prime and two-primes conditions, and, again, target eccentricity influenced (or, rather, confounded) the priming effects for the dual-prime condition with the largest separation between the two primes. When eccentricity was controlled for, synchronicity priming was found only for the two-primes distance-0 and two-primes distance-1 conditions (the effect in these conditions was as large as that in the one-prime condition), but not for the two-primes distance-2 condition, in which the separation between the two primes was the largest.

One interpretation of the absence of priming in the latter (two-primes distance-2) condition might be that the two primes produce separate signals entering into a competitive interaction with one other, with one winning the competition. This would reduce the overall synchronicity priming effect (averaged across the two prime locations), as, statistically, the winning prime location would be the target location on only 50% of the (target-present) trials. However, if this were true, one would have expected significant, albeit reduced priming on two-primes distance-2 trials (which was, however, not the case).

An alternative explanation might be that the two primes, separated by ‘distance 2’, somehow integrate their signals into a single prime field (perhaps with a lessened field strength at marginal field locations). This would predict priming for target presented intermediate between the two prime locations (even though the premask elements at the intermediate locations would have been presented asynchronously to the synchronous premask elements). This possibility was further explored in Experiment 3 and 4.

Experiment 3

Experiment 3 was designed to examine whether two spatially non-contiguous synchronous primes would integrate their signals to form a single, coherent ‘prime field’, which facilitates detection even for targets presented at locations intermediate between the primes. Several outcomes are conceivable. First, the two signals could integrate to a ‘Gaussian-type’ prime field, with maximum field strength in the center position between the two primes generating it. Somewhat counter-intuitively, this would lead to larger priming effects for targets presented in-between the primes. A second possibility is that the primes form a ‘square-wave-type’ prime field signal with the primed regions defined by relatively sharp edges. In this case, detection of targets in-between primes should benefit to the same degree from priming as targets presented directly on prime locations.

Method

Experiment 3 used the 5×5 matrix, already used in Experiment 1. In contrast to Experiment 1 (in which targets were always presented directly on prime positions), in Experiment 3, targets could also appear at locations in-between the prime positions. 50% of all trials were target-present trials and 50% target-absent trials. The experiment consisted of a total of 1280 trials: 320 random-premask trials, 320 one-prime trials, and 640 dual-prime trials (for target present trials, there were 160 trials with two primes separated by distance 0 and 160 trials with two primes separated by distance 1, on one half of these trials the target appeared at the same location of one of both primes, on the other half the target appeared between both primes, see Figure 4.21). All combinations of conditions were varied randomly from trial to trial.

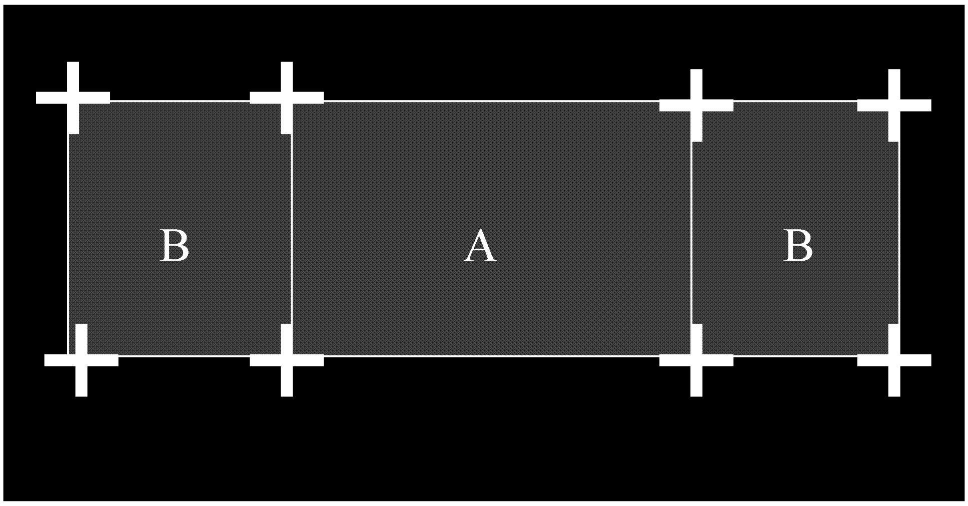

Figure 4.21: Possible target regions (positions): A) Between Primes B) On Prime.

Results

RT analysis. RTs on trials on which a response error was made (5.11 % of all trials), extreme RTs (< 150 ms and > 2500 ms), and RTs 2.5 standard deviations above or below the mean for each observer (2.99 % of all trials) were removed from the data. Figure 4.22 presents the correct mean RTs (and their associated standard errors [SE mean]) as a function of Premask (random, one-prime on-target, two-primes on-target, two-primes between-target) x Target (present, absent) condition.

First, a two-way ANOVA with main terms for Premask (random, one-prime, two-primes) and Target was computed, excluding trials with target positions between dual primes (as this condition was not defined for target-absent trials). This analysis revealed a significant effects for Premask, F(2, 24) = 9.637, p < .01, Target, F(1, 12) = 15.131, p < .01, and Premask x Target, F(2, 24) = 3.740, p < .05. RTs were faster for target-present trials than for target-absent trials (978 [44] vs. 1195 [86] ms), and there were a synchronicity priming effect only when a target was present (Premask x Target interaction). Responses were overall slowest on random-premask trials, intermediate on one-prime trials, and fastest on two-primes trials (RTs and their associated standard errors

[SE mean]: 1099 [63], 1087 [62], and 1074 [63] ms, respectively). Pairwise comparisons (Bonferroni adjusted) revealed that, on target-present trials, the one-prime and two-primes conditions showed significant priming relative to the random-premask baseline (priming effects and their associated standard errors [SE mean]: 24 [7] and 40 [9] ms, respectively); the difference in the size of these effects was non-significant. [In contrast, no reliable priming effects were to be found for target-absent trials (-2 [7] ms vs. 9 [6] ms, respectively).]

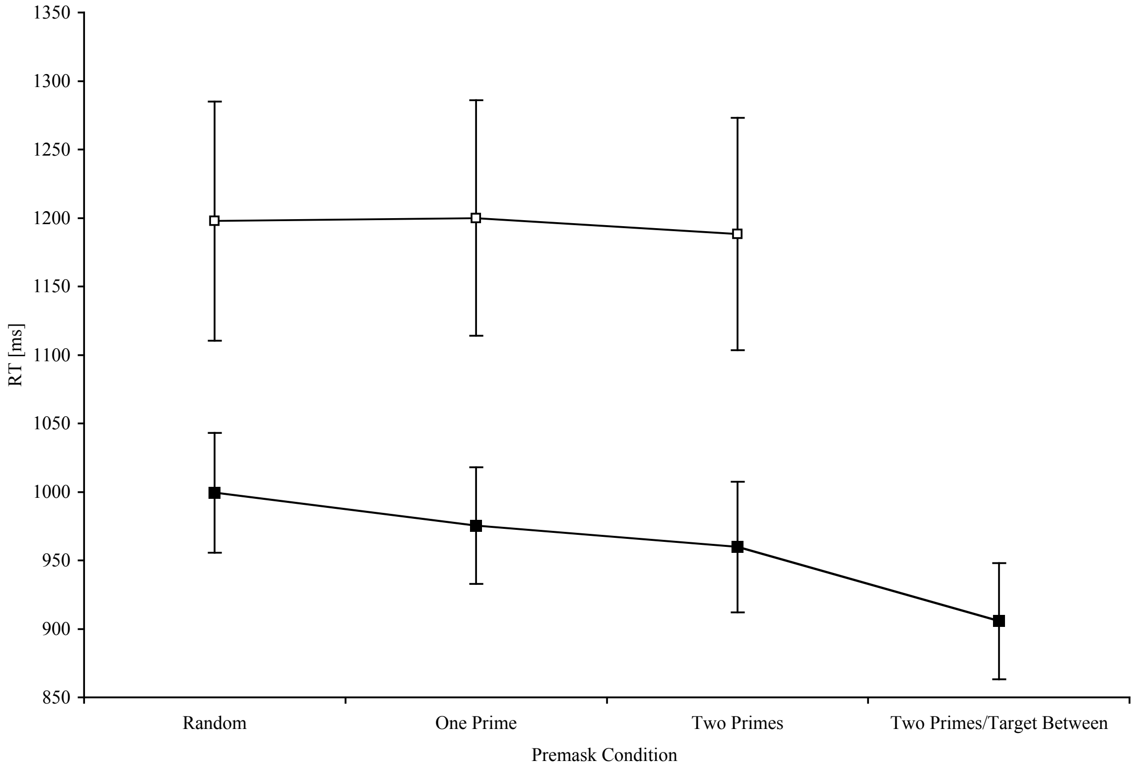

Figure 4.22: Mean correct target-present and target-absent RTs (and their associated standard errors [SE mean]) as a function of Premask condition (random, one-prime on-target, two-primes on-target, two-primes between target). Filled squares represent target-present RTs, open squares target absent RTs.

Next, in another one-way ANOVA, the target-present premask conditions were compared against each other, this time including the condition ‘two-primes between-target’. The Premask effect was a highly significant, F(3, 36) = 30.678, p < .001. Pairwise comparisons (Bonferroni adjusted) of the differences between conditions revealed significant synchronicity priming effects for all synchronous premask conditions, with the (reliably) largests effect for the 'two-primes between-target' condition: 94 [9] ms (only the one-prime and the two-primes on-target conditions did not differ significantly from each other, with priming effects of 24 [7] and 40 [9] ms, respectively) (see Figure 4.23).

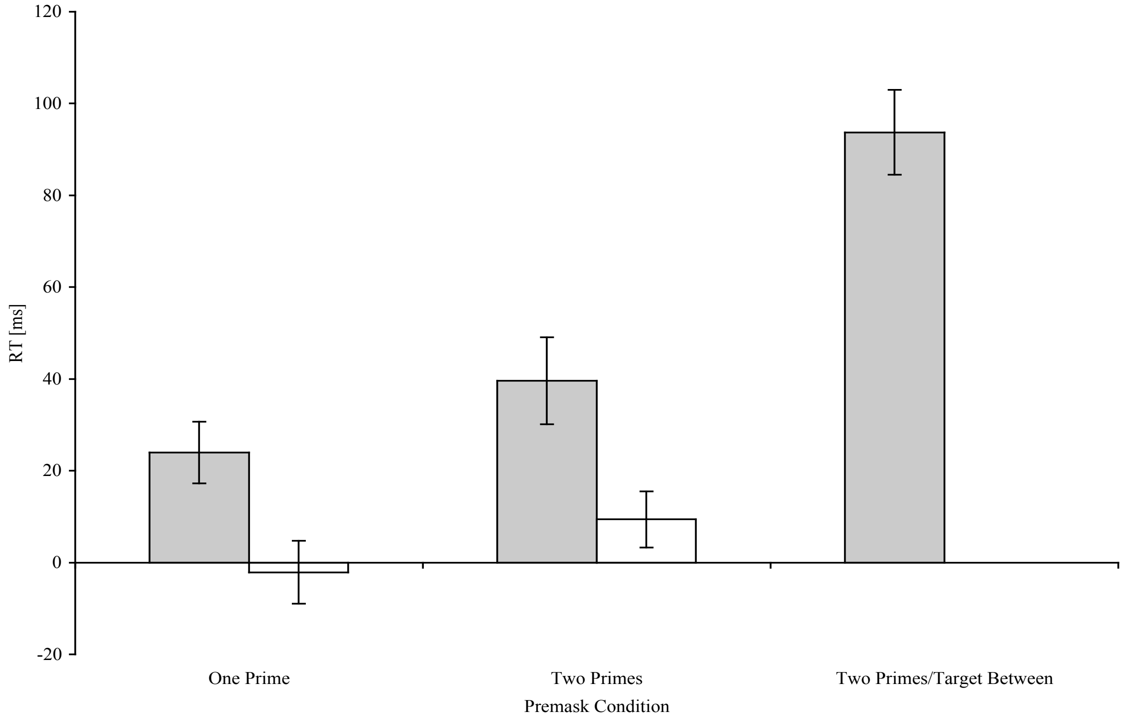

Figure 4.23: Mean priming effects (and their associated standard errors [SE mean]) as a function of Premask (one-prime on-target, two-primes on-target, two-primes between target) for target-present (grey bars) and target-absent data (shaded bars).

As for the previous experiments, another analysis was conducted excluding the four possible target positions in the center of the 5×5 display matrix. Again, an ANOVA with the terms Premask and Target was computed, excluding trials on which the target appeared between dual primes (two-primes between-target). This analysis revealed all effects to be significant (see Figure 4.24): Premask, F(3, 36) = 9.928, p < .001, Target, F(1, 12) = 14.566, p < .01, and Premask x Target, F(3, 36) = 4.934, p < .01. Pairwise comparisons (Bonferroni adjusted) of the random premask condition against the three remaining (synchronous-premask) conditions revealed significant priming for each condition on target-present trials (40 [7] ms, p < .001, for one-prime, 48 [12] ms, p = .001 for two-primes distance-0, and 65 [13] ms, p <. 001, for two-primes-distance-1) (see Figure 4.25). [There were no reliable differences among conditions for target absent trials.]

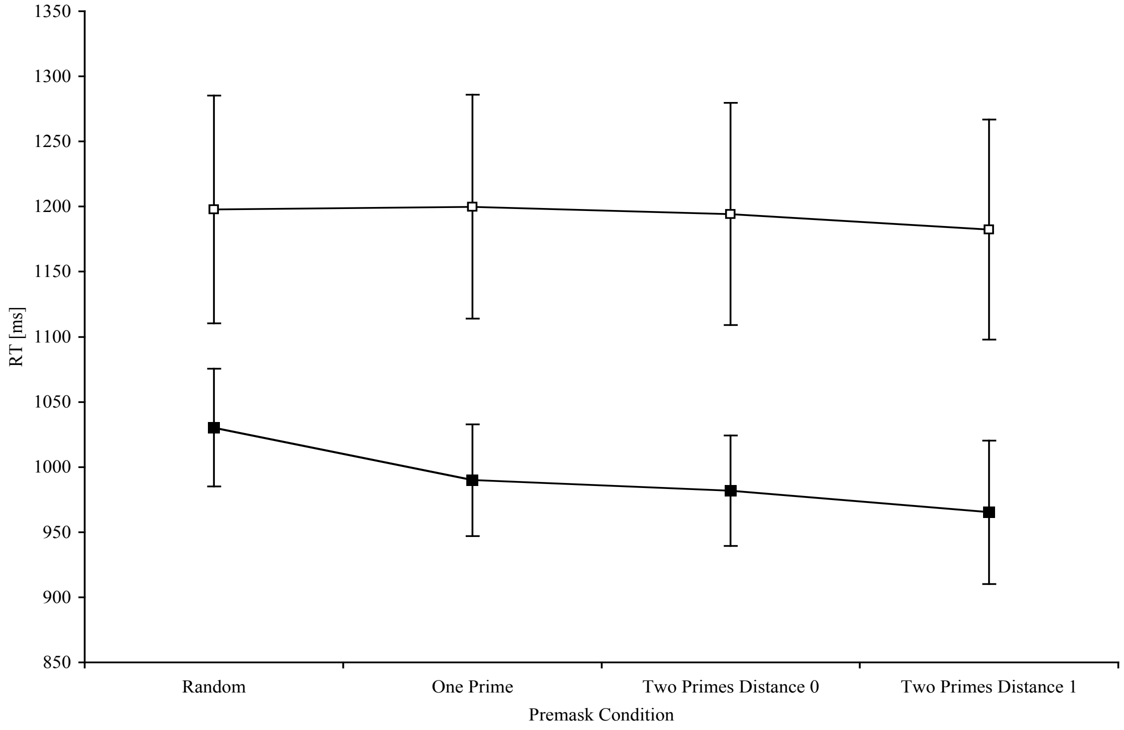

Figure 4.24: Mean correct target-present and target-absent RTs (and their associated standard errors [SE mean]) as a function of Premask condition (random, one-prime, two-primes distance-0, two-primes-distance 1). Filled squares represent target-present data (on-prime targets only), open squares target-absent data.

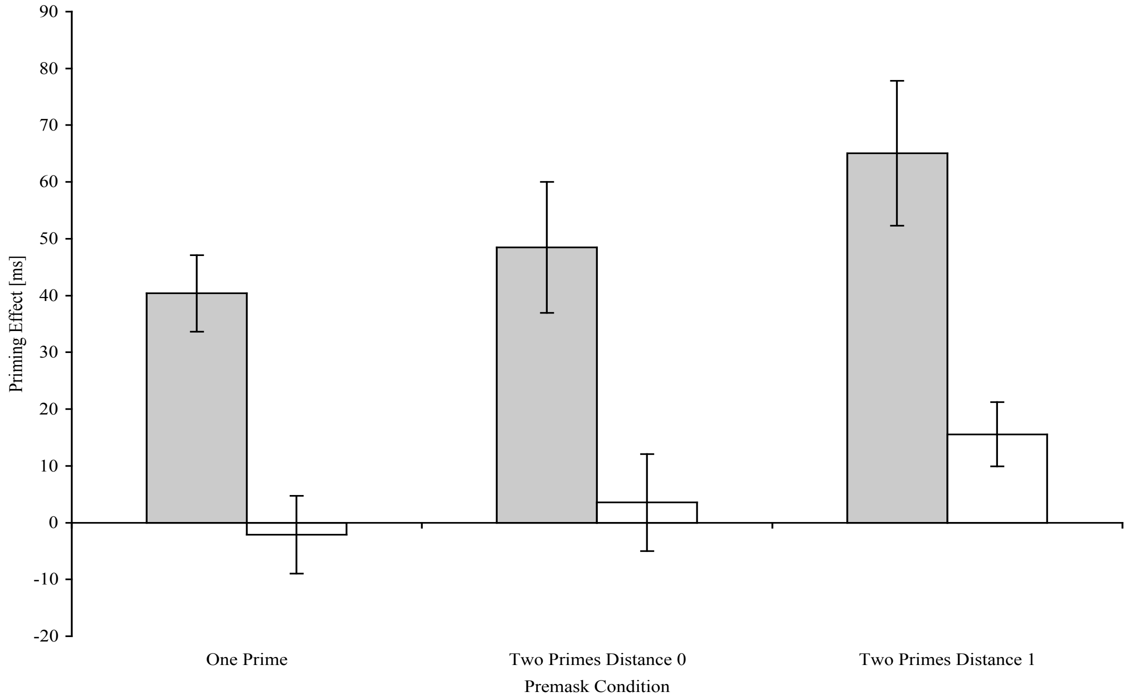

Figure 4.25: Mean priming effects (and their associated standard errors [SE mean]) as a function of Premask condition (one-prime, two-primes distance-0, two-primes-distance 1), separately for target-present (on-prime targets only; grey bars) and target-absent data (white bars).

The theoretically more interesting analysis concerns the comparison, with dual primes, of the various distance (0, 1) and target position conditions (on-target, between-target). For this comparison to be undistorted, it was necessary to exclude further target locations from the analysis. In particular, not only the central target locations were excluded, but also the corner locations of the display matrix, as a target could never appear on a corner location and, at the same time, between two prime locations (i.e., by definition, a target appearing at a corner location could not be an in-between target). The remaining data (after exclusion of corner locations) were examined by a two-way ANOVA with the factors Prime Distance (0, 1) and Target Position (on-prime-target, between-primes-target). This revealed the following results (see Figure 4.26 and 4.27): significant main effect for Target Position, F(1, 12) = 17.609, p < .01, with faster RTs to targets appearing between dual primes, relative to targets appearing on one of the dual primes (RTs and their associated standard error [SE mean]: 926 [44] and 960 [46] ms for between-target and on-target conditions, respectively). The main effect of Prime Distance and the Distance x Target Position interaction were not significant, F(1, 12) = .438 and F(1, 12) = .988, respectively.

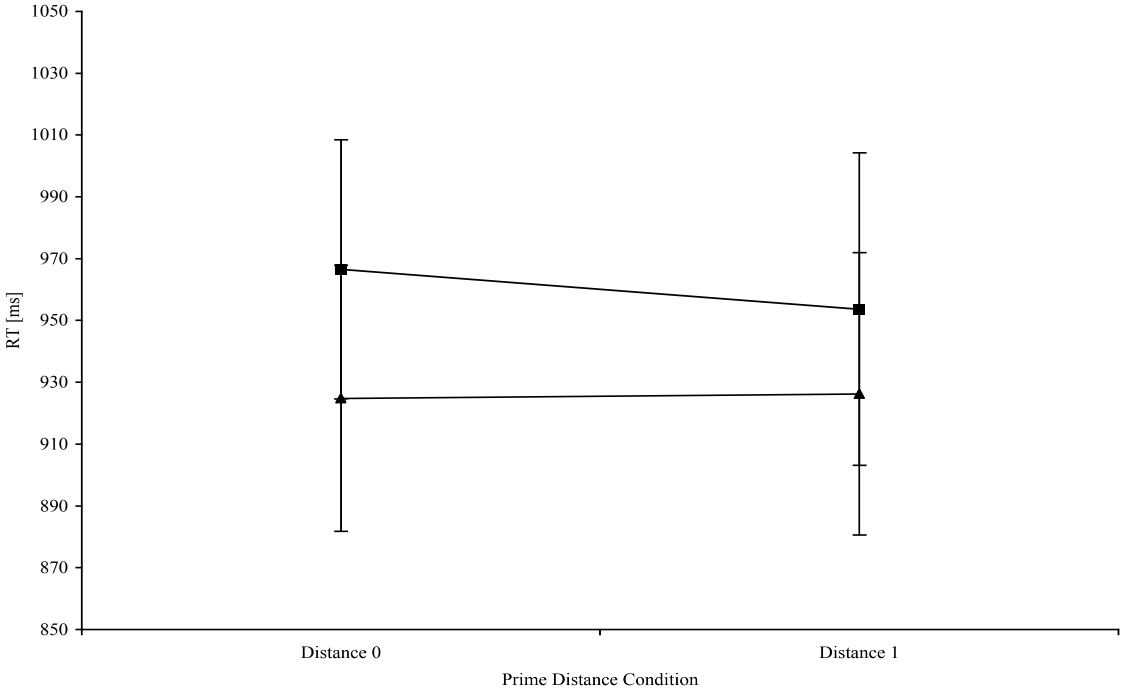

Figure 4.26: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Prime Distance (distance-0, distance-1) and Target Position (on-prime-target, between-primes-target). Squares represent on-target data and triangles between-target data.

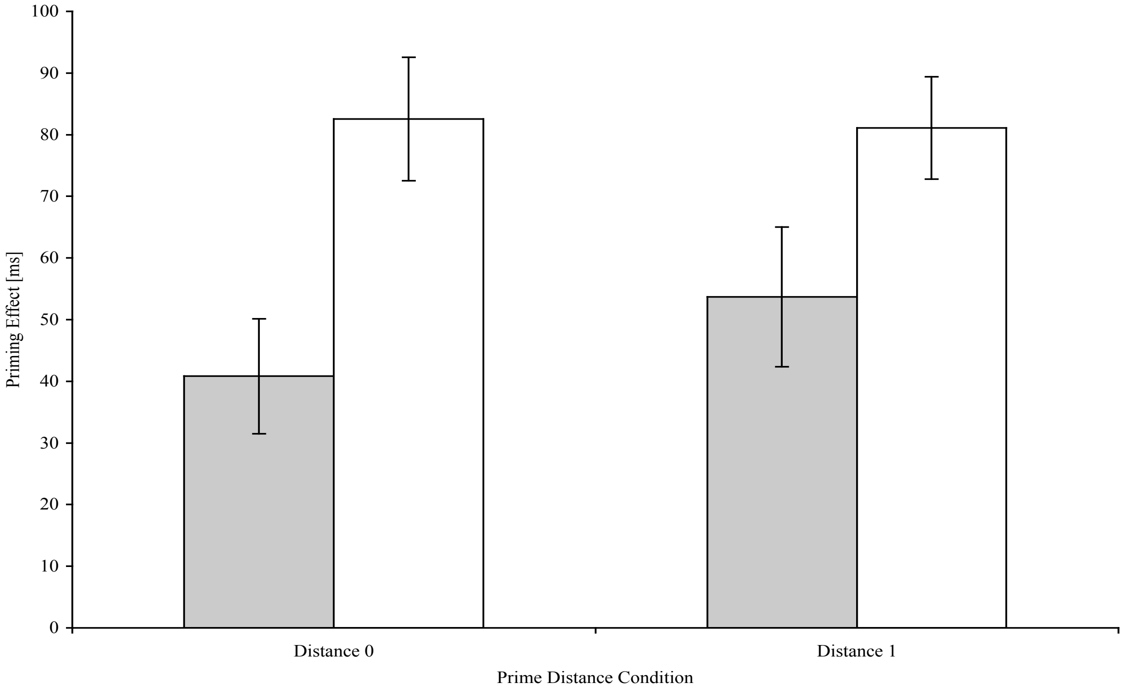

Figure 4.27: Mean priming effects (and their associated standard errors [SE mean]) as a function Prime Distance (distance-0, distance-1) and Target Position (on-prime-target, between-prime-target). Grey bars represent on-target data and white bars between-target data, respectively.

Error analysis. The error data are presented in Figures 4.28 and 4.29. For the data set in which central target positions were excluded, the overall error rates were 4.38% misses (target-present trials) and 1.12% false alarms (target-absent trials). A Premask x Target ANOVA of the arc-sine transformed error data (same factors as in second RT-ANOVA) revealed a significant effect for Premask, F(3, 36) = 5.041, p < .01, and target, F(1, 12) = 31.371, p < .001, and a marginally significant Premask x Target interaction, F(2.005, 24.055) = 3.396, p = .05 (G-G). Pairwise comparisons (Bonferroni adjusted) against the random-premask condition revealed no reliable differences for target-absent trials; but for target-present trials, the miss rate for the two-primes distance 1 condition was significantly lower than the rate for the random-premask condition (p =. 001). As can be seen from Figure 4.28, the error rates (in particular, the miss rates) were reduced on two-primes conditions, consistent with the previous experiments.

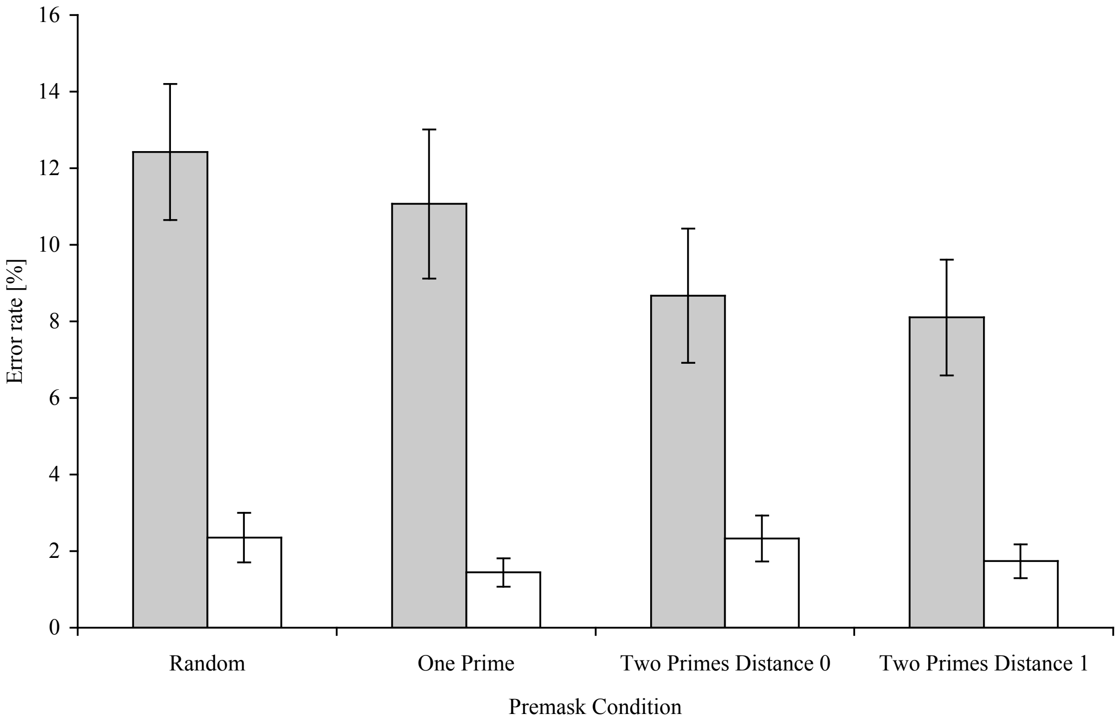

Figure 4.28: Mean error rates (and their associated standard errors [SE mean]) as a function of Premask condition (one-prime, two-primes distance-0, two-primes distance-1) and Target (present, absent). Grey bars represent target-present data, white bars target-absent data.

A second two-way ANOVA of the miss rates in dual-primes conditions, with a design corresponding to that of the third ANOVA of the RT data (with corner positions excluded from analysis), showed no significant effects of Prime Distance, Target Position, and Distance x Target Position, F(1, 12) = 0.496, F(1, 12) = 0.705, and F(1, 12) = 0.158, respectively.

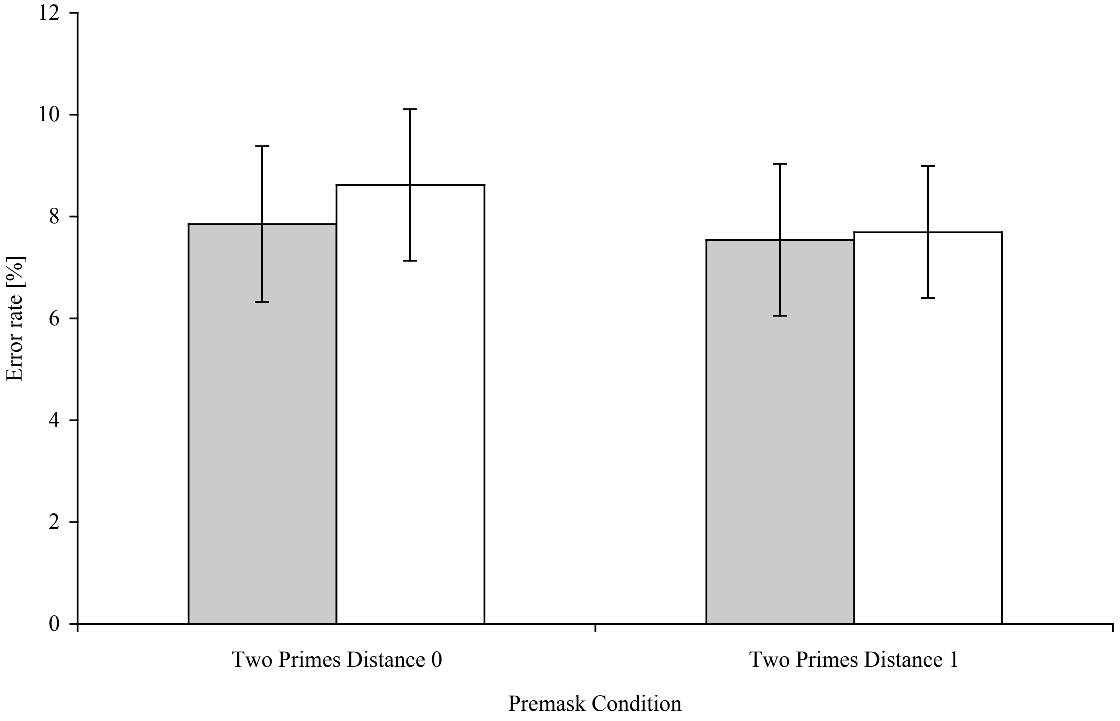

Figure 4.29: Mean error rates (and their associated standard errors [SE mean]) as a function of Prime Distance (0, 1) and Target Position (on-prime-target, between-prime-target). Grey bars represent on-target data and white bars between-target data.

Discussion

By systematically varying target position (target on prime, target between dual primes), it could be examined whether targets which were presented between two synchronous primes, would yield a larger priming effect than targets presented directly on prime locations. This was indeed the case: between-prime targets benefited from larger priming effects than on-prime targets. This was the case even when the two synchronous premasks were separated by one row of intervening premask crosses (which were presented asynchronously relative to the synchronous-premask crosses). This pattern of effects suggests that the synchronous-prime signals are integrated, in a ‘Gaussian-type’ fashion, into a single coherent prime field (with the integration working even across asynchronously flickering premask elements), with peak signal strength in the middle of the field.

However, it cannot be ruled out that the large ‘priming’ effects observed for between-prime targets is only based on prime signal integration. Although target positions were controlled for, targets between primes were systematically nearer to the central horizontal or vertical axes of the display matrix, relative to identical prime trials. Experiment 4 was designed to control for this possible eccentricity confound.

Experiment 4

Experiment 4 was designed to re-examine the priming effects for targets presented between prime locations, using one larger distance between primes than in Experiment 3 (6×6 matrix, permitting the additional ‘two-primes distance-2 condition’ to be introduced; see Experiment 2).

Furthermore, additional conditions were introduced to control for possible (eccentricity) confounds of the priming effects for between-prime targets obtained in Experiment 3. In particular, to control for the effect of central-axis neighborhood on trials with between-prime targets, two further target position conditions were implemented: ‘lateral-to-prime target’ and ‘lateral-between-prime target’ conditions. On ‘lateral-to-prime target’ trials, the target appeared next (that is, lateral) with respect to a synchronous prime, with two overlapping element locations; and on ‘lateral-between-primes target’ trials, the target appeared between the primes, but mislocated such that only two target elements were collinear with the prime elements (this compares with in-between-primes targets for which all four elements were collinear with the prime elements). As the latter (‘lateral-between-primes’) target positions were also in the direct neighborhood of the central display axes, but not (entirely) within the peak region of the integrated prime signals, a smaller or no priming facilitation should be evident relative to random-premask condition (see Figure 4.30).

Finally, additional single-prime conditions were implemented in which target postions could be mislocated relative to the prime. In particular, there were four possible distances separating the prime and target positions. This made it possible to examine whether mislocated targets would receive a priming advantage or, respectively, a disadvantage, relative to the random-premask baseline, as a function of their distance from the prime. Although this question was examined by Elliott and Müller (1998, Experiment 3) using a 3×3 matrix, it cannot be ruled out that primes at larger distances than could be realized in the 3×3 matrix have an influence on target detection.

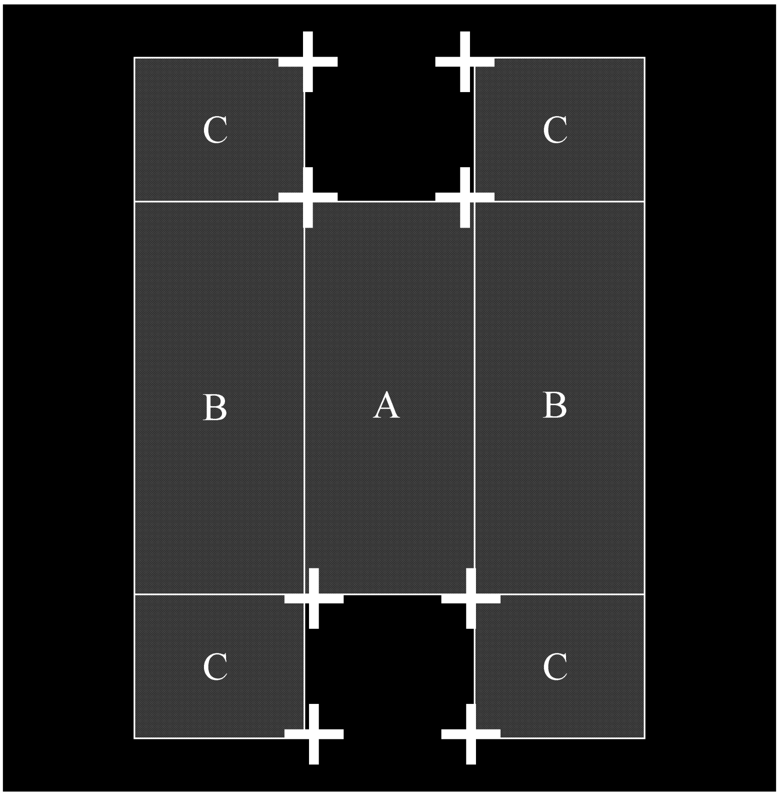

Figure 4.30: Example illustration of possible target positions which are not on one of the primes. The figure shows 2 primes vertically separated by distance 2. Region A) Between primes B) Lateral-between primes C) Lateral of prime. Those configurations were identical for all prime distance conditions, irrespective of horizontal or vertical alignment.

Method

The experiment consisted of 2500 experimental trials: 400 with random premasks, 800 with one-prime premasks (on target-present trials: 200 on-prime targets, 80 targets mislocated by 1 unit of distance, 60 mislocated by 2 units, 40 by 3 units, and 20 by 4 units), and 1300 with two-prime premasks (240 distance 0, 250 distance 1, 170 distance 2). 50% of all trials were target-present trials and 40% target-absent trials. All combinations of conditions were varied randomly from trial to trial.

Results

RT analysis. RTs on trials on which a response error was made (4.14% of all trials), extreme RTs (< 150 ms and > 2500 ms), and RTs above or below 2.5 standard deviations the mean for each observer (2.79% of all trials) were removed from the data prior to RT analysis. Similar to the previous experiments, a Premask x Target ANOVA was computed on the complete data set (data not shown). As in the previous experiments, this ANOVA revealed priming effects to be evident in both the one-prime and two-primes conditions, but only for target-present trials. That is, all effects were significant, Premask, F(2, 18) = 5.683, p < .05; Target, F(1, 9) = 13.188, p < .01; and Premask x Target, F(1.246, 11.211) = 4.566, p < .05 (G-G).

Following this ANOVA, a second analysis examined only trials with 'target on prime' and target positions at the edges of the 6×6 matrix were examined (i.e., excluding the nine central matrix positions), to make the conditions comparable (see Figure 4.31). This ANOVA comprised main terms for Premask (random, one-prime, two-primes distance-0, two-primes distance-1, two-primes distance-2) and Target (present, absent). There were significant main effects for Premask and Target, F(4, 36) = 16.627, p < .001 and F(1, 9) = 9.669, p < .05, and a significant Premask x Target interaction, F(4, 36) = 6.362, p < .01. Pairwise comparisons of the target- present data (Bonferroni adjusted) revealed significant synchronicity priming for the one-prime condition and for the two-prime distance-0 and distance-1 conditions (p < .001 for all tests), but not for the two-primes distance-2 condition, in which the RTs were near-equal to the random-premask condition (919 [60] vs. 915 [64] ms). For the other conditions, the priming effects was equivalent in magnitude (priming effects and their associated standard errors [SE mean]: 61 [10] ms, 67 [11], and 67 [9] ms, respectively, for the one-prime, two-primes distance-0, and two-primes distance-1 conditions) (see Figure 4.32).

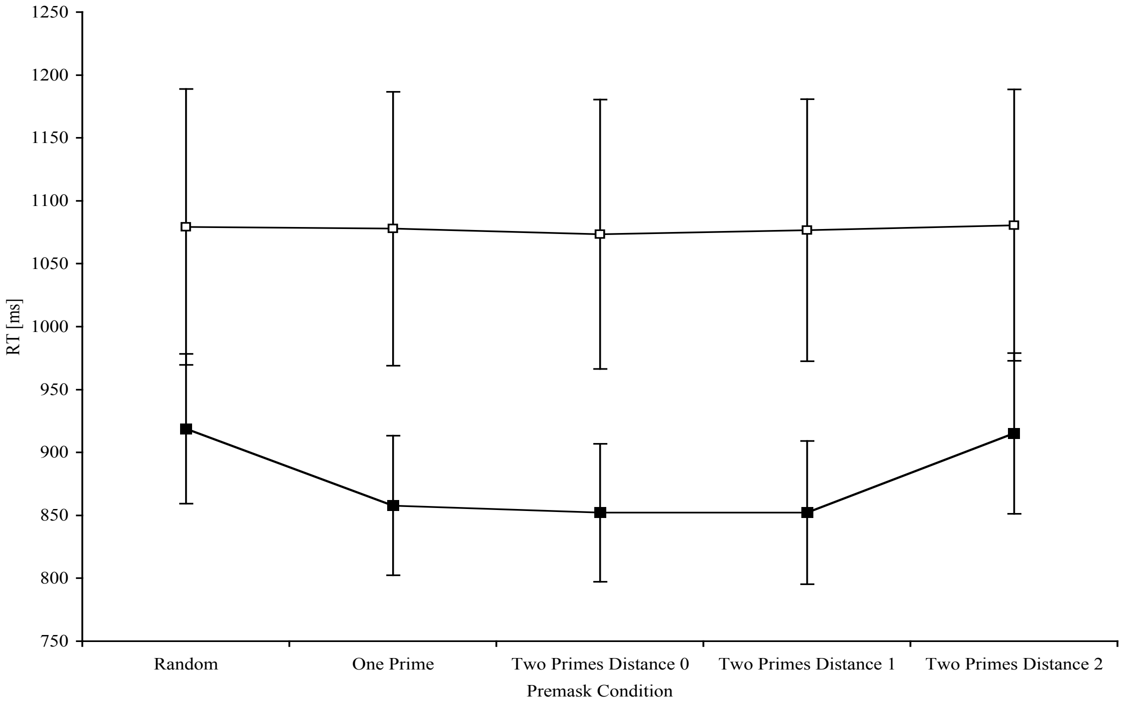

Figure 4.31: Mean correct target-present and target-absent RTs (and their associated standard errors [SE mean]) as a function of Premask condition (random, one-prime, two-pimes distance-0, two-pimes distance-1, two-pimes distance-2). Filled squares represent target-present data, open squares target-absent data.

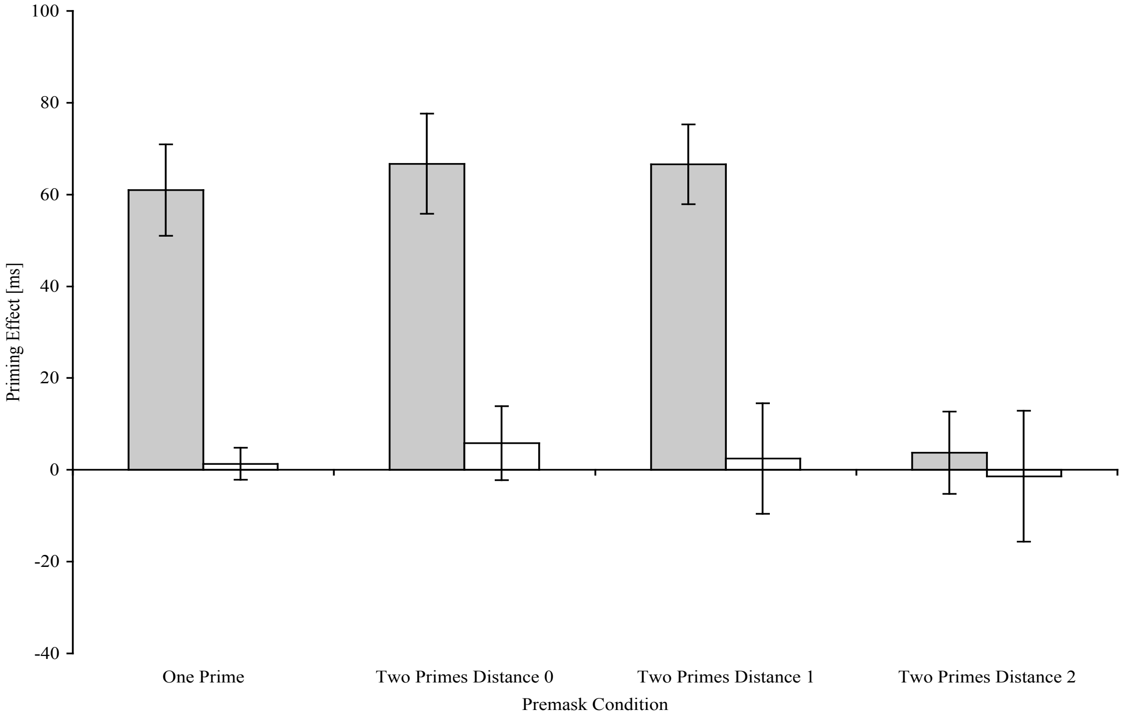

Figure 4.32: Mean priming effects (and their associated standard errors [SE mean]) as a function of Premask condition (random, one-prime, two-primes distance-0, two-primes distance-1, two-primes distance-2) and Target (present, absent). Grey bars represent target-present data, white bars target-absent data..

A third ANOVA, of dual-prime conditions only, was computed to examine RTs for targets which did not appear (directly) on one of the two prime locations: a Prime Distance (0, 1, 2) x Target Position (between-primes, lateral-between-primes, lateral-to-prime) ANOVA (see Figure 4.33 for the relevant data). For this analysis, target positions in the matrix corners as well as the central matrix area were excluded, because these positions were no defined in all conditions. There was no significant effect of Prime Distance, F(2, 18) = 2.818. However, the main effect Target Position was significant, F(2, 18) = 146.966, p < .001: RTs were fastest to targets presented between primes, intermediate for targets lateral between primes, and slowest for targets lateral to primes. The Prime Distance x Target Position interaction was also significant, F(4, 36) = 2.641, p < .05, due to a differential distance effect (solely) for targets presented lateral to primes (RTs to such targets increased as a function of prime distance). The corresponding synchronicity priming effects (relative to the random-premask condition) are depicted in Figure 4.34. As can be seen, there was a large and significant synchronicity priming only for targets presented between primes (58 [7] ms across prime distance conditions); targets presented laterally between primes also showed some evidence of priming (3 [6] ms across prime distance conditions); in contrast, targets presented lateral of the prime showed either no priming (4 [8] ms, prime distance-0 condition) or negative priming (increasing from the distance-1 to the distance-2 condition, -19 [7] and –42 [13], respectively). A pairwise comparison (Bonferroni adjusted) of the single Prime Distance x Target Position conditions with the random premask condition showed significant results only for the three between prime conditions (p = .002 for distance-0, p < .001 for distance-1 and distance-2 conditions, respectively)

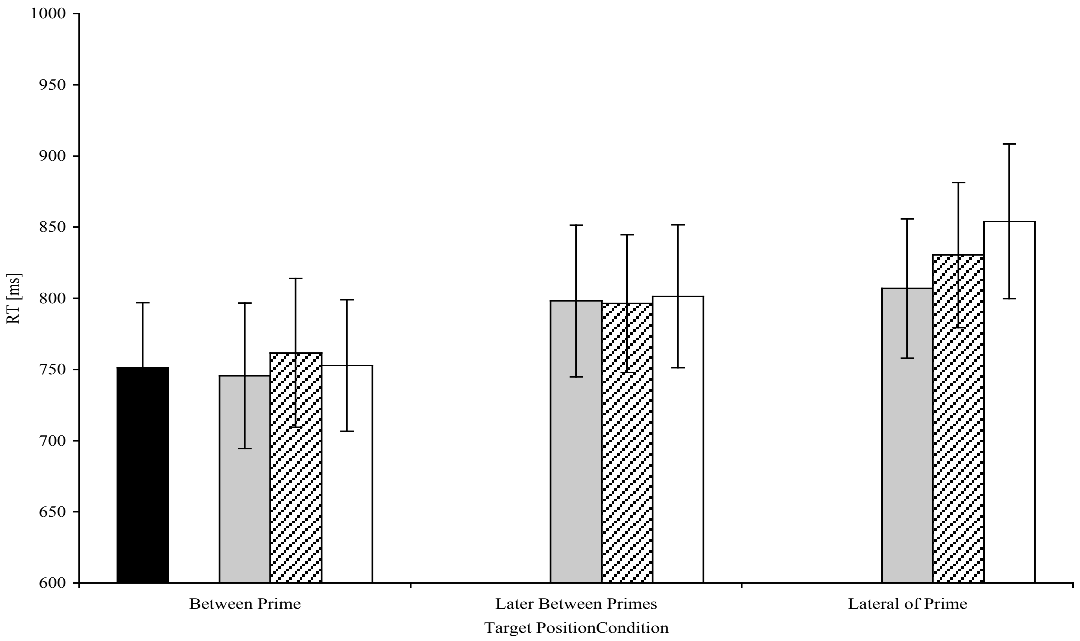

Figure 4.33: Mean correct target-present RTs (and their associated standard errors [SE mean]) as a function of Target Position (between-primes, lateral-between-primes, lateral-to-prime). Grey bars show the data for dual-prime distance 0, shaded bars for distance 1, and white bars for distance 2, the black bar shows the single prime RT as comparison aid.

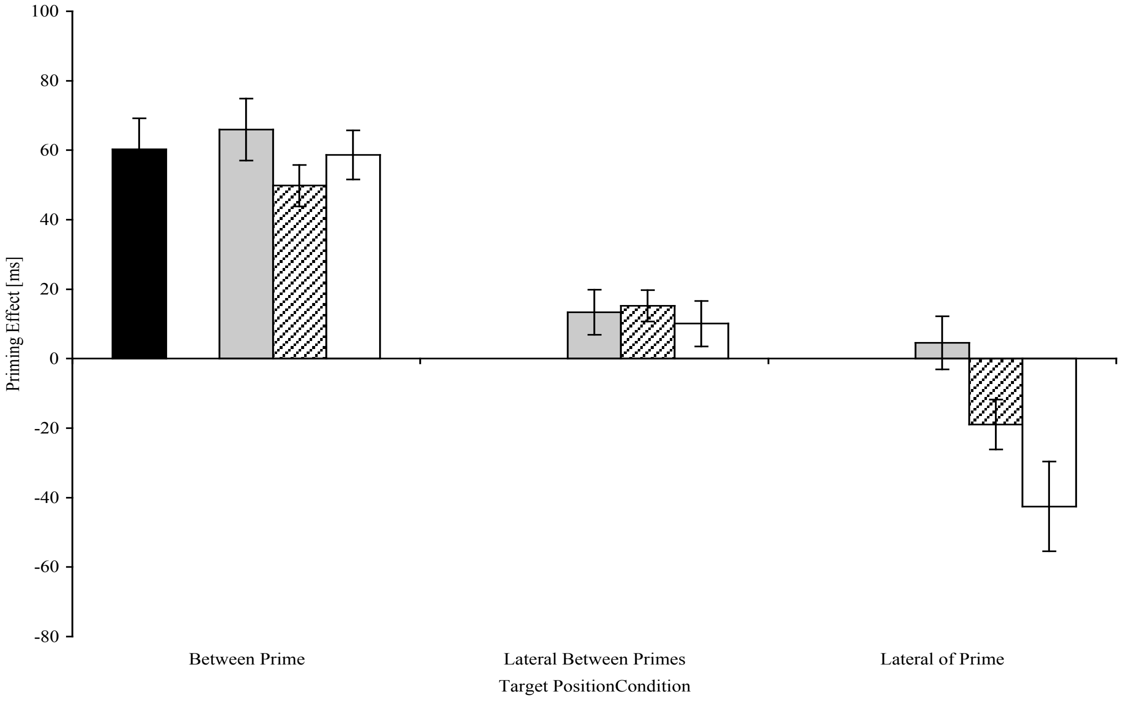

Figure 4.34: Mean priming effects (and their associated standard errors [SE mean]) as a function of Target Position (between-primes, lateral-between-primes, lateral-to-prime). Grey bars show Distance 0, shaded bars Distance 1, and white bars Distance 2 condition, the black bar shows the single prime condition effect as comparison aid.

Finally, the data for the control condition (single prime, target mislocated by a varying distance relative to the prime location) were analyzed by an ANOVA with the single factor Target Position (random, on-prime, mislocated-1, mislocated-2, mislocated-3, mislocated-4), followed by multiple comparisons (Bonferroni adjusted) among the various levels of this factor. In a first step, all target positions (target-present trials only) were included in the analysis; see Figure 4.35 for the results. The Target Position effect was significant, $F(5, 45) = 27.960$, $p < .001$. The multiple comparisons revealed that both the one-prime and the mislocated-4 condition differed significantly from the random-premask baseline, with the former showing a positive synchronicity priming effect (of 55 [7] ms) and the latter a negative effect (of –83 [11] ms). In fact, there also appeared be a systematic distance effect, in that RTs to mislocated targets increased monotonically as a function of prime-target separation. In a second step, the analysis included only target positions at the edges of the display matrix (i.e., the same positions included in the 'on-prime target' analysis above). Again, the main effect of Target Position was significant, $F(5, 45) = 10.214$, $p < .001$; however, the multiple comparisons revealed only the 'on-prime' condition to produce a significant priming effect (of 61 [10] ms, $p = .003$), while none of the other, 'mislocated' conditions differed reliably from the random-premask baseline and amongst each other (see Figure 4.36). That is, the systematic distance effect that obtained in the first analysis step vanished when target eccentricity was controlled for.

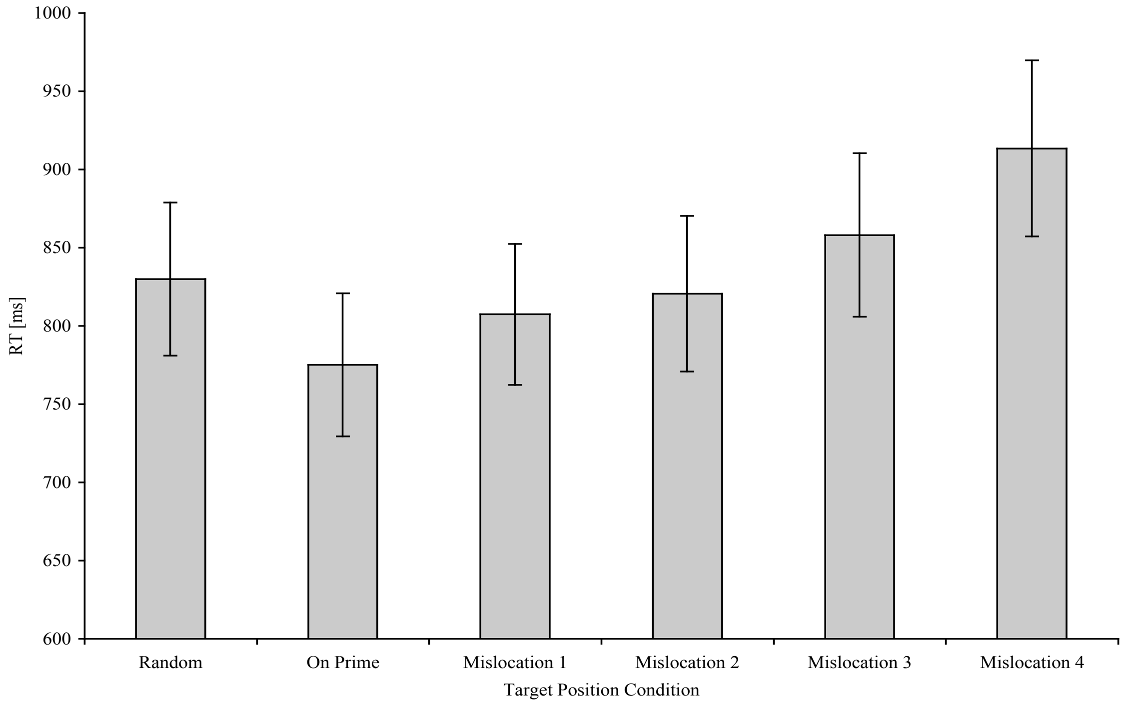

Figure 4.35: Mean correct target-present RTs (and their associated standard errors [SE mean]) as a function of Target Position (random, on-prime, mislocated-1, mislocated-2, mislocated-3, mislocated-4); data for all target positions.

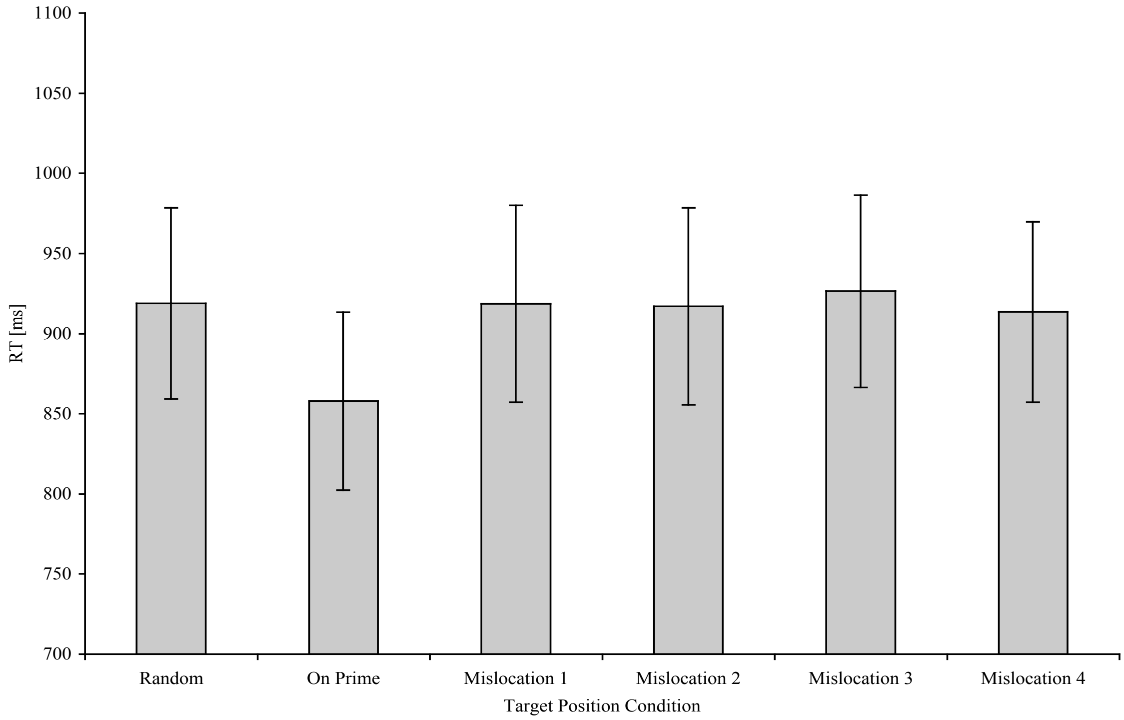

Figure 4.36: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Target Position (random, on-prime, mislocated-1, mislocated-2, mislocated-3, mislocated-4) ; data of controlled target positions.

Error analysis. The error data are presented in Figures 4.37 and 4.38. The arc-sine transformed error data were examined by an ANOVA with the same terms as in the RT-data ANOVA. For the (target-positions controlled) 'on-prime' data set, the overall error rates were 9.12% misses (target-present trials) and 1.94% false alarms (target-absent trials). There was only a significant main effect for the factor Target, F(1, 9) = 60.293, p < .001 (Premask, F(4, 36) = 0.755; Premask x Target, F(4, 36) = 0.638).

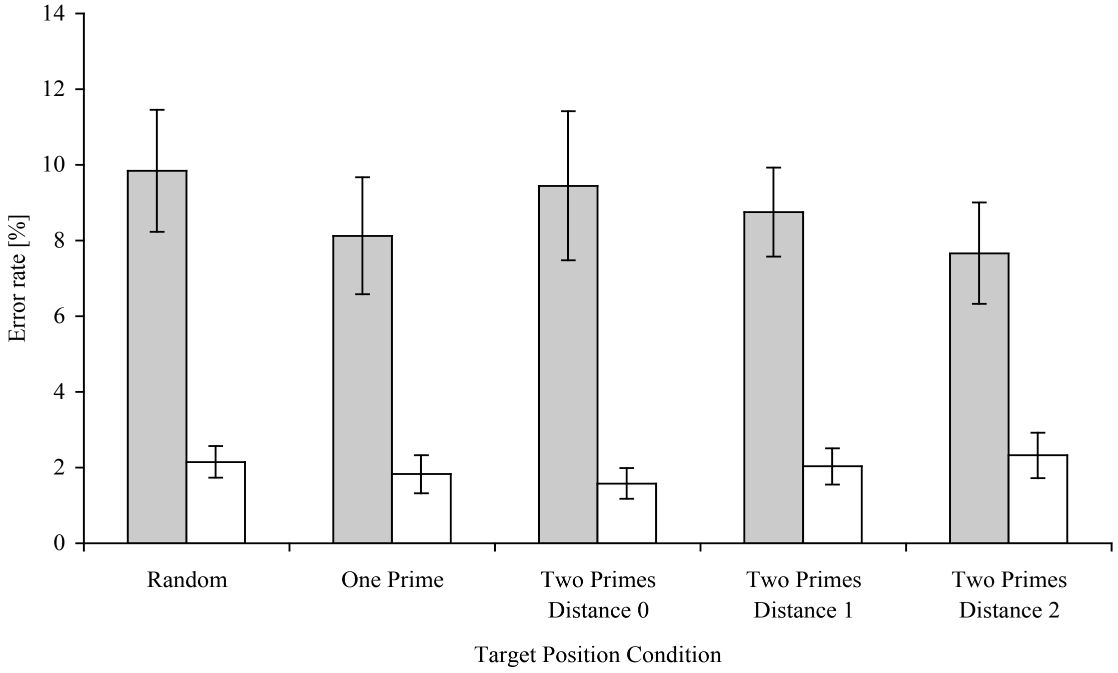

Figure 4.37: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Target Position (random, on-prime, mislocated-1, mislocated-2, mislocated-3, mislocated-4) ; data of controlled target positions.

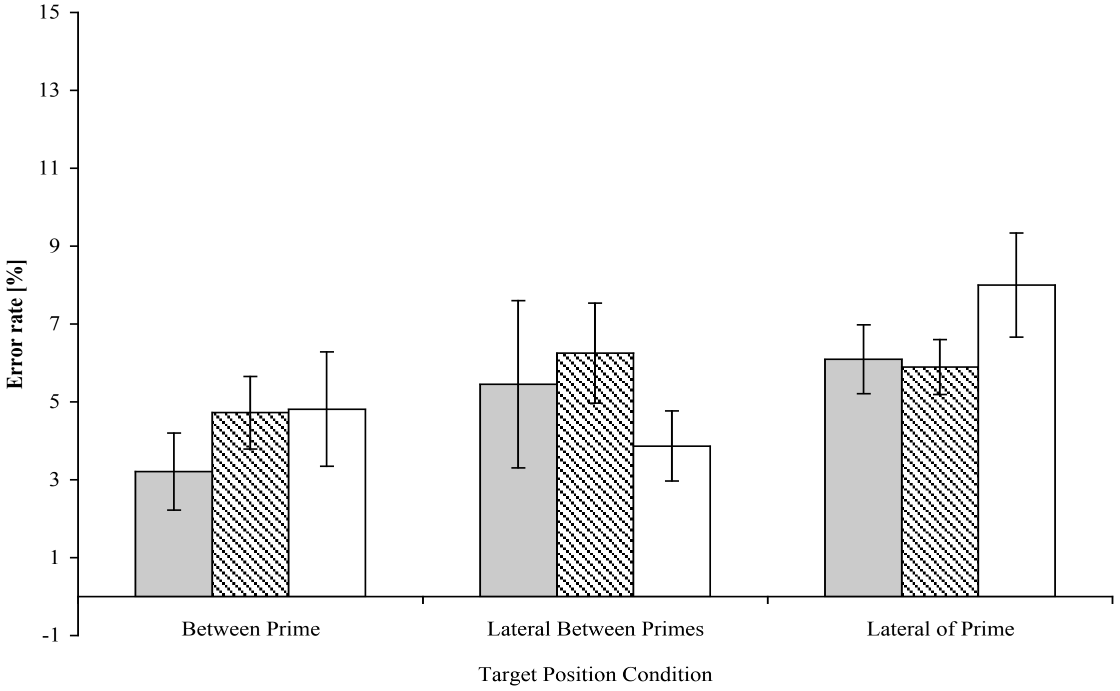

Figure 4.38: Mean error rates (and their associated standard errors [SE mean]) as a function of Premask (random, one prime, distance 0, distance 1, distance 2) and Target (present, absent). Grey bars represent target-present data, white bars target-absent data.

The analysis for 'between-target' conditions also failed to reveal any significant effects, F(2, 18) = 0.850, F(2, 18) = 3.088, and F(4, 36) = 1.170, for Prime Distance, Target Position, and their interaction, respectively.

An analysis of the error rates in the control condition (single prime, target mislocated by a varying distance relative to the prime location) revealed a significant Target Position effect, F(2.595, 23.354) = 4.483 (G-G), when all target positions were included in the analysis: However, multiple comparisons (Bonferroni adjusted) revealed no reliable differences between the single conditions (data not shown). The analysis of the error rates for the data with eccentricity-controlled target positions failed to reveal a significant Target Position effect, F(5, 45) = 1.111 (data not shown).

In sum, this time, the error data was too noisy to retrieve reliable results. However, a look at Figure 4.37 shows that, consistent with the present RT data and the previous experiments, error rates decrease on two prime conditions.

Discussion

Experiment 4 examined the effect of dual primes on target detection, including targets presented at locations between the primes. The results showed equally large synchronicity priming effects for on-prime and between-prime targets with distances 0 and 1 between primes. With largest separation (distance 2), the priming effect vanished when targets appeared on prime. This pattern is consistent with Experiment 2. However, there was a very large synchrony priming effect in the between-prime condition. Although no larger priming effect was found for distance 0 and distance 1 condition, the additionally introduced target position control conditions showed that the facilitatory effect is dependent on target position. That is, largest priming effects were achieved only for between-prime target locations positioned collinearly between the two prime positions. A slight mislocation of the target still leads to somewhat faster RTs, but not to reliable priming effects. [The error data were too noisy to yield reliable results, but the overall pattern was consistent with the previous experiments.]

A possible explanation of the present results is that dual prime signals become integrated into a single elongated prime field which is ‘Gaussian-shaped’. Target detection is expedited if a stimulus appears between the two primes, where field strength is highest. However, if the two primes are located too far apart (in Experiment 4, more than about 4.8º of visual angle), the edges of the prime field loose strength, lessening the facilitation for targets presented there. An alternative explanation might be that the prime field has no region of maximum strength, but rather that the field strength is equal at all (field) locations, corresponding to a ‘square-wave-type’ function suggested above. The present results for the distance 0 and distance 1 conditions would argue in favor of this account. However, it fail to explain why, with prime distance 2, there are priming effects for between-prime targets, but not for on-prime targets.

General Discussion

The present study extended the priming paradigm introduced by Elliott and Müller (1998, 2000, 2001) by introducing 5×5 and 6×6 display matrices in which dual primes were embedded at different distances relative to each other. The results demonstrate that dual-prime information presented in a premask matrix flickering at 40-Hz can expedite detection of a single target in the following target matrix. Experiments 1 and 3 (5×5 matrix) showed that priming effects for dual-prime conditions were equivalent in size to the single-prime condition. The priming effects were not dependent on inter-prime distance, that is, the effects did not differ whether primes were or were not separated by a row of premask crosses. However, the priming effects vanished in conditions in which the primes were separated by two rows of premask crosses (Experiments 2 and 4; 6×6 matrix). Priming effects were also evident in dual prime conditions when the target was located between the two primes (Experiments 3 and 4). In Experiment 3 (5×5 matrix), the target could appear in the middle of two directly adjacent primes (distance 0) or between two primes spatially separated by a row of premask crosses (distance 1; with two elements of the target figure overlapping with prime elements). Interestingly, the priming effects for these ‘between-prime’ conditions were significantly larger than for ‘on-prime’ conditions. This pattern was slightly different with 6×6 matrix display (Experiment 4). Here, priming effects for between-prime targets were as large as the ‘on-prime’ effects (distances 0 and 1), but this was not true for the largest inter-prime distance condition in which the two primes were separated by two rows of premask crosses (distance 2). In this condition, consistent with Experiment 2, ‘on prime’ trials showed no priming effects, but ‘between-prime’ priming effects were evident and as large as on the other prime distance conditions.

These pattern of results suggest that a dynamic 'prime field' is generated by the two synchronous primes. There are two possible forms of such fields. First, the primes integrate to form one coherent field, which has a 'square-wave-type' strength distribution with more or less sharp boundaries (see Figure 4.39). With this type of prime field, RTs for targets between and on primes should lead to equally large priming effects. The results of Experiment 4 provide some support for this type of field. However, if prime strength were equally distributed (as it should be within this type of field), why then were there priming effects effects observed for the distance-2 between-prime condition, but not for distance-2 on-prime condition.

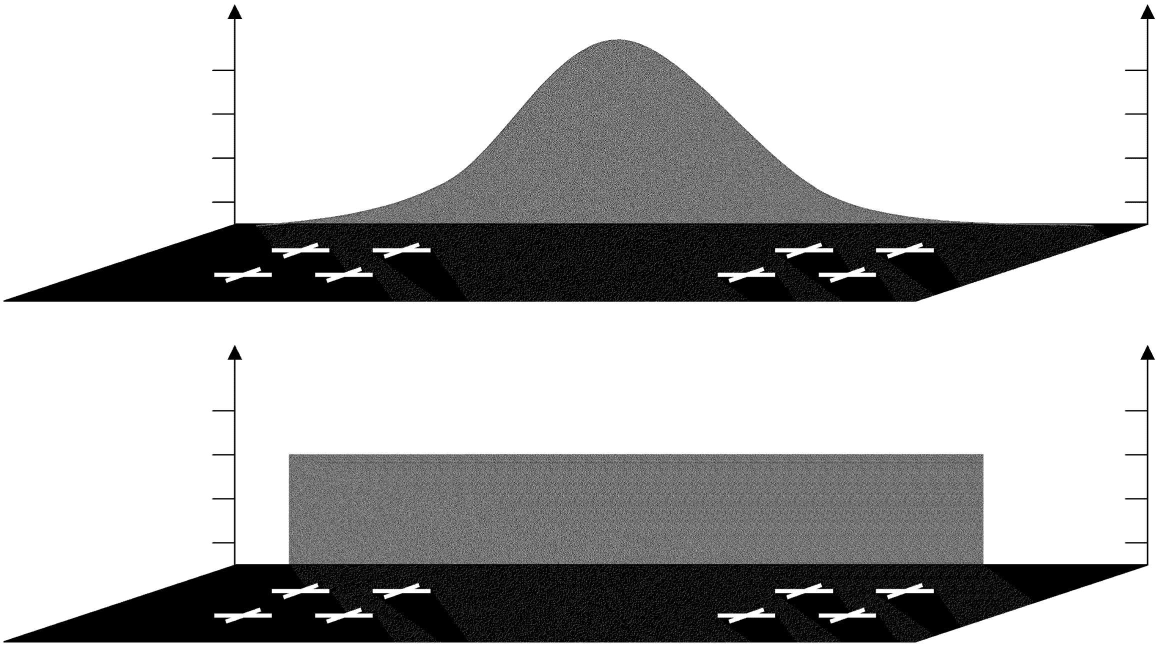

Figure 4.39: Two possible form of prime strength distribution. The upper graphic shows a 'gaussian-type' of strength distribution, the lower a 'square-wave' type.

The second possible type of prime field would exhibit more of a 'Gaussian-type' shape (see Figure 4.39). That is, the field strength is maximal in the center position between the two primes and decreases with distance from the center. The results of Experiments 3 support this view, but also Experiments 2 and 4. The latter experiments showed that, if targets appeared on primes separated by the largest distance, no priming effects were evident (for on-prime targets), which may reflect a decrease in prime field strength.

The 5×5 und 6×6 displays extended about 7.3° and 8.1° of visual angle, respectively. This matches the size of receptive fields in higher visuals areas (e.g., V3 and V4). It is also consistent with the view that the integration of dual prime signals across spatial separations is accomplished via top-down projections from higher- to lower-tier visual coding mechanisms (see also Elliott & Müller, 2000).

The error data in all experiments showed consistent results with the RT data. This was not necessarily expected, as in previous studies error rates were not affected by synchronous prime presentation (e.g., Elliott & Müller, 1998, 2000). An explanation for this could be the greater difficulty of search for a target figure within 5×5 and 6×6 matrices, compared to the 3×3 matrix used previous studies.

In sum, the present findings are consistent with results found by Elliott & Müller (1998, 2000, 2001). Furthermore, the results suggest that presentation of spatially separate, dual primes leads to the formation of a dynamic prime field, which may be achieved through feedback connections from units with lager receptive fields in higher visual areas (such as V3 and V4). Although, an elongated, Gaussian-shaped function of prime field strength is suggested by the present findings, the precise nature of this prime field is not entirely clear from the present data. Also, it remains unclear whether the prime field provides an attractor for spatial-attentional allocation or whether it facilitates target coding prior to the allocation of attention.

Chapter 5: Target-Figure Dependence of Synchrony Priming

Abstract

Within a 3×3 matrix of 90° corner junctions, detection of a Kanizsa-type square is facilitated when the target display is preceded by a 40-Hz flickering premask of 3×3 crosses, with four crosses synchronously oscillating at the subsequent target location. Four experiments examined wether this ‘*synchrony-priming*’ (e.g., Elliott & Müller, 1998) generates a location-specific prime ‘spot’ circumscribed by the prime elements in the flickering premask, or whether the priming is dependent for its realization on the onset of a target figure following premask matrix. In Experiment 1 figural and non-figural targets were presented. Experiment 2 introduced a dot-probe technique (e.g., Kim & Cave, 1995). In Experiment 3 non-figural target positions were varied according to the Gestalt principle of good continuation. Experiment 4 controlled for a possible ceiling effect by introducing a spatial cueing (e.g., Posner, 1980) manipulation. The ‘standard’ priming effect was replicated with figural targets, but no synchrony priming effects were found for non-figural targets. The results show that synchronous primes have no facilitatory effect at positions within their circumscribed area and that synchrony priming may indeed depend largely on target figure information presented after premask offset which subsequent coding is consequently expedited.

Theoretical background

One of the central problems to be solve by the brain is the binding of separately coded object features into a coherent object representations. This set of questions is referred to as the ‘binding problem’. There have been various approaches in Experimental Psychology that have attempted to address how this problem is solved, in particular: examination of Gestalt principles of perceptual organization, of the relationship of grouping and binding processes to mechanisms of visual attention, and of the way in which these principles and processes are implemented in the feature-object coding system. A newer development is the examination of temporal factors for grouping and binding via psychophysical methods.

Results of single-cell recording studies have suggested a role of synchronized visuo-cortical cell oscillations for feature-object binding (‘temporal binding’). If feature elements were presented simultaneously and their spatial arrangement satisfied a Gestalt principle (e.g., collinearity), cells in the visual cortex which responded to those elements adjusted their firing behavior and oscillated in synchrony, without a shift in phase (e.g., Gray, König, Engel, & Singer, 1989). These findings were taken as evidence that the critical neurophysiological correlates of perceptual grouping consist of synchronized oscillatory activity patterns, which are phase-locked across separate groups of feature-coding neurons.

Several new psychophysical paradigms have been developed recently, the results of which support the notion that feature-object binding involves temporal coding (e.g., Elliott & Müller, 1998, 2000, 2001; Usher & Donnelly, 1998). That is, perceptual organisation could be based on early, probably pre-attentive, stages of visual processing, and temporal coding could play a role in these organisation processes.

The present study is based on the 'synchronicity-priming' paradigm developed by Elliott and Müller (e.g., 1998, 2000, 2001).). In this paradigm, a flickering (oscillating) matrix (premask) of figurally neutral premask-elements is presented, which is replaced after a certain time by a matrix of figure and distractor elements (see Figure 5.1). More precisely, in the original studies, the premask display consisted of a matrix of 3×3 crosses and the target display of a matrix of 3×3 90° (i.e., L-type) corner junctions. In the target display, four of the corner junctions in one matrix quadrant could form a to-be-detected target figure, a Kanizsa-type square (whereas the distractor junctions could not be grouped to form a closed figure). Elliott and Müller found that detection of the target figure was expedited when the four premask crosses in the matrix quadrant in which the target figure appeared later were repeatedly presented *synchronously* (i.e., within the same display frame), relative to a 'random' control condition in which the premask crosses in the relevant quadrant were presented *asynchronously* (i.e., in different display frames; not that the random premask display consisted also of one frame with four elements, which were, however, not presented within the same matrix quadrant). Importantly, this 'synchronicity priming' effect occurs only when the frame components of the premask matrix, including the frame with the four synchronous crosses (which hitherto will be referred to as '*synchronous prime*') are presented with a frequency of 40-Hz (as well as other 'preferred' gamma-band frequencies, e.g., 33, 46, 53, 59, and 66 Hz; see Elliott & Müller, 1999, 2004).

As the synchronicity-priming effect was found to be dependent on target presence, Elliott and Müller (1998) interpreted the priming as resulting from a mechanism which expedites target figure coding, without operating as a spatial-attentional cue. However, their evidence for this was only of indirect nature: there were no 'costs' relative to the random-premask baseline condition when the target figure was presented in another matrix quadrant to that where the (preceding) synchronous premask had appeared. It remains unclear whether the priming is dependent on the presentation of a target figure which accords with Gestalt principles (e.g., collinearity) or if it generates a location-specific signal that is independent of the target figure. Elliott (1998) found that substitution of the nine premask crosses by nine circles, in which the following target inducers were presented, also produces a facilitatory effect. That is, presenting no directly relevant featural information within the 40-Hz flickering premask has a similar effect on the detection of the subsequent target as presentation of figurally relevant information (note, though, that it is unclear whether circular premask elements are as quite effective in producing priming as premask crosses). Elliott took this (and the previous results) to mean that the synchronous prime possesses no figural definition itself. However, what would happen if figural information is presented in the premask, but no figural target stimulus is following? If the whole region circumscribed by the four prime inducers is primed, then a priming effect should also occur at inner positions of the prime region. If this were the case, it would not necessarily be inconsistent with the above findings of Elliott, as, with premask circles, the synchronous presentation of the prime elements could lead to a spread of activation from one element to another. The second possibility is that simply no synchrony priming effect occurs. This would argue that the synchrony priming effect is dependent on the presentation of a target figure, the formation of which is expedited by the synchronous prime, as suggested by Elliott and Müller (1998).

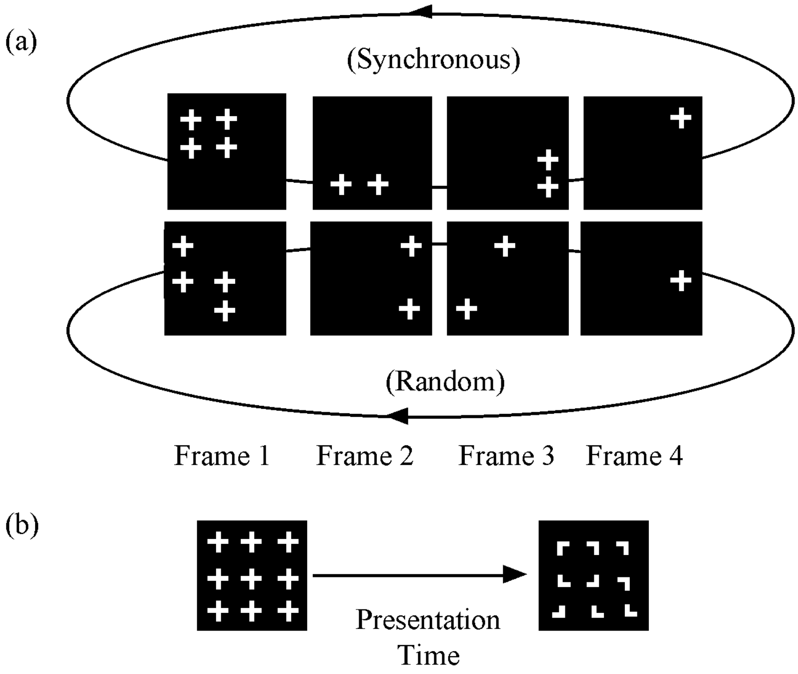

Figure 5.1: (a) Example sequence of the four premask frames in the synchronous and random conditions. The premask oscillation frequency was defined as the frequency of premask frames per second. For example, at 40-Hz, the four premask frames were presented 10 times per 1000 milliseconds, with a constant frame exposition duration of 25 ms and an inter-frame intervall of < 1ms. (b) The premask sequence was continuously repeated until the target display was presented, this induced the impression of a stochastically flickering display of nine crosses.

Scope of the study

Four experiments were conducted to examine the effects of synchronous primes on target stimuli which have no (or nearly no) figural information. Instead of Kanizsa-type targets, simple dot targets were presented after the presentation of a 40-Hz flickering premask. In one condition of the Experiment 1, the original target stimuli were presented to replicate the synchronicity priming effect found by Elliott and Müller (1998), so as to ensure that priming occurs in the examined group of observers. In another condition, the presence of a simple dot-probe target (rather than a Kanizsa-type square) had to be detected. In this way, it was possible to examine whether the synchronous prime facilitates the whole region circumscribed by the prime elements. Experiment 2 examined whether the synchronous prime generates a signal already during premask presentation. Elliott (1998) found that priming effects are generated between 100 and 200 ms after premask onset (i.e., after one or two cycles of premask frames). However, the flickering premask was always followed by a target display. Thus, it remains unclear whether the onset of a target figure is crucial for the priming to materialize. To answer this question, a dot-probe technique (e.g., Kim & Cave, 1995) was introduced to examine whether the synchronous prime carries (spatial) information already during premask presentation. Experiment 3 was similar to Experiment 1. However, the target dot-probe could appear at different positions relative to the presented prime elements. In one condition, the target dot could appear at a position collinearly aligned relative to the premask cross segments constituting the synchronous prime. This condition was introduced to examine whether the priming effect requires collinear grouping of target and prime elements (see also Donnelly et al., 1991). Experiment 4 was an extension of Experiment 3, examining whether the dot-probe detection task is at all influenceable by (in general) facilitatory processes. In addition, it examined the possible role of visuo-spatial attention for synchrony priming. Other experiments (see Chapter 3) had shown that misdirection of spatial attention can lead to enhanced priming effects.

General Method

In all four experiments, the experimental set-up and design were generally the same; any relevant differences are reported in the Method sections for the individual experiments.

Participants. Ten observers took part in Experiments 1, 2, and 4, and nine in Experiment 3. All observers had normal or corrected-to-normal visual acuity. Observers were naive about the purpose of the experiments and were paid at a rate of € (Euro) 8.00 per hour.

Apparatus. Event timing, data collection, and stimulus generation were controlled by a PC-compatible computer, which also controlled oscilloscopic image presentation through an Interactive Electronics Systems point plotter buffer with 8 MB frame store memory (Finley, 1985). Stimuli were presented on a 6” Tektronix 608-oscilloscope monitor equipped with a very fast-decay P15 phosphor. The use of a P15 phosphor ensured that on-screen image persistence reduced to 10% of normal image intensity within 2.8µs of image termination (Bell, 1970). The Interactive Electronics Systems point plotter buffer allowed pixels to be plotted at a rate of one pixel every microsecond. The presentation frequency of frames across the entire premask display was kept constant at 40-Hz, while the entire premask matrix, consisting of a sequence of four separate frames, was recycled at a rate of 10 repeats per second (i.e., each premask frame repeated at 10 Hz). Frames had a constant exposure duration of 25 ms and an inter-frame interval of less than 1 ms (see Figure 5.1). The continual recycling of the premask frame sequence produced the phenomenal experience of a flickering display of nine crosses, within which observers were unable to discern the structure of a given frame. Both the individual premask frames and the target display frames were presented semi-static at a fixed, 1 kHz refresh frequency.

<u>Stimuli.</u> In all experiments observers viewed the monitor at a distance of 57 cm (maintained via a chin rest). The experiments were conducted under controlled lighting conditions (mean screen surround luminance 0.078 cd/m^2), with stimulus luminance maintained at 0.3 cd/m^2 upon a background field of 0.075 cd/m^2. Display elements were arranged around the center of the monitor screen (see Figure 5.1). Premask crosses subtended 98′ of visual angle and exhibited horizontal and vertical separations of 2° 39′. The total 3×3 premask display matrix subtended 4° 80′×4° 80′ of visual angle. Premask frames could consist of 1, 2, 3, or 4 crosses presented simultaneously (Figure 5.1). As a target dot (Experiments 1, 3, and 4) as well as a dot-probe (Experiment 2), a point was presented on the oscilloscopic screen, which subtended 2′×2′ of visual angle and had a luminance of 0.3 cd/m^2. Dot targets could appear in the middle of a matrix quadrant (Experiment 1 and 2) or varying positions (Experiment 3 and 4) (see relevant Method sections for details). Junction elements in the target display (Experiment 1 and 2) subtended 54′ of visual angle and were separated horizontally and vertically by 2° 39′ The target display subtended 4° 80′×4° 80′ of visual angle.

<u>Design.</u> In all experiments, the flickering premask matrix could either contain a synchronous prime in one of the quadrants (*synchronous premask*), or the premask elements were arranged randomly across quadrants and frames (*random premask*). In Experiment 1, there could also be a mislocated prime (*synchronous mislocated premask*), which was presented in a different quadrant to that of the subsequent target. The target display either did (*target present*) or did not contain a target figure, a Kanizsa-type square (*target absent*). The target figure, dot target, or dot-probe could appear in any one of the

four possible matrix quadrants. Experiments 3 and 4 introduced a greater range of possible target positions, which are described in detail in the relevant Method sections..

The experiments consisted of two sessions (one sessions in Experiment 2), which lasted about 50 minutes, and were divided into 10 blocks of 3 (unrecorded) warming-up trials preceding the experimental trials. The blocks were separated by short breaks. Prior to each experiment, observers performed one practice block of trials (data not recorded).

Experiment 1

Experiment 1 was conducted to replicate the synchronicity priming found by Elliott and Müller (Experiment 3, 1998), by presenting the original target stimulus, a Kaizsa-type square, in the target display matrix. In a second condition, observers had to respond to a simple dot presented as a target. In this way, it was possible to examine whether the synchronous prime produces facilitatation for the whole (inner) region circumscribed by the prime elements.

Method

Participants. Ten observers (6 female; mean age 25.4 years; all with normal or corrected-to-normal vision) took part in Experiment 1.

Design and Procedure. The experiment consisted of a total of 1920 (50% target-present and 50% target-absent trials) experimental trials, target present trials were split up as follows: 480 random-premask trials, 240 synchronous-premask trials, and 240 synchronous-mislocated-premask trials. Target Stimulus conditions were presented in separate experimental sessions (50% figure targets and 50% dot targets), with (figure- vs. dot-target) session counterbalanced across observers. In each session, all combinations of Premask and Target conditions were varied randomly from trial to trial.

At the beginning of each trial, a fixation cross was presented in the center of the screen for 500 ms. Then, after a 300 ms blank screen, the flickering premask was presented for 600 ms. In the figure target condition, observers had to discern, as rapidly and accurately as possible, the presence or absence of a target Kanizsa-type square within the matrix of 90° corner junctions, which was presented immediately after premask matrix offset. In the dot target condition, only the central (premask) cross remained on the screen, and the target dot was presented in the middle of a matrix quadrant (see Figure 5.2). In both conditions, targets always remained in view until the response had been made. Observers had to press one of two buttons with the right or the left index finger for target presence or absence, respectively. The response was followed by a blank for 1000 ms, after which the next trial was presented. Observers were told to fixate the center of the display and avoid eye movements during premask display presentation. In case of an erroneous response, feedback was provided through a (300 ms) 400-Hz computer-generated tone.

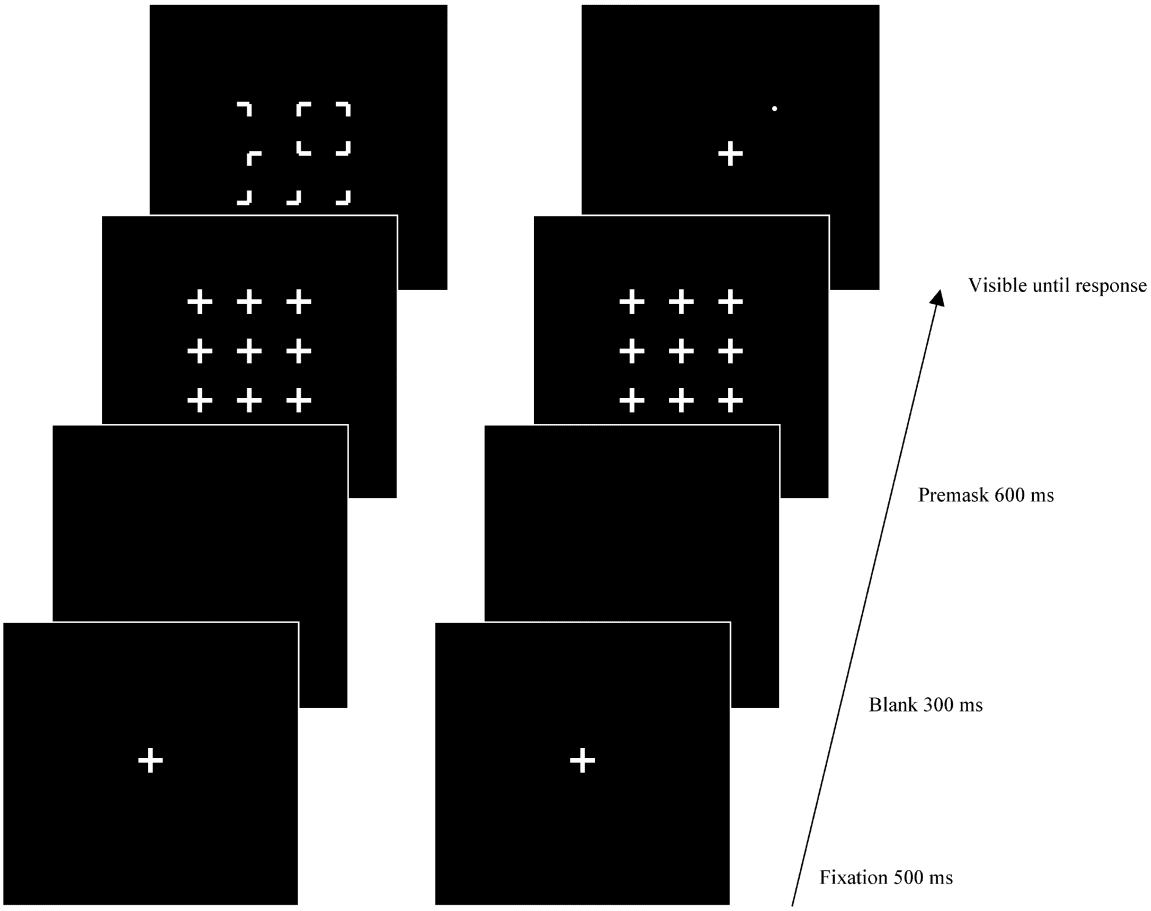

Figure 5.2: Example trials for Experiment 1. Left row shows an example trial for figural, right row for non-figural targets.

Results

RT analysis. RTs on trials on which a response error was made (2.92% and 2.33% for the figure and dot target conditions, respectively), extreme RTs (< 150 ms and > 2000 ms), and RTs 2.5 standard deviations above or below the mean for each observer and target figure condition (2.35% and 2.62% for the figure and dot target conditions, respectively) were removed from the data prior to RT analysis. Figure 5.3 presents the correct mean RTs (and their associated standard errors [SE mean]) as a function of Target Stimulus (figure, dot) x Premask (random, on-prime, mislocated) x Target (present, absent) condition.

In a first analysis step, a ANOVA with main terms for Target Stimulus, Premask, and Target was computed, excluding the mislocated conditions (as these were not defined for target-absent trials). This analysis revealed all main effects to be significant: Target Stimulus, F(1, 9) = 38.405, p < .01; Premask, F(1, 9) = 5.254, p < .05; and Target, F(1, 9) = 27.491, p < .01. Observers responded overall faster to dot targets than to figure targets (424 [20] vs. 605 [38] ms, respectively). RTs to targets preceded by a synchronous premask were overall expedited relative to the random-premask condition (513 [26] vs. 517 [27] ms, respectively). And target-present RTs were faster than target-absent RTs (486 [22] ms vs. 544 [31] ms, respectively). Furthermore, all possible two-way interactions and the three-way interaction were significant: Target Stimulus x Premask, F(1, 9) = 20.673, p < .01; Target Stimulus x Target, F(1, 9) = 15.294, p < .01; Premask x Target, F(1, 9) = 27.955, p < .01; and Target Stimulus x Premask x Target, F(1, 9) = 41.813, p < .001. Pairwise comparisons (Bonferroni adjusted) of synchronous-premask conditions against the random-premask baseline (target-present data only) revealed significant synchronicity priming for figure targets (p < .001), but not for dot targets (priming effects and their associated standard errors [SE]: 20 [4] and -1 [1] ms for figure and dot targets, respectively)(see Figure 5.4).

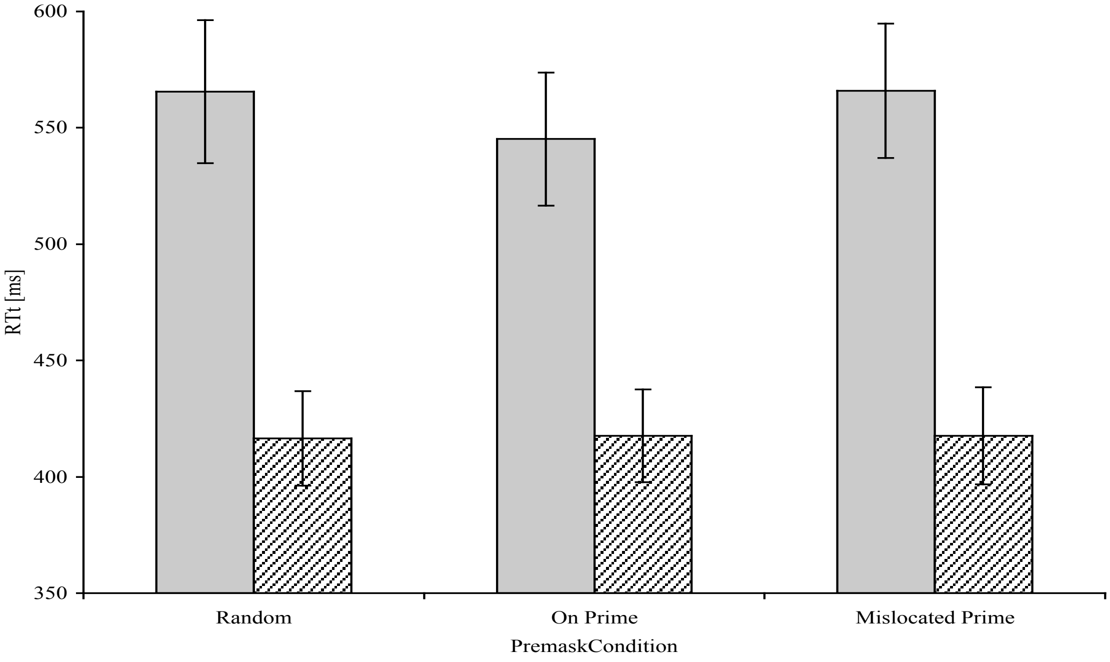

Figure 5.3: Mean correct target-present RTs (and their associated standard errors [SE mean]) as a function of Target Stimulus (figure, dot) x Premask (random, on-synchronous-prime, misclocated). Grey and shaded bars represent figure and dot targets, respectively.

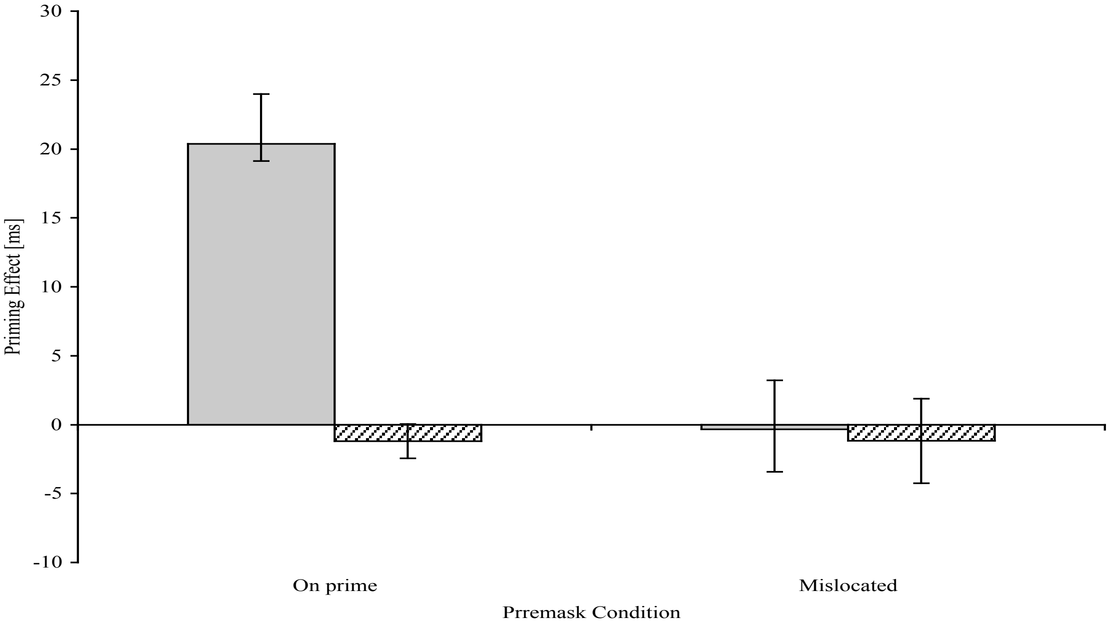

Figure 5.4: Mean priming effects (and their associated standard errors [SE mean]) as a function of Target Stimulus (figure, dot) x Premask (random, on-synchronous-prime). Grey and shaded bars represent figure and dot targets, respectively.

In a second analysis, a two-way ANOVA with the terms Target Stimulus (figure, dot) and Target Location (random, on-synchronous-prime, mislocated) was computed for target-present data only. There were again significant main effects for Target Stimulus and Target Location, F(1, 9) = 35.644, $p < .001$, and F(2, 18) = 20.953, $p < .001$, respectively. The Target Stimulus x Target Location interaction was also significant, F(2, 18) = 5.563, $p < .001$. Pairwise comparisons (Bonferroni adjusted) of the random-, on-synchronous-prime and mislocated target position conditions revealed RTs to targets presented at the location of the synchronous premask to be significantly faster relative to both the random- and the mislocated-premask conditions ($p < .001$), but only for trials with a figure target (see Figure 5.5). The mean synchronicity priming effect for mislocated targets was -0.35 [11] and -1.18 [9] ms for figure and dot targets, respectively.

In a third analysis, the mislocated-target condition was subdivided according to the three possible directions of mislocalization of the target relative to the synchronous premask (horizontal, vertical, diagonal). Again, only target-present RTs were examined, by an ANOVA with the terms Target Stimulus (figure, dot) and Target Location (random, on-prime, horizontally mislocated, vertically mislocated, diagonally mislocated); see Figure 5.6 for the data. This analysis revealed a significant main effect for Target Stimulus, F(1, 9) = 35.741, $p < .001$, and Target Location, F(4, 36) = 6.007, $p < .01$, and the Target Stimulus x Target Location interaction was significant, F(4, 36) = 7.240, $p < .001$. For figure targets, pairwise comparisons (Bonferroni adjusted) revealed a significant synchronicity-priming effect for on-prime targets and a marginally significant effect for vertically mislocated targets ($p = .001$ and $p = .021$, respectively). RTs in these two conditions were also significantly or marginally significantly faster than those to diagonally ($p < .001$ and $p = .004$) and horizontally mislocated targets ($p = .022$ and $p =$

.020). In contrast to figure targets, for dot targets, there were no reliable RT among the various target location conditions.

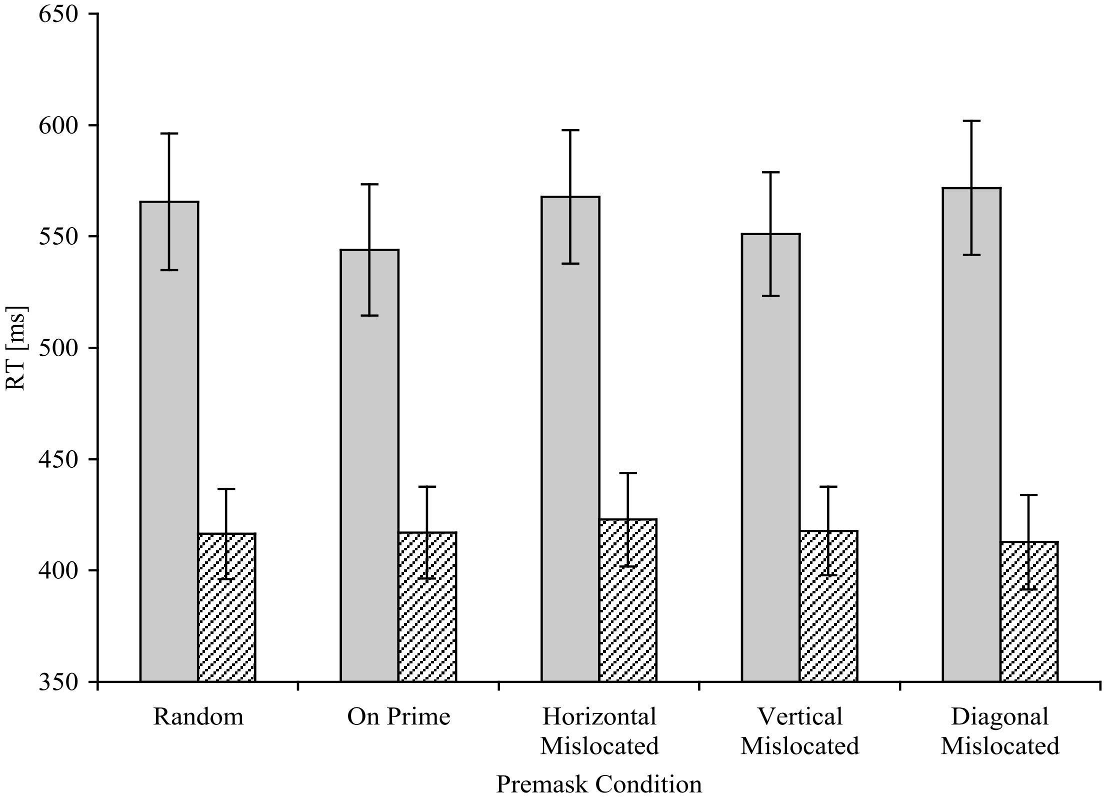

Figure 5.5: Mean correct target-present RTs (and their associated standard errors [SE mean]) as a function of Target Stimulus (figure, dot) x Target Location (random, on-prime, horizontally mislocated, vertically mislocated, diagonally mislocated). Grey and shaded bars represent figure and dot targets, respectively.

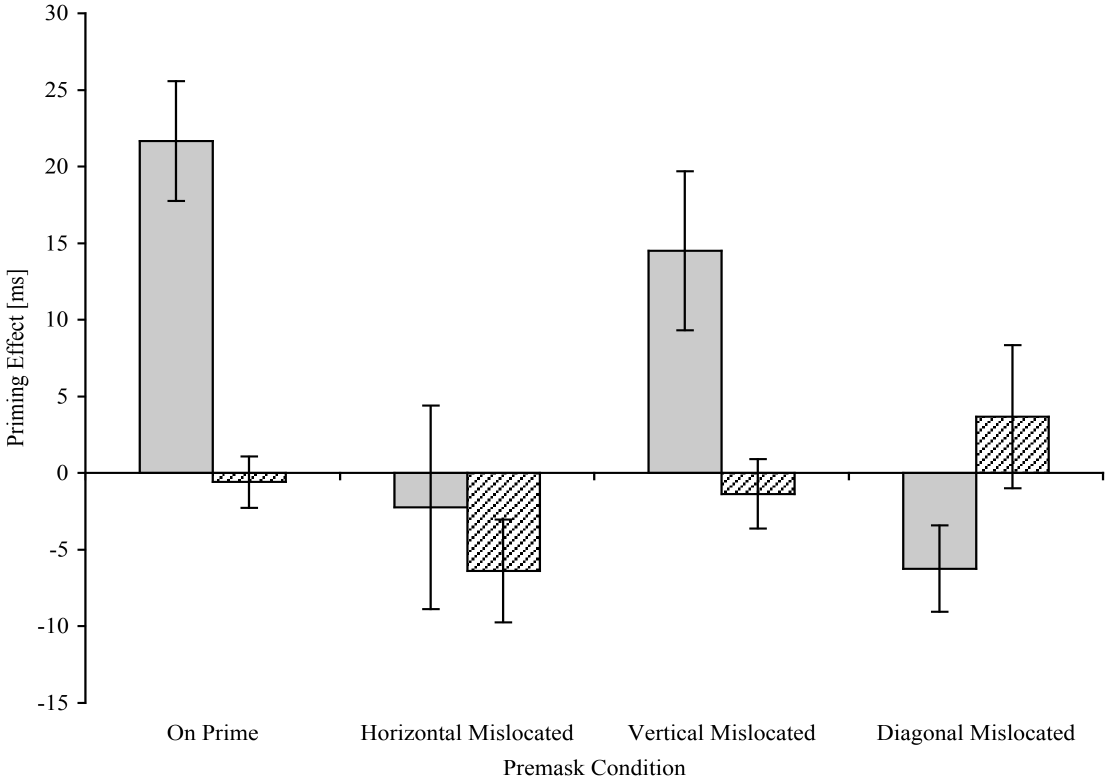

Figure 5.6: Mean priming effects (and their associated standard errors [SE mean]) as a function of Target Stimulus (figure, dot) and Target Location (random, on-prime, horizontally mislocated, vertically mislocated, diagonally mislocated). Grey and shaded bars represent figure and dot targets, respectively.

Error analysis. The overall error rates were 3.38% misses (target-present trials) and 1.86% false alarms (target-absent trials). The arc-sine transformed error data were examined by the same three ANOVAs computed for the RT data.

The first (overall) ANOVA, with the terms Target Stimulus, Premask, and Target, revealed only a significant main effect of Target, $F(1,9) = 10.100$, $p < .05$: more errors were made on target present trials (data not shown).

The second ANOVA, with the terms Target Stimulus and Target Location (random, on prime, mislocated) (see Figure 5.7), revealed a significant main effect for Target Figure, $F(1,9) = 6.283$, $p < .05$: more (target-miss) errors were made with figure targets than with dot targets (3.94 [0.84] % vs. 2.82 [0.72] %, respectively).

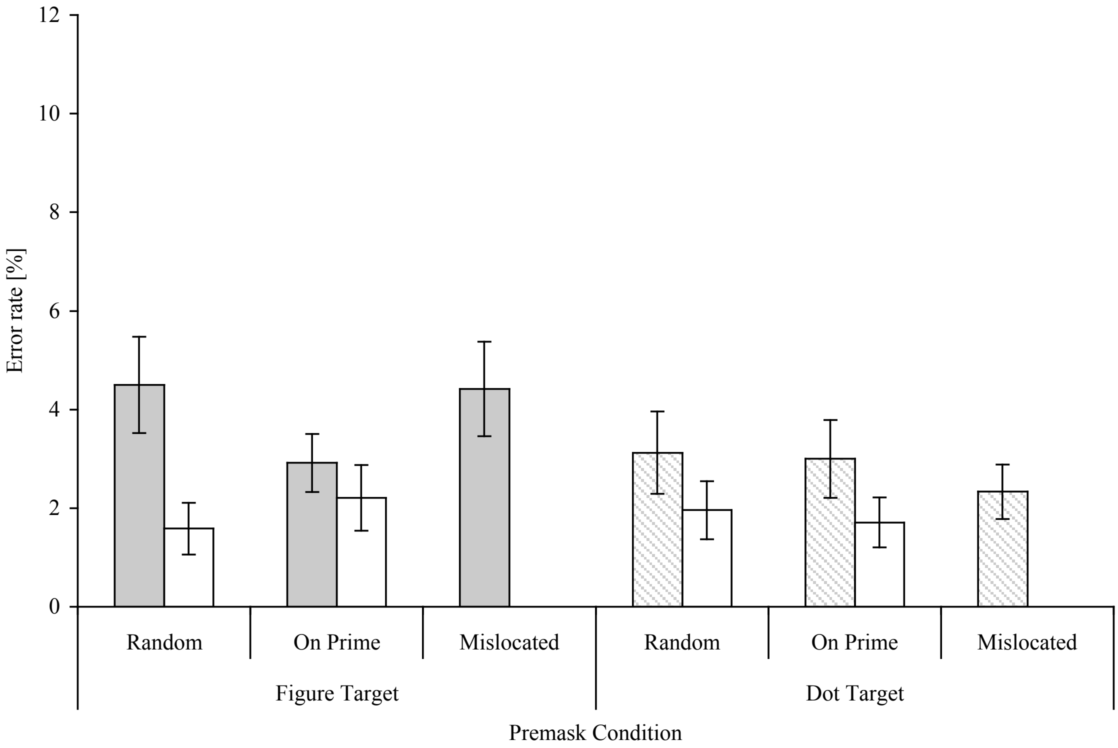

Figure 5.7: Mean error rates (and their associated standard errors [SE mean]) as a function of Target Location (random, on-prime, mislocated), separately for figure and dot targets (grey and shaded bars, respectively). White bars represent target-absent data.

The third ANOVA (Figure 5.8), with the terms Target Stimulus and Target Location (random, on-prime, horizontally mislocated, vertically mislocated, diagonally mislocated) revealed a significant effect for Target Location, F(4, 36) 4.363, $p < .01$: fewer errors were made for vertically mislocated targets than for targets following a random premask (3.81 [0.9] % vs. 3.10 [0.7] %, respectively).

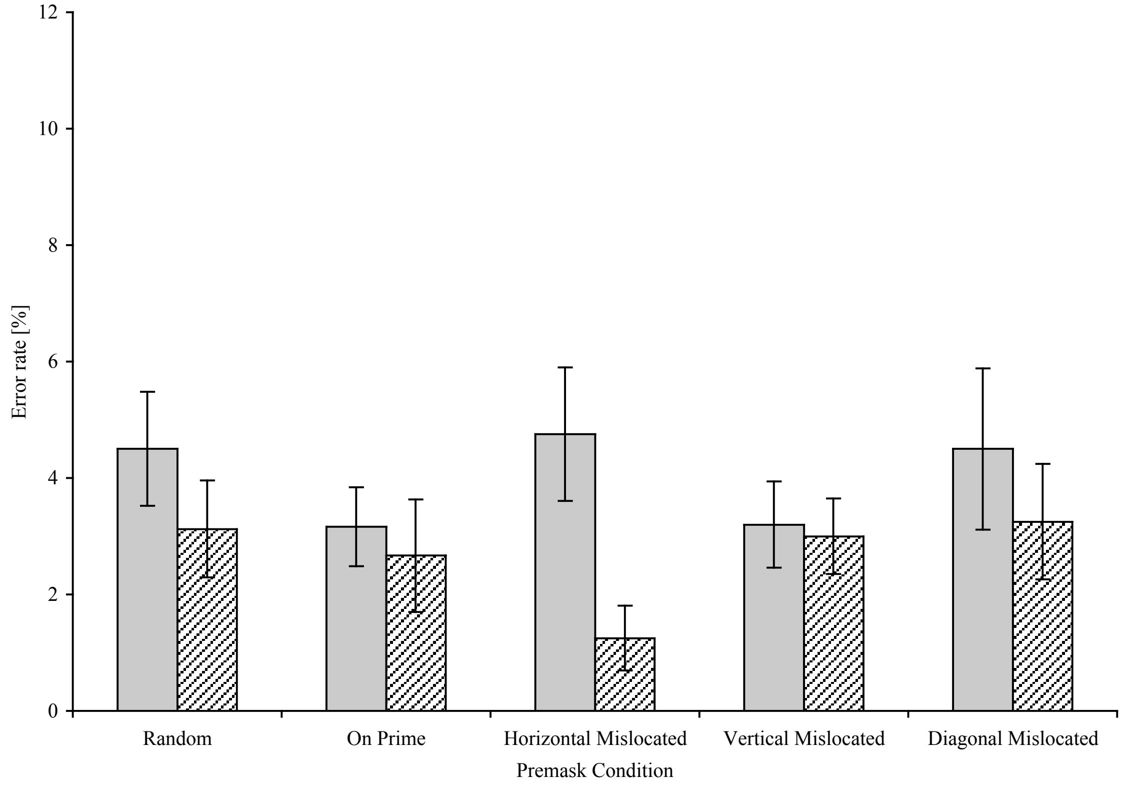

Figure 5.8: Mean error rates (and their associated standard errors [SE mean]) as a function of Target Location (random, on-prime, horizontally mislocated, vertically mislocated, diagonally mislocated), separately for figure (grey bars) and dot targets (dot bars).

Discussion

Experiment 1 replicated the results of Elliott and Müller´s Experiment 3 (1998). Observers showed significant synchronicity priming effects in the 'original', synchronous-premask condition with the Kanizsa-type target figure. However, when the mislocated-target conditions were examined as a function of the direction of mislocation, the priming effect was revealed to be dependent, to some extent, on the intra- vs. interhemispheric relation of the target relative to the prime location. When the target was presented in the same hemifield (i.e., vertically mislocated), the priming effect was hardly reduced. In contrast, when prime and target were presented in different hemifields (i.e., horizontally or diagonally mislocated), the priming effect vanished completely. This pattern may be explained in terms of time-consuming synchronization processes across the corpus callosum (e.g., Engel, König, Kreiter, & Singer, 1991).

In a second condition, observers had to respond to a simple dot target. This condition was introduced to examine whether the synchronous prime would facilitate the whole (iiner) region circumscribed by the prime elements. The results revealed no priming effects for such dot targets (and no reliable effects for such targtets as a function of target-relative-to-prime mislocalization). These results argue in favor of the figure-dependent nature of synchronicity priming, that is: locations within regions are circumscribed by prime elements do not, as such, receive facilitated processing. This also tends to argue against the idea that the complete (square-type) figure is pre-segmented from the background over the course of synchronous-prime presentation; rather, it suggests that only the single prime elements, or their nearby surround, are encoded within the temporal premask structure.

Experiment 2

Experiment 2 introduced a probe technique (e.g., Kim & Cave, 1995), combined with a secondary, non-speeded target detection task, in order to examine whether the absence of synchronicity priming in the dot-target condition in Experiment 1 was due to observers having operated a different task set (e.g., one in which they ‘ignored’ the flickering premask matrix) to that they used when performing that figure detection task (in which case they may have ‘attended’ to the premask matrix). In combining the target figure detection task, to be performed on each trial, with a dot-probe detection task, it was assumed that observers would adopt a task set appropriate for performing the former task, in which synchronicity priming is standardly observed. Thus, if the null-finding in the dot-target condition of Experiment 1 was due to observers having adopted an ‘inappropriate’ task set (ignoring the flickering premask matrix), then a synchrony priming effect may be observed in the dot-probe task of Experiment 2. This prediction is predicated on the assumption that that the detection of stimuli other than the Kanizsa-type target figure are expedited by synchronicity priming. Thus, if priming were not observed for dot-probes in Experiment 2, this would strengthen the conclusion that the prime is figure- (or, respectively figure element-) specific.

Immediately after premask display offset, a target display of 90º corner junctions (as in Experiment 1) was presented briefly, which did or did not contain a Kanisza-type target square. In addition, a dot probe could appear at three different SOAs relative to premask onset, and observers had to respond to its presence by pressing a response key (simple go-response). Assuming that the synchronous prime generates a signal already during premask presentation, one might expect priming effects to become manifest in terms of dot-probe RTs. Elliott (1998) found that priming effects were generated between

100 and 200 ms after premask onset (i.e., after one or two cycles of premask frame presentation). Based on this, dot probes were presented after 300, 400, or 500 ms after premask onset.

Method

Participants. Ten observers (5 female; mean age 26 years; all with normal or corrected-to-normal vision) took part in Experiment 2.

Apparatus. The experimental set-up was identical to Experiment 1, except that observers had to respond to the appearance of a dot-probe stimulus by pressing a response button with their right index finger (simple go-response).

Design and Procedure. In addition to the two target conditions (target figure presented at location of random- vs. synchronous-premask) described in the General Method section (see above), there was also a dot probe condition. A dot probe could appear during the presentation of the flickering premask, either 300, 400, or 500 ms after premask onset. After premask offset, a target display was presented briefly, which could contain a target. Probe and target could appear in one of the four possible matrix quadrants, with a probe presented in the middle of a qquadrant.

The experiment consisted of 480 experimental trials: 240 random-premask and 240 synchronous-premask trials. A dot probe was presented on 50% of the trials (80 trials for each onset condition), and a target was also presented on 50% of the trials (without linkage between dot probe and target presentation). All combinations of conditions were varied randomly from trial to trial.

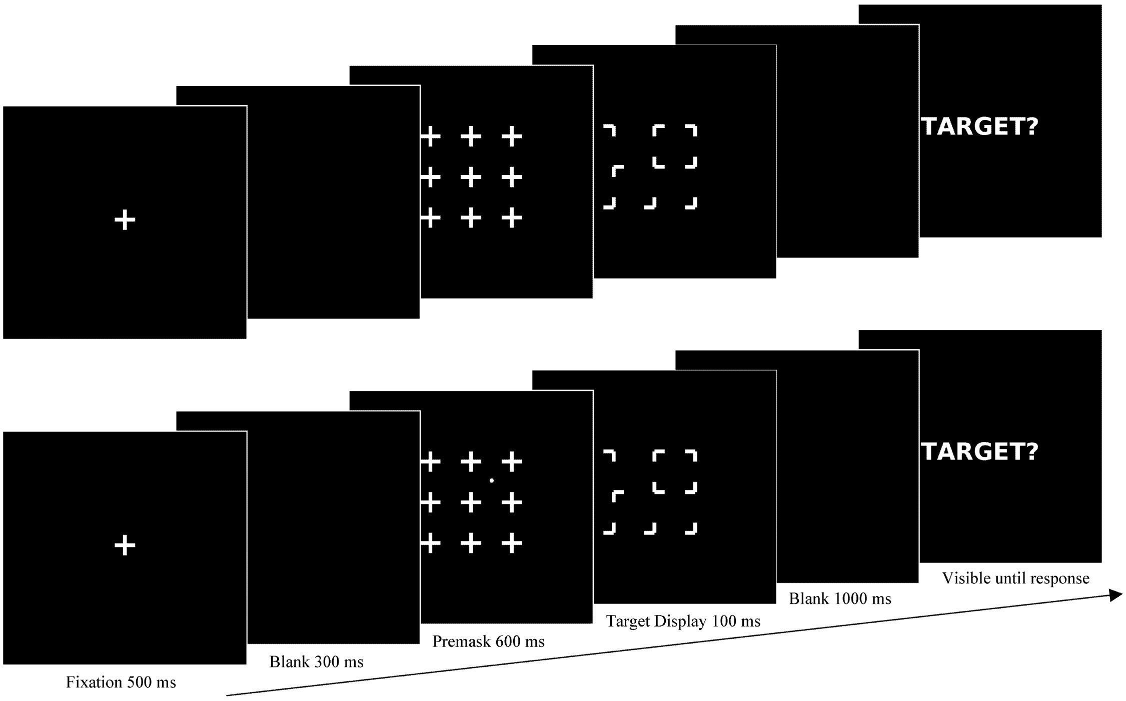

Figure 5.9: Example trials. Upper row shows a trial withou a dot-probe. In the lower row a dot-probe is presented at the upper right matrix quadrant.

At the beginning of each trial, a fixation cross was presented in the center of the screen for 500 ms. After a 300 ms blank screen, the flickering premask was presented for 600 ms. A dot probe could appear for 100 ms in the middle of a matrix quadrant after 300, 400, or 500 ms post premask onset. Observers had to indicate, as rapidly as possible, the presence of a dot-probe stimulus in the premask display by pressing a response key with their right index finger, or to withhold a response when no dot probe was presented (Go/No-go paradigm). Upon premask offset, the target display was presented 50 ms, followed by a blank screen for 100 ms. After the blank screen, the question 'TARGET?' appeared on the screen and remained in view until a response key was pressed on the keyboard. Observers pressed the "Y" or the "X" key with their left middle and index finger, respectively, to respond target-present and target-absent, respectively. The response was followed by a blank for 1000 ms, after which the next trial was presented. Observers were told to fixate the center of the display and avoid eye movements during premask display presentation. In case of an erroneous 'TARGET' response, feedback was provided through a (300 ms) 400-Hz computer-generated tone.

Results

RT analysis. RTs on trials on which a response error was made (3.28% of all trials) and extreme RTs (< 150 ms and > 1500 ms) were excluded from the analysis of the dot-probe RTs. Figure 5.10 presents the correct mean RTs (and their associated standard errors [SE mean]) as a function of Premask condition (random, synchron) x Probe Onset (300, 400, 500 ms) condition. The data were examined by a two-way ANOVA, with terms for Premask and Probe Onset. This analysis revealed no significant main effect for Premask, F(1, 10) = 0.395, and the Premask x Probe Onset interaction was non-significant, F(1.227, 12.268) = 0.105. The only significant effect was the main effect for Probe Onset, F(1.178, 11.781) = 15.644, p < .01 (Greenhouse-Geisser corrected degrees of freedom [G-G]): dot-probe RTs became faster as time of the dot-probe onset approached the onset of the target display (reaction times and their associated standard errors [SE mean]: 493 [25], 451 [18], 423 [16] ms for 300-, 400-, and 500-ms dot-probe onset times, respectively). This is effect is interesting, because it shows that observers were preparing for target presentation. Despite this, the dot-probe RTs showed no evidence of synchronicity priming.

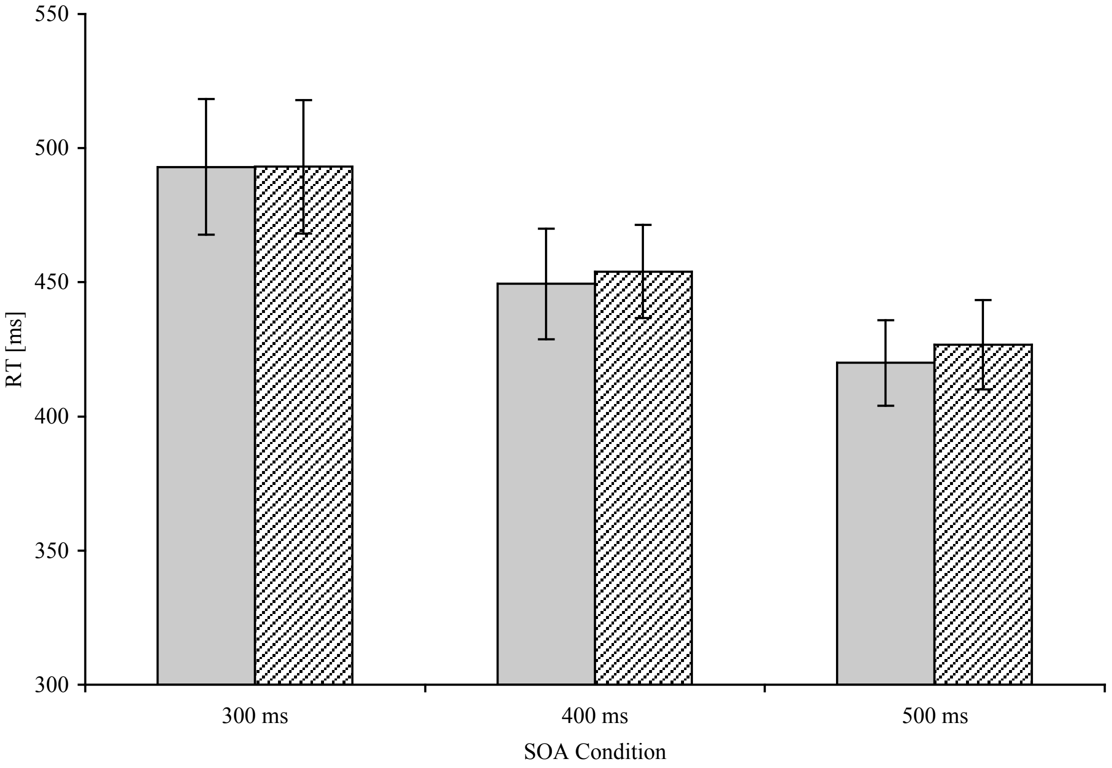

Figure 5.10: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Premask condition (random, synchronous) and Probe Onset (300, 400, 500 ms).

Error analysis. The rates of erroneous dot-probe responses are presented in Figure 5.11. The overall error rates were 3.68 % misses (probe-present trials) and 2.88% false alarms (probe-absent trials). A Premask x Probe Onset ANOVA of the miss rate data failed to reveal any significant effects.

Performance in the second, non-speeded target figure detection task was also analyzed by a Premask x Probe Onset ANOVA (see Figure 5.12), which revealed no significant effects. Overall, there were 5.04% misses (target-present trials) and 5.50% false alarms (target-absent trials). The fact that there was no synchronicity priming effect on these non-speeded target-present/absent judgments may be due to the 50-ms target display presentation being so long as to permit near-perfect performance. [A priming effect in terms of response accuracy might be found if the exposure time of the target display is reduced below 50 ms.]

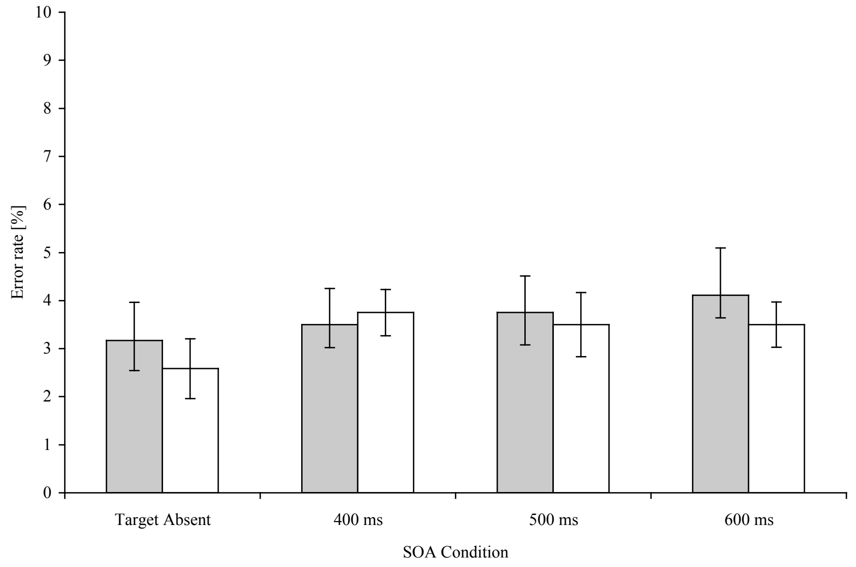

Figure 5.11: Mean error rates (and their associated standard errors [SE mean]) for the dot-probe detection task. Grey bars show error rates for random-premask trials, white bars for synchronous-premask trials, for each dot-probe onset condition (300, 400, 500 ms).

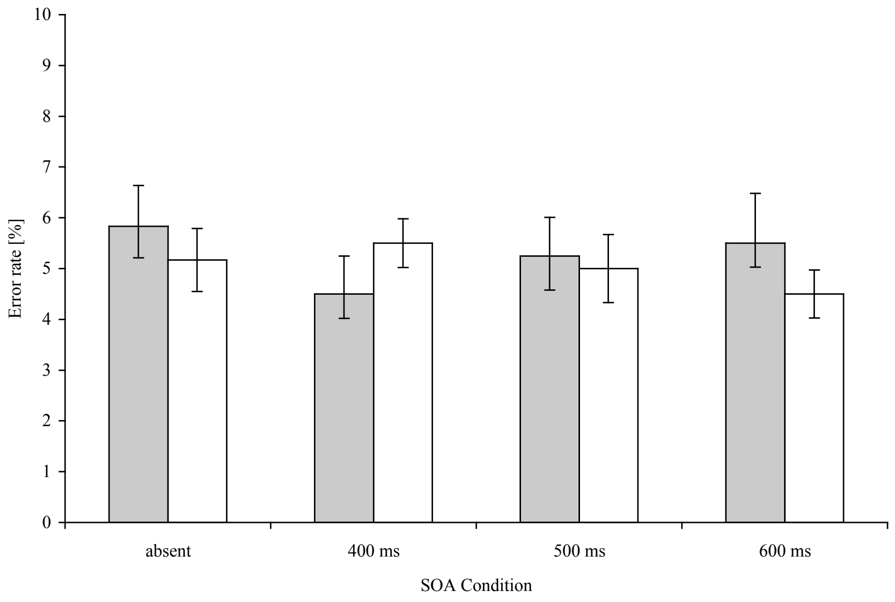

Figure 5.12: Mean error rates (and their associated standard errors [SE mean]) for the target (figure) detection task. Grey bars show error rates for random-premask trials, white bars for synchronous-premask trials, for each dot-probe onset condition (300, 400, 500 ms).

Discussion

The results of Experiment show clearly that, for dot-probe detection, no synchrony priming effect was manifest at any probe onset SOA, even though there was evidence that observers adopted a task set similar to that used in the 'standard' synchrony priming paradigm. Observers' RTs to the dot probes were the faster, the shorter the time of the dot-probe onset relative to target (figure) display onset. This represents a typical 'warning signal effect' (e.g., Posner, 1980), with the onset of the premask matrix serving a timing signal for preparatory processes that 'anticipate' the time of probe and, respectively, target appearance (the longer the premask is presented, the more likely it is for the probe to appear).

Given that observers attended to the premask matrix to predict the time of probe/target presentation (i.e., given that they adopted the 'standard' task set), the null-finding of synchronicity priming for dot-probe detection becomes interesting. It suggests, in line with the non-finding in Experiment 1, the manifestation of the synchronous prime is critically dependent on the (subsequently presented) target figure: there seems to be no prime signal generated by the 40-Hz flickering premask, which would have a facilitatory effect for non-figue targets presented within the region defined by the prime elements.

Experiment 3

Experiment 3 was similar to Experiment 1, with the difference that the target dot could appear at varying positions relative to the presented prime elements. More precisely, except for the position in the middle of a matrix quadrant, it could also appear at three different distances relative to the middle position (see Figure 5.13). At the farthest distance, the target dot appeared collinearily between two cross segements of a preceding prime (on sychronous-premask condition). In this way, it became possible to examine wether the priming effect requires, or involves, collinear grouping of prime, and respectively, target elements (e.g., Donnelly et al., 1991). A possible outcome may be that synchrony priming occurs only in collinear conditions, but not in the three other conditions in which the target appeared inside the area circumscribed by the four prime elements. Another possibility is that, the nearer the target positions relative to a collinear line segments, the larger or more reliable the priming effect.

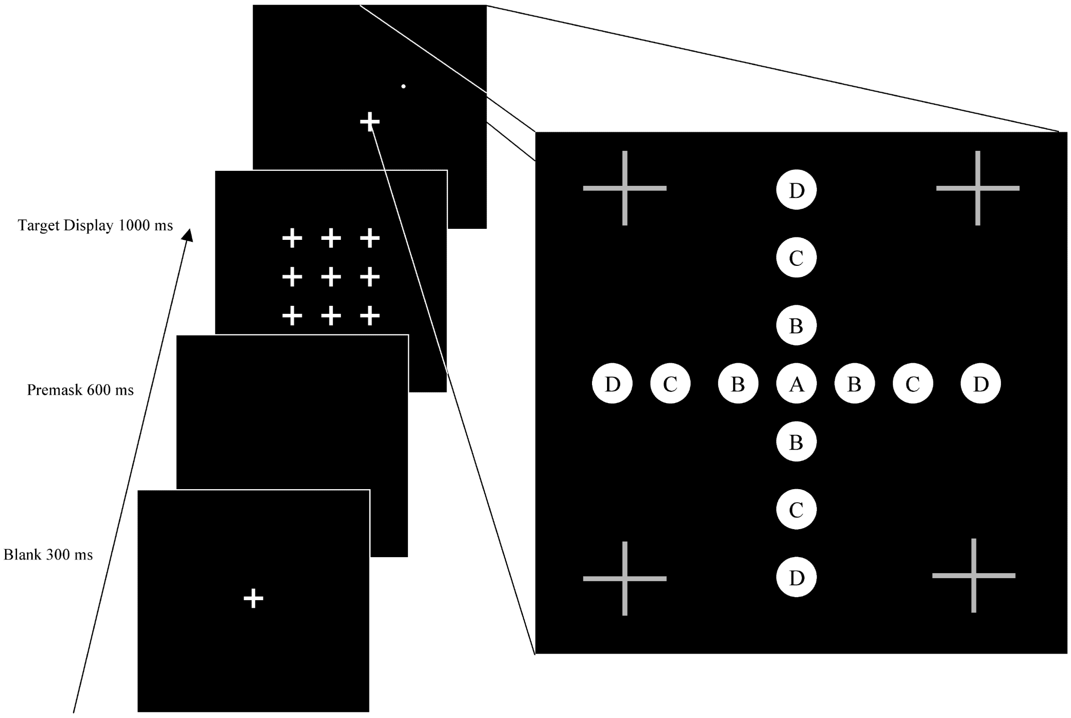

Figure 5.13: Example trial and possible target positions in Experiment 3. A) Middleposition B) Distance 1 C) Distance 2 D) Distance 3/Collinear

Method

Participants. Nine observers (6 female; mean age 24 years; all with normal or corrected-to-normal vision) took part in Experiment 3.

Design and Procedure. In addition to the premask conditions described in the General Method section (see above), the condition Target Position was introduced which had four levels (see Figure 5.13). As in Experiment 1, a target dot could appear in the middle of a matrix quadrant; but it could also appear at three different distances relative to the middle position. At the farthest distance, the target dot was presented collinearily between two cross segments of a preceding prime (sychronous-premask condition). The target distances were varied horizontally and vertically.

Experiment 3 consisted a total of 1200 experimental trials: 600 random-premask and 600 synchronous-premask trials. 50% of all trials were target-present trials and 50%

target-absent trials. Target present trials were equally split up by target position conditions (150 trials in each condition). All combinations of conditions were varied randomly from trial to trial.

At the beginning of each trial, a fixation cross was presented in the center of the screen for 500 ms. After a 300 ms blank screen, the flickering premask matrix was presented for 600 ms. Directly after premask matrix offset, observers had to detect, as rapidly and accurately as possible, the presence or absence of a target dot. The target display (a single dot) remained in view for 1000 ms or until a response had been made. Observers had to press a button with their right index finger for target presence and withhold a response when no target appeared (Go-/No-go task). The response (or time-out) was followed by a blank for 1000 ms, after which the next trial was presented. Observers were told to fixate the center of the display and avoid eye movements during premask display presentation. In case of an erroneous response, feedback was provided through a (300 ms) 400-Hz computer-generated tone.

Results

RT analysis. RTs on trials on which a response error was made (0.13% of all trials), extreme RTs (< 150 ms), and RTs 2.5 standard deviations above or below the mean for each observer (3.34% of all trials) were removed from the data prior to RT analysis. Figure 5.14 presents the correct mean RTs (and their associated standard errors [SE mean]) as a function of Premask (random, synchronous) and Target Position (middle, distance 1, distance 2, distance 3/collinear). A two-way ANOVA with main terms for Premask and Traget Position only revealed a significant effect for Target Position , F(3, 24) = 23.446, p < .001. There were no effects involving Premask (main effect, F(1, 8) < 0.001; Premask x Target Position interaction, F(3, 24) = 2.389). Multiple comparisons

(Bonferroni adjusted) showed that RTs to targets presented collinearly with the line segments in the preemask/target display (distance-3/collinear condition) were significantly slower than RTs in all other Target Position conditions. Further, RTs to targets at middle positions were significantly faster than RTs presented at distance 2 (309 [8], 311 [9], 314 [9], and 319 [9] ms for middle, distance-1, distance-2, and distance-3/colinear conditions, respectively).

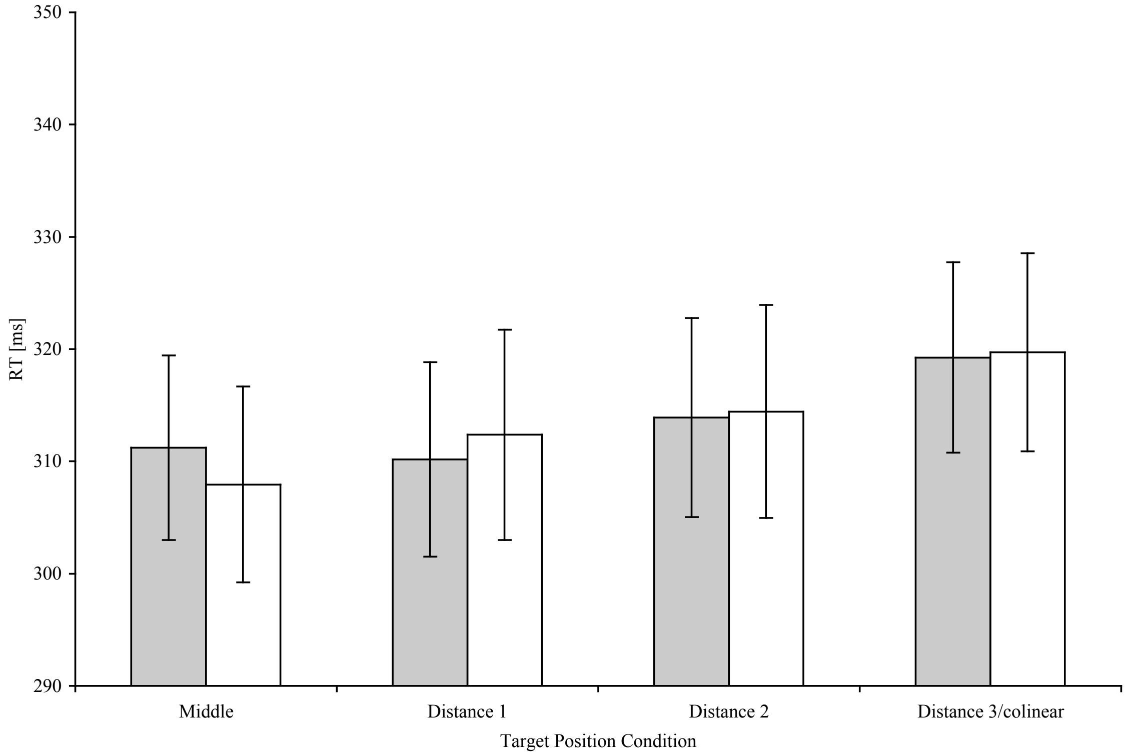

Figure 5.14: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Target Position (middle, dis-1, dis-2, dis-3/collinear) x Premask (random, synchronous). Grey and white bars represent random- and synchronous-premask conditions, respectively.

In a second analysis step, the ‘distance-3/collinear’ condition was subdivided into an ‘inner’ and ‘outer collinear’ condition. A Premask x Target Position (middle, distance 1, distance 2, inner-collinear, outer-collinear) ANOVA again revealed a significant effect for Target Position, F(1.859, 14.874) = 4.440, p < .05 (Greenhouse-Geisser corrected degrees of freedom). Furthermore, while there was no significant effect for Premask, F(1,

8) = 0.415, the Premask x Target position interaction was significant, F(4, 24) = 22.327, p < .001. This was due to significant differences between middle-position RTs and distance-1 and distance-2 RTs on synchronous-premask, but not random-premask trials, and a significant difference between distance-1 and distance-2 RTs on random-premask, but not synchronous- premask trials (see Figure 5.15).

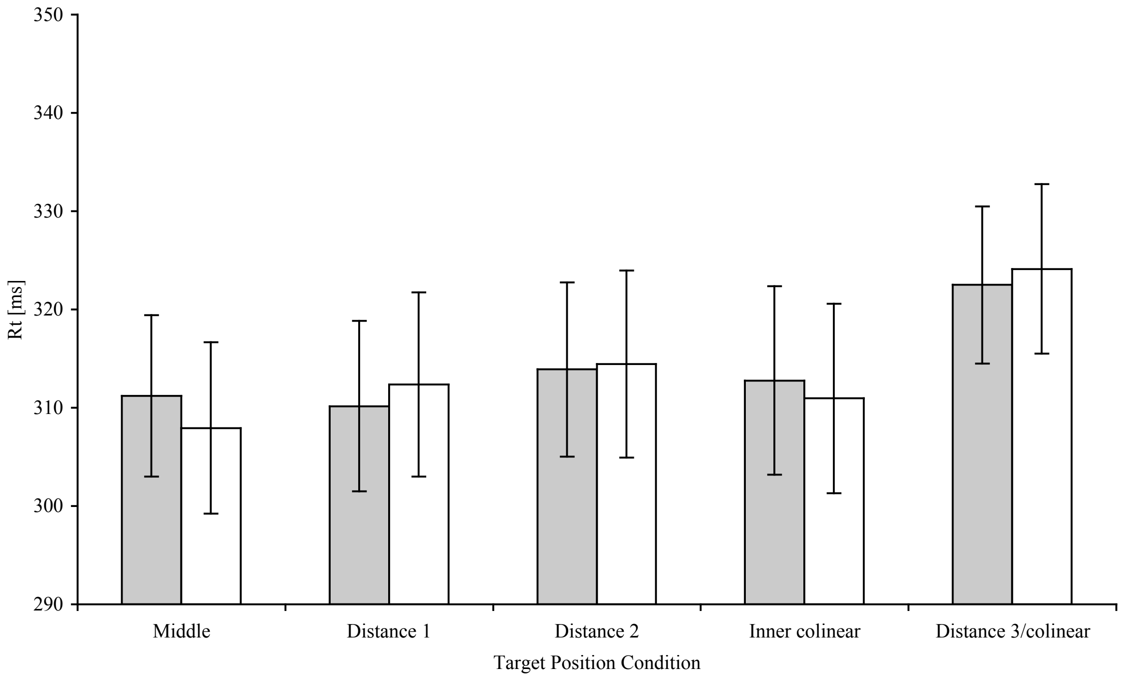

Figure 5.15: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Target Position (middle, dis-0, dis-1, dis-2, inner-collinear, outer-collinear) x Premask (random, synchronous). Grey and white bars represent random- and synchronous- premask conditions, respectively.

Error analysis. Too few errors were made (0.13 %) to permit a reliable error data analysis.

Discussion

The results Experiment 3 show no reliable priming effects for dot targets presented at any of the four possible target locations. Instead, only increasing RTs were observed the more distant a target dot appeared relative to the middle positions. [There were slight, but non-significant trends towards priming at best for middle and inner-collinear positions.] Thus, the findings argue that even collinear points between synchronously presented prime elements do not receive facilitated processing. This would argue against the notion that the activity pattern generated by the synchronous prime entrains feature-coding mechanisms which may be responsible for the formation of a subsequent target, at least, as concerns the Gestalt principle of good continuation (i.e., collinearity). Another possibility could be that the two or four prime elements are encoded by cells with small receptive fields which give rise to ‘focal’ activity and which converge at higher areas of the visual system. It may then be that the priming activity triggers other perceptual grouping mechanisms (e.g.. proximity). However, if that would be the case it would be more likely for priming to occur within regions circumscribed by the prime elements, which was not observed.

Experiment 4

Experiment 4 was an extension of Experiment 3, examining whether performance of the dot detection task is at all modulable by facilitatory processes. It may well be that detection of a dot target is so efficient that it simply cannot be expedited, and that this is the reason for the lack of priming effects in Experiments 1–3. To address this question, Experiment 4 was designed to examine the potential role of visuo-spatial attention for synchrony priming. Another study (reported Chapter 3) had shown that misdirection of spatial attention (by invalid cues) can lead to enhanced priming effects. Based on this, one might expect an effect of priming on dot target detection to become manifest on invalid-cue trials (assuming that such an effect exists at all). To examine this, an auditory spatial-attentional cue was introduced, which directed attention to one of the matrix quadrants. The dot target could appear in either the middle position of a quadrant or at a collinear position between aligned premask cross segements (as in the middle and collinear conditions of Experiment 3).

Method

Participants. Ten observers (8 female; mean age 24.8 years; all with normal or corrected-to-normal vision) took part in Experiment 2.

Apparatus. An exogenous auditory cue was presented by means of a custom-made device with four loudspeakers (30 mm diameter, 8 Ω impedance, 1300 - 8000 Hz). The speakers were placed at about 5 cm distance to the corners of the oscilloscopic screen. The device had a separate energy supply and was controlled through the parallel port of the same computer that controlled the point-plotter buffer system and recorded the data.

Stimuli. The stimuli were the same as in Experiment 3, with the difference that exogenous auditory were cues presented after the premask offset. Valid and invalid cues consisted of a 25-ms beep (same duration as a single premask frame, 1500 Hz) prodiuced by a speaker at one of the four corners of the screen. In neutral-cue conditions, the four speakers were sounded together, which led to the impression of the beep originating from the middle of the screen. Thus, neutral cued did not ‘indicate’ any particular display quadrant (Figure 5.16).

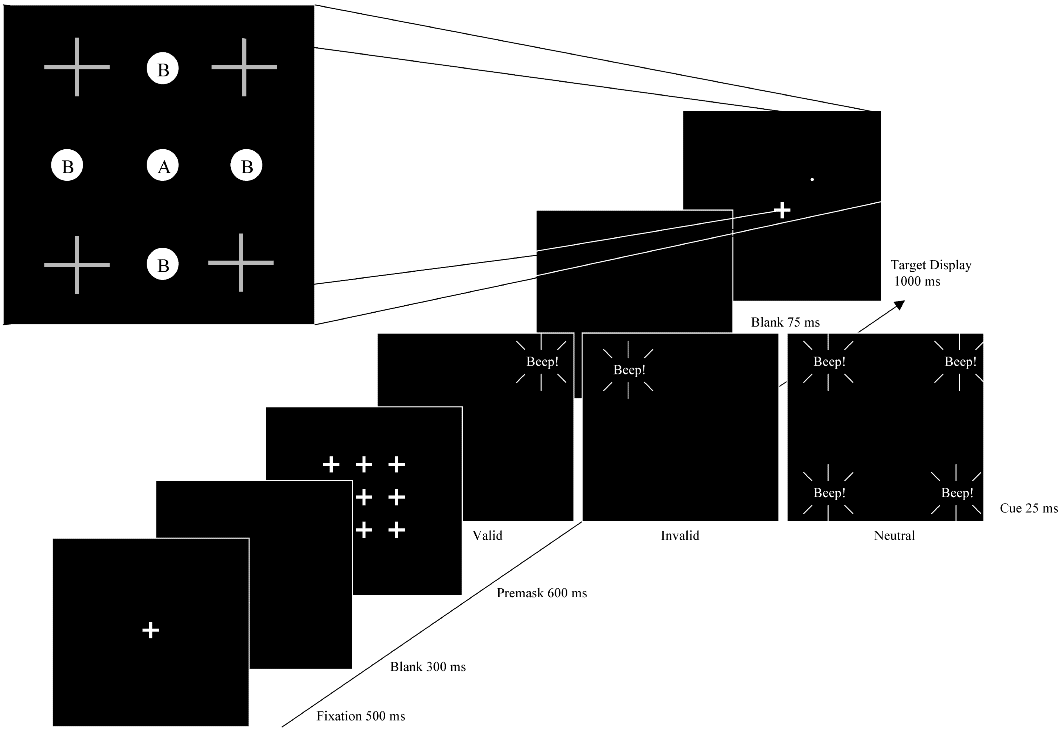

Figure 5.16: Trials and possible target positions in Experiment 4. A) Middle position B) collinear positions. Cueing was provided by an acoustic cue coming from one of four loudspeakers near the matrix quadrants (or all loudspeakers in neutral-cue condition).

Procedure. See Figure 5.16 for the sequence of events on a trial. At the beginning of each trial, a fixation cross was presented in the center of the screen for 500 ms. After a 300 ms blank screen, the flickering premask matrix was presented for 600 ms. After premask matrix offset, the auditory cue was sounded for 25 ms. 100 ms after premask offset (i.e., 75 ms after cue offset), a target dot could be presented to which observers to respond as rapidly as possible. This target display (i.e., the dot target) remained in view for 1000 ms or until a response had been made. Observers had to press a single button with their right index finger for target presence, or withhold a response when no target appeared (go/no-go task). The response (or time-out) was followed by a blank screen for 1000 ms, after which the next trial was presented. Observers were told to fixate the centre of the display and avoid eye movements during premask display presentation. In case of an erroneous response, feedback was provided through a (300 ms) 400-Hz computer-generated tone.

The experiment consisted of a total of 1800 experimental trials: 900 random-premask and 900 synchronous-premask trials. 1080 trials were 'go' trials (60%) and 720 'no-go' trials (40%). The 'go' trials were compose of 480 neutral-cue, 480 valid-cue (80%), and 120 invalid-cue (20%) trials. All these types of trial were equally divided between the two premask conditions. All combinations of conditions were varied randomly from trial to trial.

Results

RT analysis. RTs on trials on which a response error was made (2.23% of all trials), extreme RTs (< 150 ms), and RTs 2.5 standard deviations above or below the mean for each observer (2.79% of all trials) were removed from the data prior to RT analysis. A three-way ANOVA of the RT data, with main terms for Cueing, Premask, and Target Position, revealed significant main effects for Cueing and Target Position, F(2, 18) = 5.688, p < .05, and F(1, 9) = 281.733, p < .001, respectively, and a significant Cueing x Target Position interaction, F(2, 18) = 5.311, p < .05. No other effects were significant (see Figure 5.17). Multiple comparison (Bonferroni adjusted) among Cueing conditions revealed neutral-trial RTs to be significantly slower than valid-trial RTs (p = .007; RTs and their associated standard errors [SE mean]: 316 [9], 310 [10], and 313 [10] ms for neutral, valid, and invalid cues, respectively). RTs to middle-position dot targets were faster than RTs to collinear dot target (309 [10] vs. 317 [9] ms). Pairwise comparison (Bonferroni adjusted) of the Cueing x Target Position effect showed that RTs for middle-position target were faster than RTs for collinear-position targets for neutral- and valid-cue trials (p < .001), but not for invalid-cue trials.

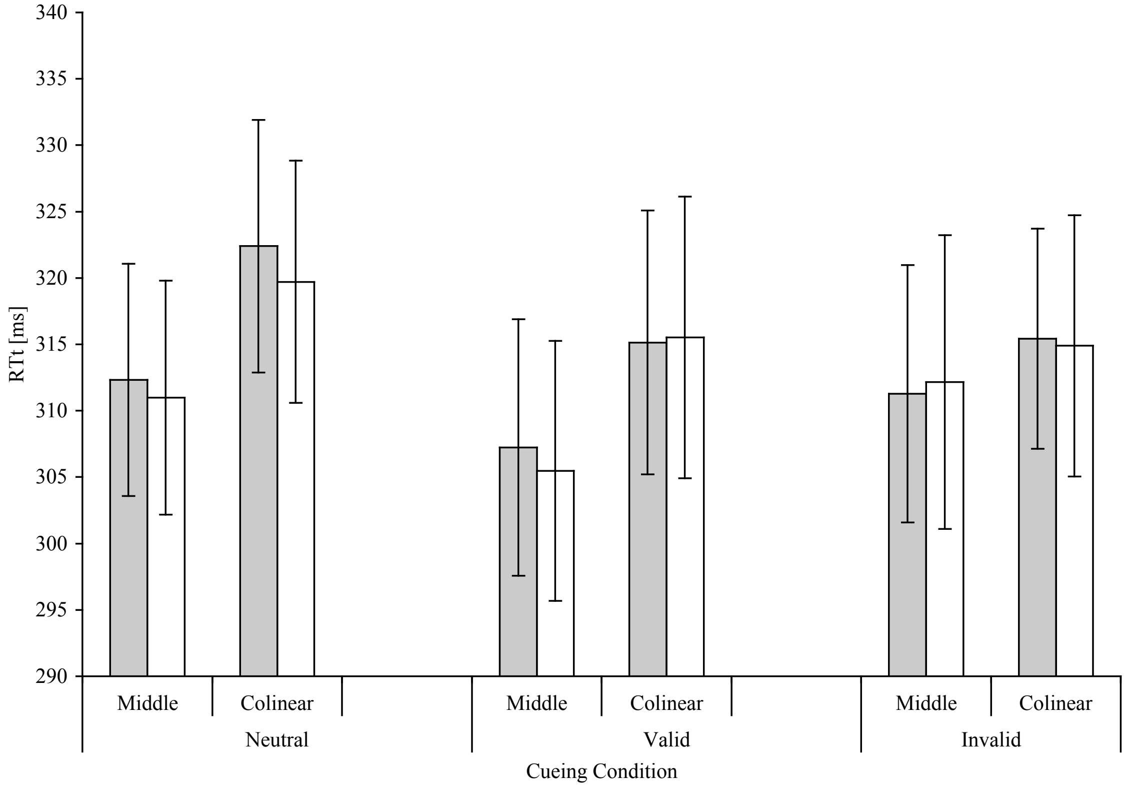

Figure 5.17: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Cueing (Neutral, Valid, Invalid) x Target Position (Middle, Collinear) x Premask (Random, Synchron).

In a second analysis step, the target positions subdivided into ‘inner’ and ‘outer collinear’ positions (see Figures 5.18 – 5.20). A Cueing x Premask x Target Position ANOVA, with an additional level for the term Target Position, essentially revealed the same pattern of effects as the first ANOVA: Cueing, F(2, 18) = 4.320, p < .05; Target Position, F(1.248, 11.231) = 98.479, p < .001 (Greenhouse-Geisser corrected degrees of freedom); and Cueing x Target Position, F(4, 36) = 3.841, p < .05. The interaction was due to faster RTs for inner positions on invalid-cue trials, but not on neutral- and valid-cue trials. Even though there is some tendency towards an RT-difference between random- and synchronous-premask conditions for collinear-inner dot target positions on neutral- and invalid-cue trials, the Cueing x Premask x Target Position interaction was non-significant, F(4, 36) = 1.963, p = .121. The corresponding priming effects are presented in Figure 5.21.

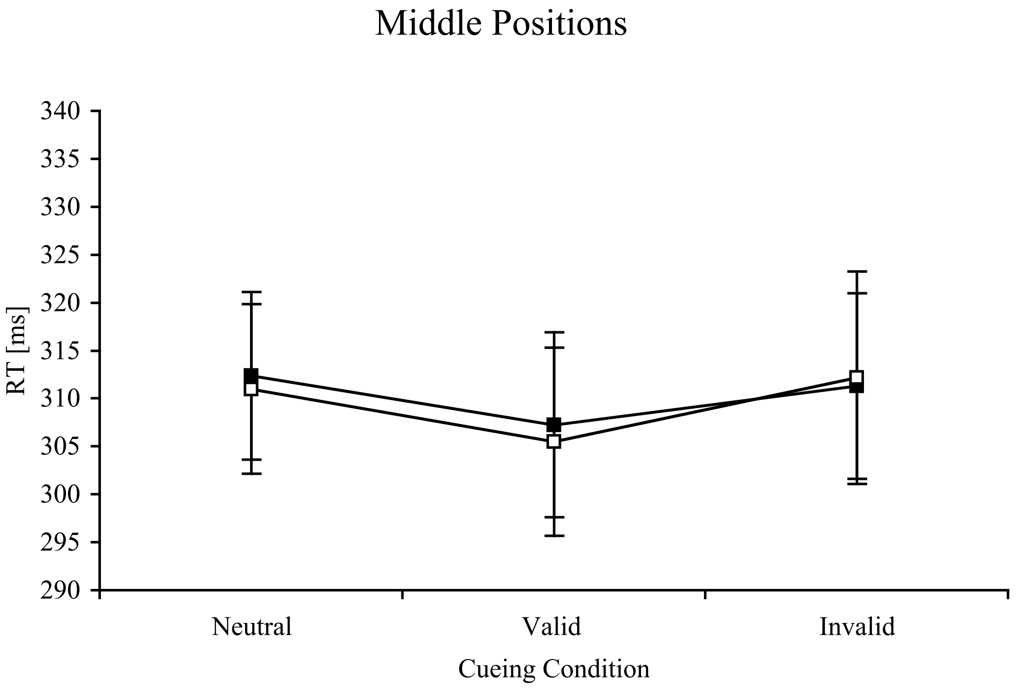

Figure 5.18: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Cueing (neutral, valid, invalid) x Premask (random, synchronous) condition. Filled and open squares represent random- and synchronous-premask conditions, respectively..

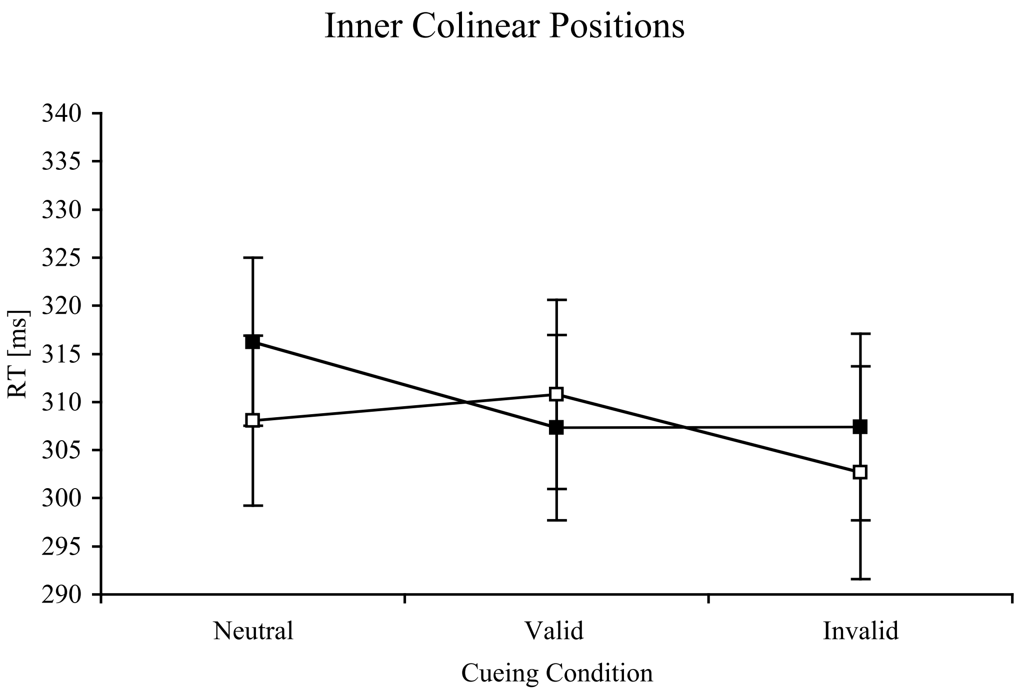

Figure 5.19: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Cueing (neutral, valid, invalid) x Premask (random, synchronous) condition. Filled and open squares represent random- and synchronous-premask conditions, respectively.

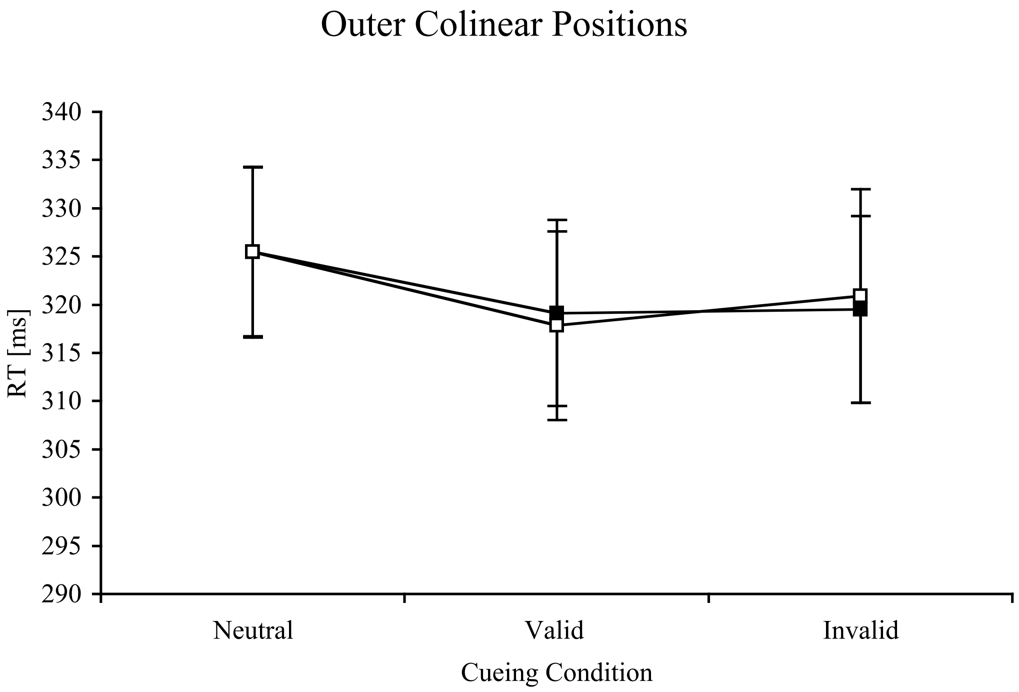

Figure 5.20: Mean correct RTs (and their associated standard errors [SE mean]) as a function of Cueing (Neutral, Valid, Invalid) x Premask (Random, Synchron). Filled and open squares represent random and synchron conditions, respectively.

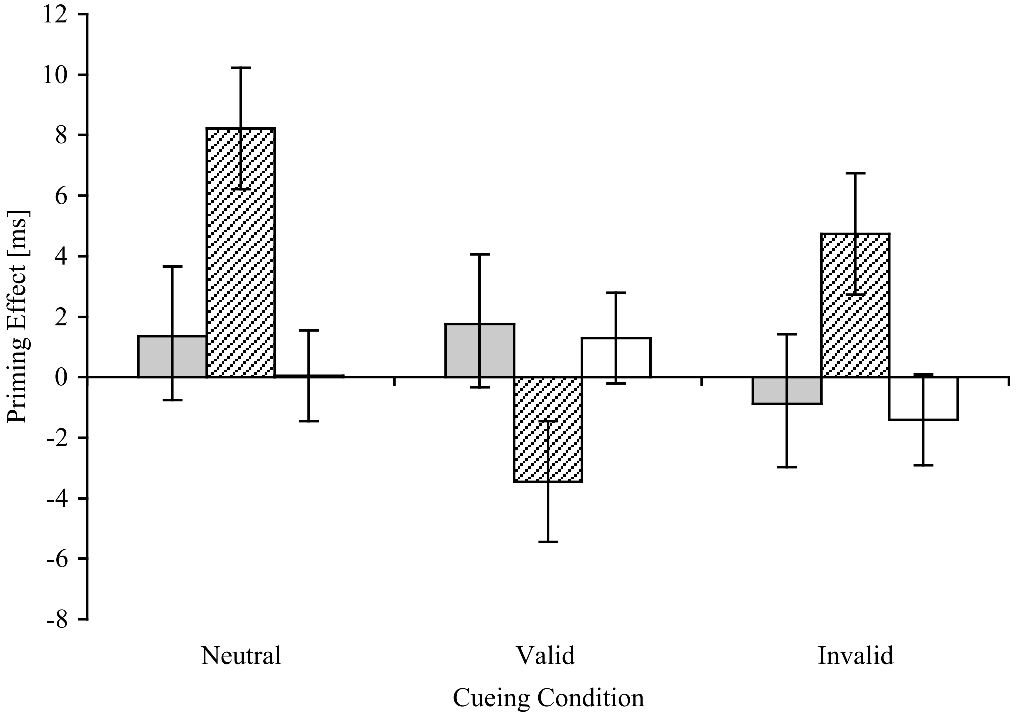

Figure 5.21: Mean priming effects (and their associated standard errors [SE mean]) as a function of Cueing (neutral, valid, invalid) x Target Position (middle, inner-collinear, outer-collinear). Grey, shaded, and white bars represent middle, inner-collinear, and outer collinear target position conditions, respectively.

Error analysis. The overall error rates were 2.72% misses and 1.79% false alarms. A Cueing x Premask x Target ANOVA failed to reveal any significant effects.

Also in the second the ANOVA with terms Cueing, Premask, and Target Position no significant effects were revealed.

Discussion

Experiment 4 showed that detection of a simple target dot can be further enhanced by directing spatial attention in advance to the target quadrant. This suggests that the results of the previous experiments were not simply due to a 'ceiling effect', that is, near-optimal task performance that is no longer modulable by experimental manipulations.

The finding that invalid cues produced no costs relative to the neutral-cue ‘baseline’ can be explained. While an invalid ‘beep’ coming from the left or the right could be clearly localized, it was hard for the observers to discern whether the cue came from the upper or the lower position. This means that, no matter whether the cue came from the left or right, it was equally ‘valid’ for targets that appeared at the upper or the lower position. That is, processing was facilitated for targets presented on the same side as the cue, no matter whether they were presented at the (actually) cued location or a non-cued location.

Consistent with previous experiments (see Chapter 3), there was also some numerical evidence of a synchronicity priming effect for invalidly cued dot targets appearing at inner collinear positions. This also held for neutral-cue trials. The latter finding may not be too surprising, because the neutral cue consisted of all speakers beeping together, which produced the subjective impression of the beep originating from the center of the display. As inner collinear positions were at a certain distance from the central position, a neutral cue could have the same attention mis-guiding effect as an invalid cue.

What remains unclear, however, is why dot targets presented at outer collinear positions did not display a tendency towards a priming effect on invalid- and neutral cue trials. It may be that the offset of the premask crosses directly before dot target presentation masked the appearance of a dot target, and that the masking was stronger for outer, than for inner, collinear positions, thereby also ‘masking’ any priming effects for outer collinear dot targets.

General Discussion

The present study examined the nature of the synchrony priming effect, that is, the facilitatory effect on target detection resulting from the prior presentation, at the target location, of a 40-Hz (i.e., locally actually 10-Hz) synchronous stimulus pattern. In particular, it was investigated whether the synchronous prime generates a location-specific prime ‘spot’ circumscribed by the prime elements in the flickering premask, or whether the priming is dependent for its realization on the onset of a target figure following premask matrix offset.

Experiment 1 replicated the ‘standard’ effect found by Elliott and Müller (1998, 2000, 2001). In addition, a differential effect was found when the prime and the subsequent target figure were mislocated relative to each other. In the original Experiment 3 of Elliott and Müller, mislocated primes seemed to have no effect on target detection (i.e., they produced no RT costs relative to the random-premask baseline). The results of Experiment 1 paint a different picture: primes that were vertically mislocated relative to the following target produced nearly the same priming effects as ‘valid’ primes. In contrast, only primes thatb were located in the other hemifield (horizontal or diagonal mislocation) failed to generate any priming effect. This pattern is still consistent with the findings of Elliott and Müller (Experiment 3, 1998), but it provides more insight into possible underlying neural mechanisms. The priming seems to be dependent on the intra- and inter-hemispheric spatial relation of the target relative to the prime, which is suggestive of time-consuming synchronization processes across the corpus callosum (e.g., Engel, König, Kreiter, & Singer, 1991).

In Experiments 1–3, the non-figure (i.e., dot target and dot probe) conditions showed no priming effects, irrespective of whether or not the task set was similar to the ‘standard’ synchronicity priming paradigm (Experiment 2), and whether or not the dot positions were aligned according to the Gestalt principle of good continuation (i.e., collinearity) (Experiment 3). A possible explanation for the latter findings is that the two or four prime elements are encoded by cells with small receptive fields, which produce ‘focal’ activity that converges only in higher areas of the visual system. This has several implications for the mechanisms generating the prime information. If higher visual areas with cells that have larger receptive fields receive the spatio-temporal structure of the flickering premask and induce coherent oscillations at lower levels of the visual system by backwards propagation (e.g., Gilbert, 1993), how can the spatial area of facilitatory activation be so location-specific? An explanation may be a process of phase shifting generated by the interaction of the bottom-up 10-Hz rhythm of synchronous premask re-presentation with the top-down 40-Hz rhythm (see Elliott & Müller, 2001). In this way, the synchronous prime will take on a 40-Hz pattern, while at the same time being temporally segmented from the non-prime premask elements.

Experiment 4 showed that detection of a simple target dot can be further enhanced by directing spatial attention in advance to the target quadrant. This suggests that the results of the previous experiments were not simply due to a ‘ceiling effect’, that is, near-optimal task performance that is no longer modulable by experimental manipulations.

Consistent with previous experiments (see Chapter 3), there was also a tendency towards a synchronicity priming effect for invalidly and neutrally cued dot targets appearing at inner collinear positions. However, it remains unclear why dot targets presented at outer collinear positions did not display the same tendency on invalid- and neutral cue trials. It may be that the offset of the premask crosses directly before dot target presentation masked the appearance of a dot target, and that the masking was stronger for outer, than for inner, collinear positions, thereby also ‘masking’ any priming effects for outer collinear dot targets.

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Deutsche Zusammenfassung

Zu den zentralen Problemen, die das Gehirn bei der Figur-Grund-Segmentation, der Erkennung von Objekten und der Bildung von internen Objektrepräsentationen lösen muss, gehört die Bindung von separat kodierten Merkmalseigenschaften zu kohärenten Objektrepräsentationen. Dieser Fragenkomplex wird als *Bindungsproblem* bezeichnet und ist seit einiger Zeit Gegenstand von Forschern aus einer Reihe von Disziplinen im Bereich der Kognition Neurowissenschaft – v.a. der Psychologie und der Physiologie. Innerhalb der Psychologie beschäftigt man sich insbesondere mit der Untersuchung der Gestalt-Prinzipien perzeptiver Gruppierung, der Beziehung von Gruppierungs- und Bindungsprozessen zu Mechanismen der visuellen Aufmerksamkeit sowie der Art und Weise, wie diese Prinzipien und Prozesse im Merkmals-Objekt-Kodierungssystem implementiert sind. Eine jüngere Entwicklung in der psychologischen Forschung stellt die Rolle temporaler Faktoren für die Gruppierung und Bindung und die Untersuchung mittels psychophysischer Methoden ins Zentrum.

In den ersten Jahrzehnten dieses Jahrhunderts haben sich die Gestaltpsychologen (Wertheimer, 1912, 1923; Köhler, 1924; Koffka, 1935) mit den Prinzipien, die die perzeptive Organisation bzw. Gruppierung und die Figur-Grund-Wahrnehmung (z. B. Rubin, 1915) bestimmen, beschäftigt. Unter den beschriebenen „Gesetzen“ perzeptiver Organisation sind Gruppierung auf der Basis von Nähe, guter Fortsetzung (z. B. Kollinearität), Ähnlichkeit und gemeinsamem Bewegungsschicksal zu nennen. Neuerdings haben in der Gestalt-Tradition arbeitende Psychologen weitere Gesetze postuliert, wie uniformes Verbundensein („uniform connectedness“) und gemeinsame Region („common region“) (Palmer, 1992; Palmer & Rock, 1994; Palmer, 1999). Es gab auch frühe Versuche, die Gehirnmechanismen, die der perzeptiven Gruppierung zugrunde liegen, zu bestimmen (z. B. Köhler, Held & O’Connell, 1952); diese waren jedoch durch den damaligen Wissensstand über die Funktionsweise des (visuellen) Gehirns begrenzt. Hervorzuheben ist der Vorschlag der Gestaltpsychologen, dass perzeptive Organisation und Figur-Grund-Kodierung auf fest verdrahteten, präattentiv arbeitenden Gehirnmechanismen basiert.

Demgegenüber wurde in späteren Theorien der Informationsverarbeitungs-Psychologie vorgeschlagen, dass (korrekte) Merkmals-Objekt-Konjunktionen Aufmerksamkeit erfordern (z. B. Treisman & Gelade, 1980). Nach der Theorie der attentionalen Bindung folgt dem ersten parallelen (oder simultanen) Kodieren von verschiedenen Merkmals-Elementen über die gesamte visuelle Szene hinweg ein serielles Durchmustern des Displays durch einen Mechanismus fokaler Aufmerksamkeit. Wird Aufmerksamkeit auf ein Cluster von Merkmalen fokussiert, so werden diese vorübergehend zu einer kohärenten Objektrepräsentation „gebunden" (siehe auch Crick, 1984). Im Gegensatz dazu haben alternative Theorien präattentiver Merkmals-Konjunktionen (z. B. Duncan & Humphreys, 1989) vorgeschlagen, dass wenigstens einige Arten von Merkmalsbindungen auf der parallelen Stufe der visuellen Kodierung erfolgen können und dass die resultierenden Merkmals-Ensembles um Zugang zu einer kapazitätsbegrenzten Objekterkennungsstufe konkurrieren. Evidenz für die letzteren Theorien wurde durch Experimente zur visuellen Suche geliefert, die zeigten, dass durch virtuelle (illusorische) Konturen guter Fortsetzung definierte Kanizsa-Figuren parallel entdeckt werden (z. B. Davis & Driver, 1994; aber s. Gurnsey, Poirier & Gascon, 1996).

Weitere psychologische Forschung wurde durch die Ergebnisse von Einzelzell-ableitungen inspiriert, die auf die Rolle von synchronisierten visuo-kortikalen Zell-Oszillationen für die Merkmals-Objekt-Bindung (temporale Bindung) hinwiesen: Wenn Merkmalselemente simultan dargeboten wurden und ihre räumliche Anordnung einem Gestaltprinzip (wie z.B. Kollinearität) entsprach, dann adjustierten Zellen im visuellen

Kortex, die auf diese Elemente ansprachen, ihr Feuerverhalten und oszillierten synchron, ohne Phasenverschiebung (z.B. Gray, König, Engel & Singer, 1989). Diese Befunde wurden als Hinweis darauf betrachtet, dass die kritischen neurophysiologischen Korrelate der perzeptiven Gruppierung in synchronisierten oszillatorischen Aktivitätsmustern bestehen, die über verschiedene Gruppen merkmalskodierender Neurone hinweg phasengebunden sind.

Es gab mehrere Versuche, die Hypothese der „temporalen Bindung“ (z.B. Milner, 1974; von der Malsburg, 1981) psychophysisch zu untersuchen, z.B. indem man prüfte, ob die synchronisierte Darbietung von Targetelementen, asynchronisiert relativ zur Darbietung der Hintergrundelemente, die effiziente Targetkodierung bei bestimmten Stimulus-Präsentationsfrequenzen fördert (z.B. Fahle & Koch, 1995; Leonards, Fahle & Singer, 1997; Blake & Yang, 1997; Kiper, Gegenfurtner & Movshon, 1996). Obwohl die Befunde dieser Studien insgesamt kein konsistentes Bild ergaben, wurden kürzlich mehrere neue Paradigmen entwickelt, deren Ergebnisse die Vorstellung unterstützten, dass die Merkmals-Objekt-Bindung temporale Kodierung involviert (z. B. Elliott & Müller, 1998; Usher & Donnelly, 1998). Die diesen Ergebnissen zugrundeliegende psychologische Evidenz liegt also darin, dass die perzeptive Organisation auf frühen, wahrscheinlich präattentiven Stufen der visuellen Verarbeitung erfolgt und dass temporale Kodierung bei diesen Organisationsprozessen eine Rolle spielen könnte.

Die Experimente in dieser Dissertation basieren auf dem Paradigma des Sychronizitätsprimings, das von Elliott und Müller (z.B. 1998, 2000) entwickelt wurde. In diesem Paradigma wird eine mit 40-Hz flimmernde (oszillierende) Matrix (Prämaske) präsentiert. Die Matrix besteht aus (figural) neutralen Elementen (Kreuzen), welche, nach einer bestimmten Dauer der Prämaskendarbietung, durch eine Zielreizmatrix ersetzt wird, die aus Figur- und Ablenkelementen besteht. Ein Priming durch rein temporale

Information kann erreicht werden, wenn innerhalb der flimmernden Prämaske ein sogenannter synchroner Prime eingebetten wird. Die Beobachter sind sich dabei des Primes phänomenal nicht gewahr. Das Resultat ist eine, relativ zu einer Kontrollbedingung, beschleunigte Entdeckungsreaktion auf eine Zielreizfigur, die im Zielreizdisplay dargeboten wird (für eine detailierte Darstellung des Paradigmas verweise ich auf die Abbildung 3.1).

Dieser Synchronizitätsprimingeffekt ist Untersuchungsgegenstand der vorliegenden Dissertation. In Kapitel drei wird eine mögliche Interaktion von räumlicher Aufmerksamkeit und Synchronizitätsprimingeffekten untersucht. Dafür wurde das Paradigma von Elliott und Müller mit dem klassischen Paradigma des räumlichen Cueings kombiniert (z.B. Posner, 1978). Im vierten Kapitel werden die Effekte von multiplen synchronen Primes untersucht. Die Standard 3× 3 Matrix von Elliott und Müller wurde auf dafür vergrößert, um verschiedene Distanzen der Primes zu realisieren. Das fünfte Kapitel beschäftigt sich mit der Abhängigkeit des Synchronizitätsprimings von figuralen Zielreizen. Statt einer Zielreizfigur wurde den Probanden, nach Darbeitung der Prämaske, einfache (nicht-figurale) Punktstimuli präsentiert, auf die sie reagieren sollten.

Kapitel 3.

Elliott und Müller (1998) schlossen aus ihren Ergebnissen, dass der synchrone Prime nicht als räumlicher Aufmerksamkeitscue wirkt. Die Evidenz für dieses Argument ist allerdings nur indirekter Natur. Die Resultate ihrer Studie zeigten keine Kosten relativ zu einer neutralen Kontrollbedingung, wenn der synchrone Prime an einer anderen Position dargeboten wurde als der folgende Zielreiz. Solche Kosten würde man, unter bestimmten Annahmen, erwarten, wenn der synchrone Prime räumliche Aufmerksamkeit auf seine Position zieht. Sowohl theoretische Erwägungen (z.B. Crick, 1984) als auch neuere neurophysiologische Befunde (Fries, Reynolds, Rorie, & Desimone, 2001; Engel, Fries, & Singer, 2001) deuten auf die Möglichkeit aufmerksamkeitsbasierter Modulation von temporalen Bindungsprozessen hin. Um diesen möglichen Zusammenhang zu untersuchen wurde eine Reihe von Experimente entworfen die das Synchronizitätspriming Paradigma Elliott and Müller (z.B. 1998, 2000) mit dem klassischen Paradigma des räumlichen Cueings (z.B. Posner, 1978, 1980; Müller & Rabbitt, 1989) kombiniert.

Die Kombination eines synchronen Primes mit einem symbolischen (zentralen) Cues (endogene Aufmerksamkeit) und langen Cue-Zielreiz SOAs (Experiment 1) wurden nur additive Effekte gefunden. Das heisst, Synchronizitätsprimingeffekte waren für alle Cueing Bedingungen (neutral, valide, invalide) gleich groß. Dieses Ergebnis würde die Vorstellungen unterstützen, dass temporale Bindungsmechanismen von präattentiver Natur sind. Zwei Befunde des ersten Experiments mahnen allerdings vior übereilten Schlussfolgerungen. Erstens, die Fehlerraten deuten darauf hin, dass die Probanden durch das Cueing dazu tendierten eher zielreiz-anwesend Antworten abzugeben. Zweitens, bei Durchgängen mit validen Cues könnte ein Deckeneffekt für das Ergebnismuster verantwortlich sein. Das heisst, der synchrone Prime hätte zu einer besseren Performanz nichts beitragen können.

Im zweiten Experiment wurde mittels eines Signalentdeckungsexperiments untersucht, ob durch das Cueing möglicherweise eine explizite Wahrnehmung des synchronen Primes bewirkt wurde. Die Befunde schlossen diese Möglichkeit jedoch aus, Probanden waren unter keiner Cueing Bedingung in der Lage die Position eines Primes überzufällig korrekt anzugeben.

Um genauer zu untersuchen, ob die Befunde des ersten Experiments durch einen möglichen top-down Einfluss (z.B. eine Zielreizerwartung, wie sie durch endogenes Cueing aufgebaut werden kann) beeinflusst worden sind, wurden im nächsten Experiment (Experiment 3) exogene visuelle Cues eingeführt. Diese sollten räumliche

Aufmerksamkeit lenken und dabei, durch eine kurze Cue-Zielreiz SOA, mögliche Erwartungen der Probanden minimieren (z.B. Müller & Humphreys, 1991). Die direkten Cues wurden den Probanden direkt nach dem Prämaskenoffset dargeboten. Die Ergebnisse zeigten diesmal eine Interaktion zwischen visuell-räumlicher Aufmerksamkeit und dem synchronen Prime. Das Ergebnismuster war jedoch kontra-intuitiv, anstatt einer Beschleunignung der RZn in Durchgängen mit validen Cues, kam es, im zu größeren Primingeffekten bei Durchgängen mit invaliden Cues im Vergleich zu Durchgängen mit neutralen und validen Cues.

Um eine mögliche Konfundierung mit der zusätzlichen visuellen Information der peripheren Cues auszuschließen, wurde in Experiment 4 ein peripherer akustischer Cue eingeführt. Bis auf die Modalität des Cues war das experimentelle Design identisch mit Experiment 3. Die Ergebnisse waren konsistent mit denen des dritten Experiments. Dieses Ergebnismuster ist jedoch nicht einfach mit einer Einflussnahme visuell-räumlicher Aufmerksamkeit auf relativ automatische Bindungsprozesse gleichzusetzen (ähnlich der Prozesse, von denen angenommen wird, sie seien präattentiver Natur, wie z.B. Zielreiz-Popout in visuellen Suchaufgaben (Treisman & Gelade, 1980)).

Das fünfte Experimente setzte räumliches Cueing und Synchronizitätspriming in direkte Konkurrenz. Cues (direkte visuelle) und synchroner Prime konnten dabei unterschiedliche Positionen indizieren, sowohl relativ zueinander als auch relativ zum folgenden Zielreiz. Die Ergebnisse waren wiederum konsistent mit den vorhergehenden Experimenten, allerdings gab es keine Evidenz für eine direkte Konkurrenz von Cue- und Primeinformation. Das heisst, Durchgängen mit validen Cues wurden durch “invalide” synchrone Primes nicht verlangsamt.

Eine mögliche Erklärung für die Ergebnisse dieser Experimentalserie könnte sein, dass Cueing und Synchronizitätspriming größtenteils unabhängige Prozesse sind und das ihr aufgabenerleichternder “Output” (nicht-additiv) kombiniert wird, wenn er auf den gleichen (Zielreiz-) Ort zielt. Auf der anderen Seite, wenn räumliche Aufmerksamkeit misplaziert wird, kann der Prime seine ganze Stärke entfalten und die Kosten von invalidem Cueing kompensieren. Interessanterweise funktioniert dieser Mechanismus nur ein die eben beschriebene Richtung.

Eine andere Möglichkeit ist, dass die durch Synchronizitätspriming beschleunigte Figurbildung (Elliott & Müller, 1998) an einer ungecueten Position zu einer raschen Reorientierung der Aufmerksamkeit an den geprimten (Zielreiz-) Ort führt, vorausgesetzt die gecuete Position (ohne Zielreiz) kann auf effiziente Weise als nicht-zielreizenthaltend zurückgewiesen werden. Hierbei würde die Zielreizfigur selbst zu einem effektivem “Cue” für die Reorientierung von Aufmerksamkeit werden.

Kapitel 4.

Die Studie in diesem Kapitel beschäftigt sich mit der potentiellen Rolle der dynamisch-räumlichen Struktur von multiplen (dualen) synchronen Primes bezüglich der Zielreizdetektion. Gemäß dem “recurrent model”, das von Elliott und Müller (2004) vorgeschlagen wurde, wird die Primeinformation zuerst auf höheren Stufen der visuellen Verarbeitung (mit relativ großen rezeptiven Feldern) generiert, um dann auf frühere Stufen der Verarbeitung (mit kleineren rezeptiven Feldern) “zurückpropagiert” zu werden. Ziel war es zu untersuchen, welche Art von dynamischer Primestruktur generiert werden würde, wenn zwei Primes simultan dargeboten werden. Dafür wurde in vier Experimenten die Standard 3×3 Prämaske auf 5×5 bzw. 6×6 Elemente vergößert, dadurch wurde es möglich verschiedene räumliche Distanzen zwischen den Primes zu realisieren.

Die Ergebnisse zeigen, dass duale Primeinformation in einer mit 40-Hz flimmernden Prämaske die Entdeckung eines einzelnen Zielreizes in einer Zielreizmatrix beschleunigen kann . In Experiment 1 (5×5 Matrix) traten gleich große Primingeffekte für duale Primes zu Tage, wie sie auch für einzelne Primes gefunden werden. Dabei waren die Primingeffekte nicht von der Inter-Primedistanz abhängig. Das bedeutet, die Effekte untschieden sich nicht, wenn die Primes nebeneinanderlagen oder räumlich getrennt waren. In Experiment 2 wurde eine noch größere Matrix (6×6) verwendet, um noch eine dritte (die größte) Inter-Primedistanz zu realisieren. Die Resultate dieses Experiments zeigten ein mit Experiment 1 konsistentes Muster an Effekten für die ersten beiden Inter-Primedistanzen. In der Bedingung mit der größten Inter-Primedistanz zeigten sich jedoch keine Primingeffekte. Es scheint, dass synchrone Primes, die eine bestimmte Distanz zueinander besitzen (in diesem Fall mehr als ~3° 50') keine fazilitatorischen Effekte mehr generieren. Dies könnte bedeuten, dass die zwei synchronen Primes nicht zwei voneinander unabhängige Signale produzieren. Um diese Hypothese zu untersuchen wurde im nächsten Experiment (Experiment 3, 5×5 Matrix) eine Bedingung eingeführt, in der Zielreize auch an Position zwischen den Primes erscheinen konnten. Der Befund war, dass Primingeffekte auch für zwsichen den Primes liegenden Zielreizen zustande kamen. Darüberhinaus waren die Primingeffekte für zwischen-prime Positionen größer als die für Zielreize, die auf der gleichen Position von einem der beiden Primes erschienen. Dies deutet darauf hin, dass tatsächlich nicht zwei unabhängige Position geprimet werden, sondern das durch die zwei synchronen Primes eine Art "Primefeld" generiert wird, in dem auch Positionen zwischen den Primes einen Verarbeitungsvorteil geniessen. Eine mögliche Konfundierung der Effekte war, dass Zielreize zwischen den Primes immer näher an der zentralen x-y-Achse des Zielreizdisplays waren als Zielreize, die auf Primeposition dargeboten wurden. In Experiment 4 (6×6 Matrix) wurden deshalb, neben den Bedingungen auf-Prime und zwischen-Primes Zielreizpositionen, mehrere Kontrollbedinungen eingeführt. Die Resultate des vierten Experiments zeigten gleich große Primingeffekte für Zielreize, die zwischen den Primes erschienen, in allen Inter-

Primedistanz Bedingungen (auch bei der größten Distanz). Zudem, und übereinstimmend mit den Resultaten aus Experiment 2, zeigte sich das für Zielreize auf Primepositionen Primingeffekte stattfanden, jedoch nicht in der größten Distanzbedingung. Im Unterschied zu Experiment 3 waren die Primingeffekte für zwischen-Prime Zielreize nicht größer als für auf-Prime Zielreize.

Zusammenfassend deuten die Ergebnisse dieser Experimente auf ein dynamisches "Primefeld" hin, das durch zwei synchrone Primes generiert wird. Solch ein Prime Feld könnte eine Art gauss-artige Stärkeverteilung besitzen. Das heisst, die Stärke des Primesignals ist am stärksten im Zentrum zwischen den beiden Primes und nimmt mit zunehmender Distanz dazu ab. Die Ergebnisse von Experiment 3 unterstützen diese Vorstellung, aber auch die Resulate der Experimente 2 und 4. Die letzteren Experimente konnten zeigen, dass Zielreize, die auf Primepositionen und bei maximaler Distanz zwischen den Primes, dargeboten wurden keine Primingeffekte generierten. Dies könnte eine Abnahme der Prime Feldstärke widerspiegeln. Die 5×5 und 6×6 Displays hatten etwa eine Größe von 7.3° und 8.1° Sehwinkelgraden. Diese Größe passt zu der Größe von rezeptiven Feldern in höheren visuellen Arealen (z.B. V3 und V4), und ist in Übereinstimmung mit der Annahme, dass die Integration von dualen Primesignalen über räumliche Distanz durch top-down Projektionen von höherschichtigen zu niedrigschichtigen visuellen Kodierungsmechanismen zustande kommt (siehe auch Elliott & Müller, 2000).

Kapitel 5.

Die Studie in Kapitel fünf befasst sich mit der Natur des Synchronizitätsprimingeffekts. Welche Art von Information wird überhaupt geprimet? Elliott and Müller (1998) argumentierten, dass der synchrone Prime lokations-spezifisch ist, da Primingeffekte nur bei zielreiz-anwesend Durchgängen zustande kamen und ein

Zielreiz an der geprimeten Position auftaucht. Die Frage, ob nun Position innerhalb des Areals, das von den Primelementen umschrieben wird, auch geprimet wird oder ob der Primingeffekt tatsächlich vom Erscheinen einer Zielreizfigur abhängt blieb jedoch ungeklärt.

Identisch zu Experiment 3 in der Untersuchung von Elliott und Müller (1998) konnte im ersten Experiment die Prämaske einen “validen” oder “invaliden” (relativ zur Zielreizposition) synchronen Prime enthalten oder aus einer Anordnung zufälliger Prämaskenelemente bestehen (Kontrollbedingung). Das Experiment war in zwei Hauptbedingungen eingeteilt. Die erste Bedingung sollte den Primingeffekt für die Probandengruppe replizieren, indem das Standardzielreizdisplay (mit einem Kanisza-artigen Zielreiz) nach Prämaskenoffset dargeboten wurde. In der zweiten Bedinung wurde anstelle eines (figuralen Kanisza-artigen) Zielreizes ein non-figuraler Zielreizpunkt in der Mitte eines Matrixquadranten präsentiert. Dadurch war es möglich zu testen, ob die Entdeckung eines non-figuralen Zielreizes, der zwischen den Primeelementen auftauchte, durch einen synchronen Prime beschleunigt wird. Die Ergebnisse für figurale Zielreize zeigten ein konsistentes Muster zu den Befunden von Elliott und Müller. Darüberhinaus zeigten sich differentielle Effekte, wenn die Bedingung invalider synchroner Primes nach Richtung ihrer Mislokation aufgeteilt wurde. Wenn der Prime vertikal versetzt zum Zielreiz dargeboten wurde zeigten sich ebenso große Primingeffekte wie in der validen Primingbedingung. Dieser Befund lässt vermuten, dass das Priming von intra- und interhemisphärischen räumlichen Relationen abhängig ist. Darüberhinaus deutet es auf zeitverbrauchende Synchronisierungsprozesse über das Corpus Callosum hin (z.B. Engel, König, Kreiter, & Singer, 1991). In non-figuralen Bedingungen waren keine Primingeffekte evident, das heisst, der synchrone Prime hat offenbar keine fazilitatorische Wirkung für Positionen innerhalb des Primeareals. Dies ist ein Hinweis darauf, dass der

Primingeffekt tatsächlich abhängig vom Onset eines Zielreizes mit figuralen Eigenschaften ist. Es könnte jedoch auch möglich sein, dass die adäquate Einstellung auf die Aufgabe einen figuralen Zielreiz zu entdecken (task set) eine entscheidende Rolle spielt (z.B. Kingstone, 1992). Das bedeutet, es könnte sein, dass die Probanden ein Zielreizquadrat erwarten müssen, damit das System von einem beschleunigenden Primingeffekt an einem Primeort profitieren kann. Um das zu untersuchen, wurde in Experiment 2 ein sogenannter Dot-Probe eingeführt (z.B. Kim & Cave, 1995). Ein Dot-Probe konnte zu verschiedenen Zeitpunkten während der Prämaskenpräsentation in der Mitte eines Matrixquadranten auftauchen und es war Aufgabe der Probanden auf die Entdeckung des Probes zu reagieren. Zusätzlich wurde ein Zielreizdisplay nach Offset der Prämaske für sehr kurze Zeit präsentiert und die Probanden mussten, als Zweitaufgabe, die An- oder Abwesenheit eines Kanisza-artigen Quadrates feststellen. Die Ergebnisse zeigten keine Synchronizitätsprimingeffekte für die Dot-Probe Aufgabe, was darauf hinweist, dass das "task set" keine entscheidende Rolle bei der Generierung des Primings spielt. Experiment 3 untersuchte, ob non-figurale (Punkt) Zielreizentdeckung von synchronen Primes profitiert, wenn die Zielreizpositionen gemäß des Gestaltprinzips der guten Fortsetzung (d.h. Kolinearität) angeordnet sind. Dabei konnten Zielreizpunkte zwischen kolinearen Primeelementen dargeboten werden oder in verschiedenen Positionen relativ zur Mitte des eines Matrixquadranten. Es zeigte sich für keine der Zielreizpositionsbedingungen ein signifikanter Primingeffekt. In Experiment 4 konnte ein Zielreizpunkt entweder in der Mitte eines Matrixquadranten oder kolinear zwischen zwei (während der Prämaskendarbietung präsentierten) Primeelementen auftauchen. Zusätzlich wurde ein peripherer akustischer Cue dargeboten, der relativ zum Zielreizquadranten neutral, valide oder invalide sein konnte. Es wurde untersucht, ob die Ergebnisse der vorhergehenden Experimente nicht auf einen Deckeneffekt zurückzuführen sind und die

Entdeckung des Zielreizpunktes nicht eine zu einfache Aufgabe darstellte, die durch experimentelle Manipulationen nicht mehr modulierbar ist. Die Ergebnisse bestätigten diesen Verdacht nicht, es kam zu einem Cueingeffekt in Durchgängen mit validen Cues, jedoch gab es keine verlässlichen Synchronizitätsprimingeffekte.

Eine Interpretation der Ergebnisse wäre, dass der Synchronizitätsprimingeffekt tatsächlich von der Darbietung einer Zielreizfigur abhängt. Das heisst, wie bereits von Elliott und Müller (1998) vorgeschlagen, das Priming erzeugt eine beschleunigte Zielreizkodierung und dieser Effekt wird in höheren visuellen Arealen generiert. Die Befunde der vorliegenden Experimente weisen darauf hin, dass die einzelnen Primeelemente durch Zellen mit kleinen rezeptiven Feldern kodiert werden und fokale Aktivität produzieren, die in höheren Arealen des visuellen Systems konvergieren. Dies hat einige Implikationen für die Mechanismen, welche die Primeinformation generieren. Wenn höhere visuelle Areale mit Zellen (die große rezeptive Felder besitzen) die räumlich-temporale Struktur der Prämaske erhalten und kohärente Oszillationen auf niedrigeren Ebenen des visuellen Systems durch Rückwärtspropagierung induzieren (z.B., Gilbert, 1993), wie kann das räumliche Areal einer fazilitatorischen Aktivation so lokations-spezifisch sein? Eine mögliche Erklärung wäre ein Phasenverschiebungsprozess, der durch die Interaktion des “bottom-up” 10-Hz Rhythmus der synchronen Prämaskenrepräsentation mit dem “top-down” 40-Hz Rhythmus (siehe auch Elliott & Müller, 2001). Dadurch würde der synchrone Prime ein 40-Hz Muster annehmen und gleichzeitig temporal von den Nicht-Prime Prämaskenelementen segmentiert werden.

Schlussfolgerung.

Die Untersuchungen dieser Arbeit weisen darauf hin, dass der Synchronizitätsprimingeffekt ein von räumlicher Aufmerksamkeit größtenteils unabhängiger Prozess sein könnte. Der synchrone Prime könnte allerdings ein effektiver

Hinweisreiz für die rasche Reorientierung von Aufmerksamkeit an eine geprimte Position sein, wenn der Aufmerksamkeitsfokus nicht an einer (aufgaben-) relevanten Position im visuellen Feld fokkusiert ist. Weitere Befunde konnten zeigen, dass multiple synchrone Primes ein räumlich-dynamische "Primefeld" generieren, das möglicherweise eine gauss-artige Stärkeverteilung aufweist und dessen Feldstärke ihr Maximum am zentralen Punkt zwischen den Primes erreicht. Die letzten Befunde sind auch konsistent mit dem rekurrenten Modell der Primegenerierung (Elliott & Müller, 2004), wonach die Integration von multiplen räumlich separierten Primes durch top-down Projektionen von höheren zu niedrigeren Arealen im visuellen System passieren könnte. Desweiteren zeigten die Resultate, dass ein einzelner synchroner Prime keine fazilitatorischen Effekte für Positionen innerhalb der Primeelemente produziert und dass das Synchronizitätspriming tatsächlich in großem Maß von der Figurinformation abhängt, die nach Prämaskenoffset gezeigt wird und dessen Kodierung durch das Priming beschleunigt wird (Elliott & Müller 1998).

Curriculum Vitae

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Education

2003 – 2005	Ph.D. in Psychology
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