Factors affecting target perceptibility in object substitution masking

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Abstract

Object substitution masking (OSM) refers to the observation that reporting of a briefly presented target item is considerably reduced when a mask remains visible after the target offset. The size of OSM has been said to be critically dependent on the speed with which attention is deployed towards the target. One line of evidence in favour of this view is that when set size increases so does OSM. In addition, when the target location is known in advance because of a pre-cue OSM is reduced or eliminated. However, all the studies that reported an interaction between set size and OSM or between pre-cue and OSM performance was at ceiling/floor or there was no control condition. This might have led to an over-interpretation of the statistical interactions which were evidently a consequence of ceiling and floor effects in performance, or in other cases the failure to correct for clear response biases. In Chapters 2&3 the purported role of attention in OSM is investigated by manipulating orthogonally set size and mask duration. The principal finding is that, when performance is not influenced by ceiling/floor effects and the scores are corrected for response bias set size and mask duration do not interact although their individual effects are highly significant. Chapter 4 shows that the set size effect in OSM is not due to crowding; the two factors affect OSM independently. In Chapter 5 attention is manipulated in a direct manner by employing a spatial pre-cue and manipulating the cue-target onset asynchrony. Although pre-cueing the target improves performance it does not affect OSM. Finally, in Chapter 6 the participants phenomenal experience in OSM is investigated. The results show that at a relatively large number of masking trials OSM is “complete”; participants report seeing a blank space at the target location although the target is present. Collectively, the results of the present thesis show that attention does not influence OSM when it is controlled either indirectly (i.e. set size, crowding) or directly (pre-cue). What these findings show is that Di Lollo et al.'s specific implementation of the general model of the re-entrant account of awareness is invalid. The findings are also discussed in relation to other accounts of OSM , Moore and Llleras's (2003) object-updating account and Poder's (2012) attentional gating model (Chapter 7).

Contents

Chapter 1

Introduction

Our eyes are constantly “bombarded” by visual information received from the outside world. Not only is the visual world filled with details such as different colours, shapes and textures, information about this is constantly in flux as the things in our environment move through the world and we, as observers, move our position and/or our eyes. While we “experience” a rich and detailed visual world we have no direct knowledge as to how this experience is realised. In fact, we often assume that our perception of the visual world is a direct translation of the information that enters into our eyes. Furthermore, our unreflective experience is that we can perceive all or most of the visual information that is presented in our visual field. In actuality, our visual system is only capable to process a small part of the information that it receives. Thus, it needs to be selective as to which information will be further processed. What information is selected for further processing is one of the key operations of attention.

The role of attention in visual perception has been explored by scientists since the mid 19th century (Helmholtz, 1867; Külpe, 1902; Wundt, 1897) though speculation about this dates back to the writings of St Augustine in the 3rd century (see Hatfield, 1995, for a historical review on the research of attention). In the 1950s there was a major revival of research into attention mostly because of studies on auditory attention (e.g. Broadbent, 1954; Cherry, 1953). In the decades that followed, research shifted towards the study of visual attention partly because of the development of computers that allowed more precise control of the presentation of visual stimuli (Pashler, 1998). The introduction of novel experimental paradigms also contributed to the study of various aspects of visual attention and its relationship with perception. More recently, a number of studies have explored the putative role of attention in a new visual effect called four-dot masking (FDM) (e.g. Di Lollo, Enns, & Rensink, 2000; Enns & Di Lollo, 1997; Enns, 2004).This thesis reports a series of experiments investigating the role of attention in FDM and, in the final empirical chapter, the phenomenology of the effect.

In this Chapter, I begin by describing the basic problem of visual perception namely that what we see is not a literal translation of the image in the retina. Instead, only a small part of the visual input is selected for further processing. What visual information is selected is one of the key operations of attention. A number of aspects of attention are then discussed such as its deployment over space and whether what is being selected is a region in space or some object(s) in our visual field. Next, the relationship between attention and conscious perception is discussed. It will be argued that attention plays a critical role in awareness; in order to consciously perceive an object we must first attend to it. However, although attention is an important factor in awareness it is not a sufficient condition; we may attend an area or an object but we may yet be unaware of it. A number of studies on various phenomena which explore the role of attention in visual perception is described. One of these phenomena is four-dot masking (FDM) or object substitution masking (OSM)[1]. It has been suggested that FDM, unlike other forms of visual masking, is strongly influenced by manipulations of attention and in Chapter 2 the evidence in favour of this proposition is reviewed. Subsequently, the suggestion that attention plays an important role in OSM is tested by examining the effect of set size on FDM in a discrimination task (Chapter 2) and a detection task (Chapter 3). Next, the relationship between set size, crowding and mask duration is investigated (Chapter 4). In Chapter 5 attention is controlled in a more explicit manner, namely by using a cueing technique. In Chapter 6 a different aspect of OSM is explored, namely the observer's phenomenal experience of the masked target. In the final Chapter, I discuss what the findings from these experiments suggest for the current theories of OSM and I present proposals for future research.

The retinal image and the basic problems of perception

The eye is the entry point of the visual system; it focuses light onto an array of photoreceptive cells (rods and cones) on the inner surface of the back of the eye. This retinal image can be considered the starting point of what ultimately becomes our conscious visual experience. However the retinal image is inherently ambiguous. A consequence of the optical transmission is a loss of

[1] It is important to note that the term OSM is unfortunate because instead of merely describing a phenomenon, as FDM does, it incorporates a theoretical/explanatory commitment. Because in the present thesis all the experiments that will be reported employ a four dot mask the terms FDM and OSM will be used as close synonyms.

information about the distances of surfaces from the eye and about their shape (the so called inverse problem of vision). What this means is that the shape cast on the retina does not necessarily reflect the true shape of the distal stimulus (i.e. the shape of the object in its physical form) from which the reflected light originates; more problematically, no simple relationship exists between the distal stimulus and the retinal image it produces: a square can cast an image in the shape of a square, rhomboid, irregular quadrilateral, or even just a straight line, depending on the particular angle of view. Furthermore, surfaces which appear to be adjacent in the retinal image are not necessarily close in the outside world and can be those of physically separate objects. There are other ambiguities, too; an object's cast image is often partially occluded by other items in the line of view, and this can partially conceal features of the object and introduces contours which are not present in the distal stimulus. Similarly, shadowing caused either by partial occlusion of the light source or by another object can lead to variations in the light reflected from a surface and to the appearance of luminance boundaries which are not part of the actual physical surface.

It should be clear from the above brief description that the retinal image is not by itself sufficient for veridical perception. It is a task of the visual system to sort out these ambiguities and 're-parse' the world into its constituent objects. The ganglion cells of the retina are only able to perform the most elementary analysis of input. It is only through the work of the higher structures of the brain, where information is integrated across successive fixations, and through constraints on the possible interpretations of the retinal image made possible through implicit 'rules' built into the functioning of the system, that our perceptions emerge.

Visual perception offers further problems for the researcher; just as no simple relationship exists between distal objects and their retinal image, nor does one find any direct relationship between what is contained in the retinal image and our visual experience. The problem is that the retinal image contains a substantial amount of information. It is estimated that the eyes transmit around 107 - 108 bits of information along the optic nerve every second (Itti & Koch, 2001). Instead of attempting to process all this information, what the visual system does is to attempt to selectively prioritise input for further processing based on certain criteria, filtering out information deemed of lower importance. This prioritisation is one of the key operations of attention.

A question of great importance is how attention is deployed over space to select the information relevant to the organism. Furthermore, related to this question is whether what is being selected is a region in space the contents of which we selectively attend to or whether our attention is deployed directly towards some object(s) in our visual field. The next section will describe some of the theories that attempted to answer these questions.

Deployment of attention over space

As noted earlier, one of the key operations of attention is the prioritisation and selection of visual information for further processing. Because this prioritisation often occurs over space (though also over time) the type of attention that has been said to be engaged in the selection process has been termed spatial attention. How attention moves across space to “select” objects for further processing has been debated among researchers. One line of research suggests that attention moves from one attended location to another in the form of a “spotlight” (Posner, Snyder, & Davidson, 1980; Posner, 1980). According to this view, attention is seen as a “light beam” moving from one region to another illuminating the contents of these areas. Stimuli that fall within the illuminated area are said to be processed preferentially as the spotlight “enhances the efficiency of the detection of events within its beam” (Posner, 1980, p. 172). A variant of the spotlight view is that attention, instead of moving from one area to another, it rather spreads over a field. When an object of interest appears in the field, attention focuses to the object's location in a manner similar to a camera's lens zooming in on the location of an object of interest (Eriksen & St James, 1986). Another suggestion is that attention operates in the form of a gradient around the target location (Laberge & Brown, 1989). According to this view, this gradient may either spread around the target location or peak on the target (Bichot, Cave, & Pashler, 1999; Castiello & Umiltà, 1992; but also see Eriksen & Yeh, 1985).

The spotlight view of attention has been widely used and favoured as a metaphor to describe how attention focuses on different locations in space and time (e.g. Shulman, Remington, & McLean, 1979; Tsal, 1983; see Cave & Bichot, 1999 for a review). However, not all evidence is in accordance to this view (Driver & Baylis, 1989; Nakayama & Mackeben, 1989; Reinitz, 1990) and a major criticism has been that the attentional spotlight metaphor cannot account for cases in which attention splits across two different locations (e.g. Cheal & Lyon, 1989; Eriksen & Yeh, 1985; but also see Bichot et al., 1999; Castiello & Umiltà, 1992; Shaw & Shaw, 1977; Shaw, 1978 for evidence that the spotlight can in fact split in two locations).

Figure 1.1. *Examples of stimuli employed in Duncan's (1984) experiments. Participants had to report either two properties of one object (i.e. the texture and orientation of the line or the size of the box and the side of a gap) or one property of each object (e.g. orientation of the line and size of the box). Image taken from Duncan (1984, p. 505).*

An alternative to the space-based account of attentional selection is that attention instead of simply “illuminating” and selecting locations in space may instead select discrete objects. Perhaps the strongest evidence in favour of an object-based attentional account was provided by Duncan (1984). In his experiments a box was presented briefly (see Figure 1.1). In each trial the box differed in size and had a gap either to the left or to the right side. A line, struck through the box, tilted slightly either clockwise or anticlockwise and was drawn using either dots or dashes. Participants were required to report either two properties of one object (i.e. the texture and orientation of the line or the size of the box and the side of the gap) or one property of each object (e.g. orientation of the line and size of the box). Importantly, the to-be-reported properties occupied the same space so location-based models of attention would predict for Duncan's (1984) experiment that performance should have been the same in both conditions because attention focuses on locations rather than on objects. However, the results from Duncan's experiment showed that identification performance was better when the participants had to report properties that belonged to the same object compared to when they belonged to different objects. Further evidence in favour of an object-based account of attentional selection comes from studies on a phenomenon called multiple object tracking which showed that observers are quite good at tracking up to four moving items at a time (Pylyshyn & Storm, 1988; Scholl & Pylyshyn, 1999; Sears & Pylyshyn, 2000).

Information integration and attention: the binding problem

A question of great importance is how information about objects in the visual field is combined to form the perception of a detailed visual world. Given that in naturalistic scenes objects appear with different shapes, colours (and shades of colour) and are presented in different locations and orientations in a, probably, crowded background one can easily imagine the complexity of the task of gathering and combining information for a particular object(s) while ignoring information from other objects. In the past decades several theories were developed to address the problem of combining information for a particular object in the visual scene. Perhaps the most influential theory has been the feature integration theory (FIT) (Treisman & Gelade, 1980; Treisman & Sato, 1990). Psychological evidence for the FIT came from visual search tasks which involve the search for a designated target item that is presented among irrelevant items called distractors. In Treisman and Gelade's (1980) experiments observers had to search for and report a target that differ from non-target items either on a single feature (a blue letter or an “S” among green “X”s and brown “T”s) or on a conjunction of features (a green “T” among green “X”s and brown “T”s). Their results showed that when the target differed from the distractors on a single feature (i.e. it was a feature singleton) reaction time for reporting the target was relatively fast and it was not affected by the number of the distractors (i.e. set size). When, however, the observers had to perform a conjunction search reaction time at reporting the target was slower compared to single feature searches and it was greatly affected by the number of distractors; the larger the set size the slower were the observers at reporting the target. Treisman and Gelade argued that the visual input is processed in two successive stages. The first stage is pre-attentive and the processing mechanisms were said to operate in parallel on all the items in the display based on the items' features such as their colour, shape and orientation. In tasks in which the target was said to pop out on a feature dimension reaction time performance was argued to be unaffected by adding more distractors in the display. In the conjunction search task, however, because the target did not pop out as it was defined by a conjunction of features, a serial search was performed. At this stage focused spatial attention at the target location was important to integrate and bind together the target's features and form objects. This attentive stage was thought to be slow and it was influenced by the number of non-target items (i.e. set size). Importantly, the two stages were thought to be autonomous, namely that information gathered during the serial search could not be used if a parallel search followed (Wolfe, Cave, & Franzel, 1989).

Although Treisman and Gelade's feature integration theory was highly influential in suggesting that spatial attention was necessary for feature binding subsequent studies challenged several aspects of FIT. First, Duncan and Humphreys (1989, 1992) argued that the FIT was limited and that it could not account for a number of findings observed in visual search tasks. For instance, Humphreys, Riddoch and Quinlan (1985) and Humphreys Quinlan and Riddoch (1989) showed that when the distractors were identical and the target was defined by a conjunction of features but was not very different in appearance to the distractors (e.g. a search for a “T” among inverted “T”s) search times at reporting the target were not affected by set size as the FIT would predict. They suggested that the FIT should include two additional factors; firstly, the level of similarity between target and distractors and the secondly the level of similarity between the distractors. Furthermore, Nakayama and Silverman (1986), and He and Nakayama (1995) tested the FIT by manipulating the depths of targets and distractors using binocular disparity. In one experiment in Nakayama and Silverman's (1986) study blue and red distracters were segregated in different depth planes. The target could be a red item in the blue depth plane or a blue item in the red depth plane; so the target was defined by a conjunction of depth and colour features. They found that, unlike in ‘normal’ conjunction searches, reaction time remained constant across all set sizes (but see Treisman & Sato, 1990). This finding indicated that a parallel, preattentive search was performed. An important observation, however, was that observers reported that they were attending each plane selectively (Nakayama & Martini, 2011). This was a striking observation because according to FIT attention should not have been required to detect the target when it pops out from its background. Further evidence against the FIT was provided by Joseph, Chun and Nakayama (1997). These authors showed that detection performance of a uniquely oriented item (i.e. the target) among distractors was impaired when the observers had simultaneously to perform an attention demanding task. But when they were instructed to ignore the attention demanding task and to report only the presence of the target item the observers performed well (94% average correct). This finding was interpreted as showing that even under conditions in which a target popped out attention could influence performance.

An alternative (or an extension) to Treisman's FIT theory is the guided search theory (GST) (Wolfe et al., 1989; Wolfe & Horowitz, 2004; Wolfe, 1994). The development of the GST was motivated by findings that appeared to contradict the FIT; namely, when observers performed certain conjunction search tasks, search times were not affected (or they were not affected very much) by the number of distractors (e.g. McLeod, Driver, & Crisp, 1988; Steinman, 1987). As an example, observers in Wolfe, Cave and Franzel's (1989) Experiment 1 had to report the presence of a red O among green Os and red Xs. Therefore, the target was defined by a conjunction of colour and form. Set size varied between trials. The results showed that when the different levels of set size were plotted against reaction time the slopes were much shallower than those obtained in Treisman and colleagues' experiments with similar stimuli and predicted by the their FIT model. Wolfe et al. (1989) argued that their results pointed to a mechanism that allowed for the information that was collected during the parallel search to be used by processes during the serial search stage. For instance, in their Experiment 1 a parallel search for a red O (the target) resulted in the creation of a colour activation map which contained only the red items and a form activation map that contained only Os. These activations maps can be thought of as representations of the visual space with every object having its own level of activation (or weight). The colour and form activation maps were, then, thought to create a final map in which all the locations that were red were excited, all the locations that contained Os were excited and the locations that were both red and contained an O (if any) were double excited. Attention was then directed to the object in the map with the highest level of activation and a representation of the object was created.

Attention and Awareness

The main tenet of the models described above was that in order to create a complete representation of an object attention was required. Attention was thought to act as a glue cementing all the visual features of an object to create a coherent representation. This led many researchers to propose that in order to become aware of an object, attention was necessary. Perhaps the most dramatic demonstration of the relationship between attention and awareness was observed in a phenomenon termed change blindness (CB) (e.g. Rensink, O'Regan, & Clark, 1997; Rensink, 2004; Simons & Rensink, 2005). Change blindness refers to the observers' failure to report a change that occurs in their visual field. Such failure is realised in studies that employ a change detection task. A typical change detection task involves the alternate presentation of two images (Figure 1.2). The two images are identical except for in one of them a change occurs. For instance, an object in the first image may change its location in the second image, disappear or has one of its attributes changed. Observers often fail to detect the change if between the two images a blank field is inserted (Rensink et al., 1997), an eye movement is performed (Hayhoe, Bensinger, & Ballard, 1998; McConkie & Currie, 1996) or the observer blinks (O'Regan, Deubel, Clark, & Rensink, 2000). Change blindness is said to occur under these conditions because an observer does not build up a visual representation of the original scene – even under prolonged viewing conditions – strong enough to support a comparison with the representation of the modified scene. As a result, visual information obtained when the modified scene appears replaces that obtained during the presentation of the original image (Scholl, 2000).

If, however, observers focus attention near to the location where the change occurs CB is said to be attenuated or even eliminated (Rensink et al., 1997; Scholl, 2000; Wilson, Telfer, & Goddard, 2005). This has been demonstrated by using a pre-cue. For instance, Rensink et al. (1997) placed a word or a pair of words that named the location of the change on a frame at the beginning of each trial. The pre-cue was either completely valid as to where the change would occur, or partially valid (50% of the times it named the location in the image where the change would occur and 50% it named some other location). Rensink et al. found that observers identified the change quicker when a completely valid pre-cue was used compared to a partially valid pre-cue which in turn yielded better performance compared to the trials without a pre-cue. Rensink et al. argued that the pre-cue directed attention to the target location which allowed a visual representation of the change/critical object to be formed and subsequently stored in VSTM. When the change occurred a comparison between the stored information in the VSTM and what was currently presented was carried out which resulted in a successful detection of the change.

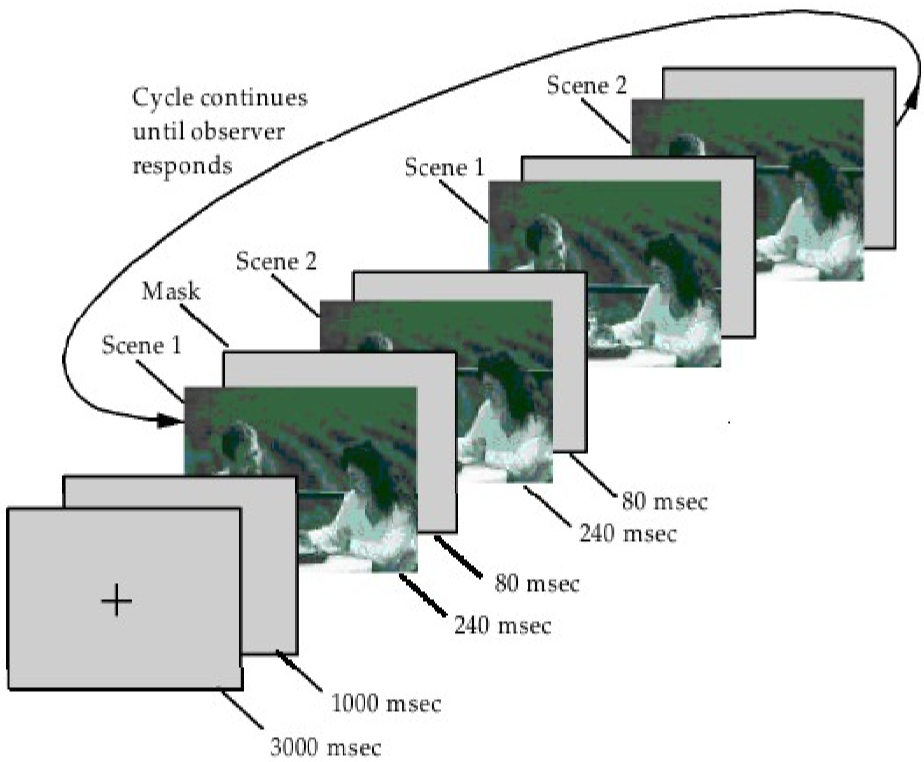

Figure 1.2. *A modified sample trial of the task used in Rensink et al.'s (1997) experiments. Each trial began with a fixation cross followed by a grey field (mask). This is, then, followed by a flicker sequence between two images (Scene 1 and Scene 2) with the mask inserted between them. The flicker sequence is repeated until observer reports the change (in this case the rail behind the woman changing location). Image taken from Scholl (2000).*

Related to change blindness is another phenomenon called inattentional blindness (Mack & Rock, 1998; Mack, Tang, Tuma, Kahn, & Rock, 1992; Rock, Linnett, Grant, & Mack, 1992). Inattentional blindness is realised under conditions in which an observer fails to report unexpected objects when his attention is engaged to another object or task. Such failure was demonstrated in an extensive series of experiments in Rock et al.'s (1992) study. In their experiments a cross was presented at fixation in eight trials (Figure 1.3). In the fourth trial an additional item appeared in one of the quadrants that were formed by the cross. This trial was termed inattention trial because the additional item appeared unexpectedly and therefore it was not expected that it will capture many attentional resources. Observers were asked to first judge and report which of the two arms that constituted the cross was longer and then if they had seen anything else in the display apart from the cross. In the fifth and sixth trial only the cross was presented and on the seventh trial the additional stimulus reappeared. Because observers now expected that an additional item might appear along with the cross, the seventh trial was termed a divided attention trial. This is because it was expected that attention would be divided between the cross and the additional item. Finally, before the eighth trial participants were instructed to ignore the cross and only report the additional item (in different experiments this item could be of any shape or colour and be presented in any of the four quadrants). This trial was termed the control trial because it was expected that the additional item would receive full focused attention and therefore discrimination performance for the attended item would be high. The results showed that across all the experiments observers failed to report the presence of the additional stimulus 25% to 75% of the times in the inattention trials. Even when they reported seeing the additional object they often failed to report its shape. In the control or focused attention trials, however, observers were almost always correct at reporting the presence of the additional object as well as its location, shape and colour. These results were taken to show that items that appear unexpectedly in the visual field may not be perceived (or fully perceived) if attention is engaged on another object or task.

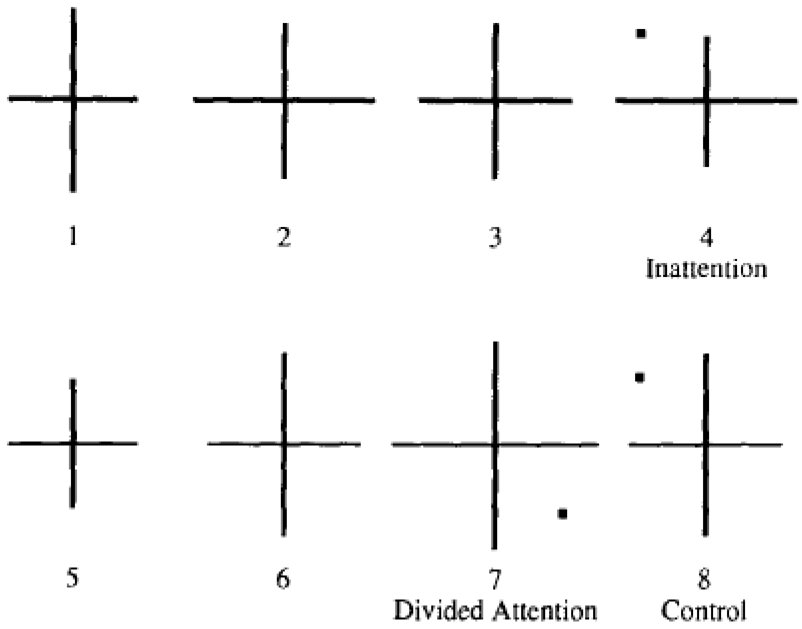

Figure 1.3. *A sample of the test stimuli and the order they were presented in Rock et al.'s (1992) study. The numbers denote the number of each trial. On the fourth trial participants were asked to make a judgment as to which of the two lines that were forming the cross was longer and if they had seen anything else in the display but for the cross. The same questions were asked in the seventh trial but it was expected that participants would know that a the additional item would appear and they would therefore divide their attention. The eighth trial was the control trial as the participants were asked to ignore the cross and report about the additional item.*

Another line of research has investigated the temporal limitations of attention. Typically, in such studies visual stimuli such as letters, words or pictures are presented in a rapid serial fashion at the centre of a screen usually for 100ms per item. Participants are required to report two (or more) items; for instance, to identify the only white letter (first target or T1) and to report the presence of a black “X” (second target or T2) in a stream of black letters. Typically, participants show an impaired performance in reporting T2 when this arrives within 500ms following T1 unless it is the item immediately after T1. But when the participants are instructed to ignore T1, performance reporting T2 increases significantly. Raymond, Shapiro and Arnell (1992) termed the phenomenon of failing to detect T2 the attentional blink (AB) – by analogy with eye blinks – during which there is an interruption of the attentional processing of the visual information that enter into the visual system. Raymond et al. attributed the attentional blink to the fact that when observers identify T1, the perceptual system allocates all the attentional resources to the processing of T1 suppressing the coding of further information for a brief period of time resulting in an impaired performance for identifying T2.

An additional finding in Raymond et al.'s study was that when the item immediately following the target was removed performance increased not only for identifying T1 but also for reporting T2. Performance for identifying T1 also improved with increments of the time interval between T1 and the item immediately following it. Additionally, when the items following T2 were removed, the AB effect vanished. The attentional blink was, therefore, taken to be dependant not only on what was happening between T1 and T2 but also on the items following each target. It appeared as if these items acted as masks reducing the visibility of each target and bringing performance to the level where the AB was observed. When these masks were removed the AB effect was not present and accuracy performance was close to ceiling.

The findings from the studies described above suggest that there is a strong link between attention and awareness. In the attentional blink, if a stimulus does not receive attention because it is presented within 200ms-500ms after the presentation and correct identification of another stimulus, observers report being unaware of its presence. In change blindness, unless attention is focused on the location (or near the location) where the change occurs, observers may not become aware of the change. In inattentional blindness, an item may not be consciously perceived if attention is engaged on another object or task. These findings led several researchers to propose that attention is necessary for awareness (e.g. Nakayama & Joseph, 1998; Rock & Gutman, 1981; Treisman & Kanwisher, 1998).

However, as it will be discussed below the relationship between attention and awareness is not a symmetrical one and is more complex than initially thought. A number of studies have shown that the deployment of attention towards the target facilitates reportability of the target not necessarily that the target has been consciously perceived. For instance, in Joseph, Chun and Nakayama's (1997) study every trial started with a stream of letters presented rapidly at fixation. All the letters were black but for one which was white and which was the target letter. At some point during or immediately following the presentation of the letters, a display with twelve Gabor patches was presented for 150ms. All the Gabor patches had the same orientation but in some trials one patch had a different orientation from the others (an oddball). A critical experimental manipulation was the lag between the onset of the target letter in the RSVP (rapid serial visual presentation) stream and the onset of the display with the Gabor patches. The lag varied between 0ms (i.e. target letter and Gabor patches had a common onset) and 700ms. Furthermore, there were two types of trials; in the dual task trials the observers had to report both the identity of the white letter in the RSVP and also the presence of a uniquely oriented Gabor patch. In the single task trials, observers were asked to ignore the stream of letters and only report if a uniquely oriented Gabor patch was present. The reasoning behind these experimental manipulations was as follows: if attention is required for the detection of such features as orientation then reporting of the target should be worse for lags between 0-500ms compared to lags greater than 500ms. This is because, as it was described earlier in the AB tasks, the detection of a second target (in this experiment the presence of the oddball) suffers when attention is engaged to the coding of the first target (in this experiment the white letter). By the same token, if the detection of a simple stimulus features such as orientation occurs at a pre-attentive stage then, on the dual task trials, reporting the presence of the oddball should be the same across all lags.

Their results showed that whereas for single task trials performance was the same across all lags, this was not the case in dual task trials. Performance at reporting the oddball deteriorated with decreased lags with minimum detection performance at lag zero. When the lag was 700ms detection performance at dual task trials almost equated that of single task trials. What this result shows is that even for orientation singletons that popped out in the display and which were considered to be unaffected by an attentional bottleneck they nevertheless required some attention in order to be reported.

The findings from Joseph et al.'s (1997) showed that the deployment of attention to the target location improves reportability of the target, not necessarily that attention facilitated target detection. Other studies have shown that although a target may be detected its presence may not be perceived. For instance, in Hsieh, Colas and Kanwisher's (2011) experiments twelve Gabor patches were presented briefly to one eye and dynamic Mondrian patterns were presented to the other eye (see Figure 1.4). The patches were green except for one which was red (a feature singleton). The purpose of the Mondrian patterns was to suppress the perception of this pop out display. After a 250ms ISI a test Gabor patch was presented either at the location which was occupied by the red Gabor patch or to the diametrically opposed location (see Figure 1.4 bottom row). The observers' task was to report the orientation of the test patch. The results showed that discrimination performance was better when the test patch was at the location previously occupied by the feature singleton compared to when it was presented to the opposite location. This result showed that although awareness of the feature singleton was suppressed it still captured attention and guided subsequent behavior.

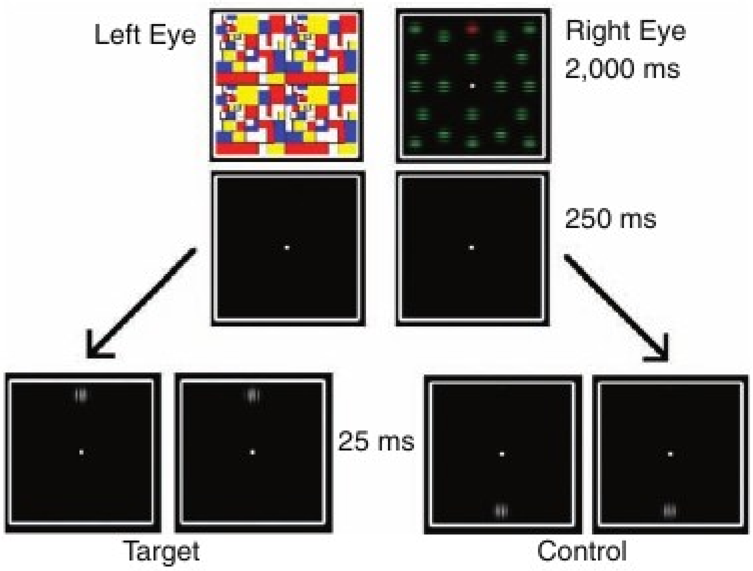

Figure 1.4. *A sample trial in Hsieh et al.'s (2011) experiments. The task was to report the orientation of the target patch (bottom part of the image).*

An important point in Hsieh, Colas and Kanwisher's (2011) study was that they demonstrated that attention may not be a sufficient condition for awareness though attending to an object may be necessary in order to become aware of it. Further evidence in favour of this view comes from blindsight studies. Blindsight is a neurological condition which is the result of a lesion in the primary visual cortex. Patients who suffer from blindsight are able to detect, discriminate or localise visual stimuli that are presented in their visual defect field although they deny being aware of them (Weiskrantz, 1986, 1996). Kentridge, Heywood and Weiskrantz (1999) used the Posner (1980) cueing paradigm to direct the observer's (a blindsighted patient) attention either to the target location (valid cue trials) or to a non-target location (invalid cue trials) in the ‘blind’ part of their visual field. On some trials the target was absent. Their results showed that the observer was faster and more accurate at reporting the target when this was validly cued compared to when it was invalidly cued. These results were further replicated in a later study by the same authors (Kentridge, Heywood, & Weiskrantz, 2004). This was similar to the previous study with the exception that this time the observer had to perform a discrimination task (if a target bar was horizontal or vertical) and that the SOA between the cue and the target varied. Similar to the results of their previous study, the observer was faster at reporting correctly the orientation of the target at the target location for the valid cue trials when the SOA was sufficiently long. He was also better at reporting the orientation of the bar at the valid cue trials compared to the invalid ones. Collectively, the data from these studies showed that although the observer reported being unaware of the presence of the target he was, nevertheless, more likely to report the target that was presented at the attended location. Kentridge et al. (1999) argued that these findings demonstrate that attention and awareness can be dissociated; attending to an object may not be a sufficient condition for awareness of that object.

Attention and awareness: evidence from fMRI and ERP studies.

The role of attention in conscious visual experience has also been investigated in studies in which the neural mechanisms of attention were explored (e.g. Brefczynski & DeYoe, 1999; Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991; Rees & Lavie, 2001; Rees, Russell, Frith, & Driver, 1999). One technique that has been used for this purpose is functional Magnetic Resonance Imaging (fMRI). This technique assumes that neural activity in the brain, in response to the presence of a visual stimulus, will change the oxygen and blood flow levels in certain brain areas. This change can then be recorded and inform about which brain areas are involved in specific mental processes (Haxby, Courtney, & Clark, 1998). In one such study Rees et al. (1999) used a task in which an inattentional blindness effect was expected. A trial consisted of displays in which a picture and a string of letters were superimposed (Figure 1.5). Sometimes the string of letters formed words and other times non-words. Participants were instructed to attend either the letters or the pictures and they were asked to detect any repetitions of pictures or strings of letters (depending on which of the two they were instructed to attend to). Observers underwent a recognition memory test after the end of a trial which showed they were able to remember most of the words when the string of letters were attended. In trials, however, in which they were instructed to attend to the pictures, performance at remembering the (unattended) words was poor. Importantly, the fMRI results were in accordance to the behavioural findings; they showed that when observers attended to the letter strings and they identified words, there was neural activation in regions of the left hemisphere that were known to be involved in word recognition tasks. Conversely, when observers attended to the pictures but not to the superimposed letters strings, there was not such neural activity in the same brain areas. Thus, the Rees et al.s' (1999) study replicates the typical finding in IB studies that observers do not become aware of stimuli that they do not attend. But, the additional finding that attended items triggered high level brain activity whereas unattended items did not, provides further support to the argument that attention is necessary for conscious visual experience.

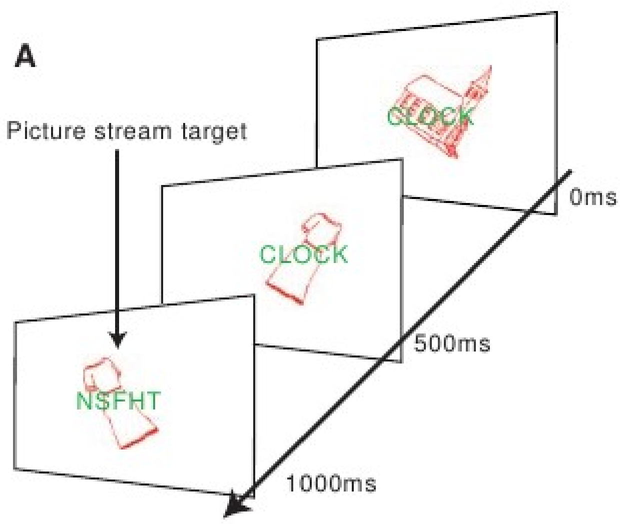

Figure 1.5. *Examples of stimuli used in Rees et al.'s (1999) study. In each frame a picture had a string of letters superimposed upon it. The task was to attend and report either the picture or the letters. Image taken from Rees et al. (1999, p. 2505).*

Another technique that has been used in research on visual attention is the Event-Related Potentials (ERP) technique (Luck, 2005; Rugg & Coles, 2002). This technique measures the synchronous firing of neurons in response to a stimulus as detected from electrodes placed on the surface of the scalp. The ERP technique is rather poor in its ability to resolve the location from which neural activity is generated in the brain. However, ERP is very precise in determining the time course of neural activity associated with a stimulus or response. There are a number of ERP components which are reliably evoked when a stimulus is presented to the eye. The earlier the components tend to be associated with sensory properties of a stimulus while the later components are more sensitive to cognitive factors such as attention. Very early visual components which occur within a 100 ms of stimulus onset (e.g. the C1 and P1) seem to be wholly dependent on sensory factors and occur irrespective of the task relevance or of a stimulus. They show sensitivity only to stimulus parameters such as intensity and retinal location. The earliest visually evoked component that it is thought to be affected by attention is the N1 (a negative wave which peaks approximately 100 ms after stimulus onset). When a stimulus is attended the N1 associated with that stimulus tends to show increased amplitude compared to when the stimulus is not attended. One ERP component which has been particularly useful in measuring the distribution of attention is the N2pc (Eimer & Mazza, 2005). This component is negative deflection in the ERP signal and occurs approximately 200 ms after the stimulus onset. Unlike the N1 the N2pc is a component associated with the lateral position of the attended stimulus with respect to the observer. It is observed most strongly in the posterior part of the scalp which is contralateral to the location of an attended target (pc. being an abbreviation of posterior contralateral). It is believed that this component is associated with attentional selection of a target stimulus governed by top down control. Though it is generally accepted the N2pc is a neural correlate of selective attention, the exact process that it reflects is still unclear. It has separately been argued to reflect the enhancement of target features during selection (Eimer, 1996; Mazza, Turatto, & Caramazza, 2009), or the suppression of adjacent distractor items during this process (Luck & Hillyard, 1994) or the perceptual salience of the selected object (Zhao et al., 2011). Though the N2pc can be thought of as a neural correlate of attentional selection its status as a marker of visual awareness it is more controversial. Some studies have shown that the N2pc correlates closely with an observer's ability to report a threshold stimulus

(Jaśkowski, van der Lubbe, Schlotterbeck, & Verleger, 2002; Verleger, Zurawska Vel Grajewska, & Jaśkowski, 2012) while others have shown clear dissociations between the two, attention and awareness (Woodman & Luck, 2003). Another candidate as a correlate of visual awareness is the VAN (visual awareness negativity). This is a negative deflection in the ERP signal that is occurring in a time window between 100 and 200 ms after stimulus onset (Koivisto, Kainulainen, & Revonsuo, 2009).

The relationship between attention and awareness has been demonstrated in the change blindness paradigm. Koivisto and Revonsuo (2003) recorded ERPs while requiring observers to perform a change detection task. When participants noticed a change there was an appearance of a VAN deflection in the ERP. However, even though this component has been suggested to be more closely related to attention than awareness it might be better described as a visual attention negativity than visual awareness negativity (see Verleger, 2010). So studies involving the N2pc and VN seem to indicate that attention and awareness usually are closely coupled but that they can be dissociated. The most reliable measure of awareness is the P3 wave. This is a late component occurring 300 ms after stimulus onset and is seen as a large positive deflection in the ERP signal.

Visual masking

In the previous section, in discussing the role of attention in awareness, the phenomenon of change blindness was described. It was reported that one of the ways to demonstrate CB is to insert a grey field between the two images. This field has been thought to act as a mask interrupting the processing of the visual information about the nature of the change and its location (Simons & Levin, 1997) resulting in CB. Later on, in describing the AB phenomenon, it was also reported that by removing the items immediately following T2 the AB was eliminated. Again, these items were thought to act as a mask on T2 limiting T2's perceptibility. The employment of stimuli that serve as a mask on an object's perceptibility has been a popular technique for the studying of spatio-temporal dynamics of visual perception and attention. The term visual masking (VM) refers to the observation that when two stimuli appear in close spatio-temporal proximity, the perceptibility of one of the stimuli suffers. The stimulus that is difficult to become aware of is called the target whereas the stimulus that impedes the perceptibility of the target is called the mask.

When the target's onset precedes the mask's onset (positive stimulus onset asynchrony – SOA) backward masking is said to occur. Depending on the spatio-temporal relationship between the target and the mask, various forms of masking emerge[2] and, for each form, different mechanisms have been proposed (see Figure 1.6 for various types of masking). For instance, when the mask spatially overlaps the target pattern masking occurs. In pattern masking the masking stimulus may consist either of random black and white dots that camouflage the target (Kinsbourne & Warrington, 1962a, 1962b; Turvey, 1973) or of a pattern that shares similar structural elements with the target (Turvey, 1973). Masking, in these cases, arises as a consequence of either integration or interruption; integration is said to operate by fusing the target's and the mask's contours in one percept at early stages of visual processing (Kahneman, 1968; Spencer & Shuntich, 1970). This mechanism predicts optimal masking when the interval between the onset of the target and the onset of the mask is approximately 0ms whereas little or no masking occurs for SOAs of 100ms or more. The interruption hypothesis, by contrast, suggests that the processing of the target is curtailed by the subsequent onset of the mask resulting in an incomplete encoding of the target (Scheerer & Bongartz, 1973; Spencer & Shuntich, 1970). The temporal signature of the interruption process is that masking peaks at SOAs of 75ms to 150ms and little masking occurs below or above this SOA range. Thus, for the interruption and integration mechanisms maximal masking is achieved at different temporal windows between the target and the mask onsets. Another distinction between the two accounts is that whereas interruption masking is sensitive to modulations of set size, masking by integration is not (Breitmeyer, 1984).

The mask, however, does not need to spatially overlap with the target for masking to be obtained as is the case in pattern masking. In metacontrast masking the perceptibility of the target (typically a disk) is impeded by a masking ring that closely surrounds the target but it does not overlap with it (M Alpern, 1953; Growney, Weisstein, & Cox, 1977; Werner, 1935). There are several characteristics that influence the masking effect in metactontrast

[2] It is important to note that there is not a satisfactory categorisation of the different types of visual masking and those described in the text are open to revision.

masking. For instance, masking is inversely proportional to the spatial separation between the ring and the disk; the larger the gap between the target and the mask the less masking is obtained. The masking effect is also sensitive to attentional manipulations (Averbach & Coriell, 1961; Ramachandran & Cobb, 1995; Shelly-Tremblay & Mack, 1999) and it is dependent on the onset asynchrony between the target and the mask; minimal or no masking occurs when the SOA is too long (>100ms) or too short (<30ms) whereas optimal masking is obtained for intermediate SOAs[3]. Thus, in metacontrast, when performance is plotted against SOA it results in a U-shape curve (Cox & Dember, 1972).

Figure 1.6*. Examples of targets and masks in various "forms of masking". In*

[3] Although the SOA at which maximal masking is achieved is often referred to as the "critical SOA" there is not an exact timing that accurately describes it and it varies greatly between studies. For instance Schiller and Smith (1966) reported a critical SOA of 65ms whereas Alpern (1953) found it to exceed 100ms. The SOA timing also varies with stimulus type or stimulus luminance and it depends on target eccentricity.

masking by structure the mask consists of the same structural elements that define the target. In masking by noise the mask is a random black and white dots pattern. In metacontrast masking the target is typically a disk and the mask a ring that fits snugly around the target. Note that here the gap between the disk and the masking ring has been enlarged for demonstration purposes.

Several models have been suggested for metacontrast masking such as the interchannel inhibition model (Breitmeyer & Ganz, 1976) and the three neuron model (Matin, 1975). These models suggest that metacontrast masking depends on low level factors such as target and mask contour competition and mask intensity. For instance, the interchannel inhibition model proposes that there are two channels that convey information for both the target and the mask in the visual system: a short-latency transient channel that transfers information about the onset/offset of the stimuli and long-latency sustained channel which transfers information regarding stimulus characteristics such as its brightness and contour. According to this model, the signal of the mask onset is transferred through the rapid transient channel and inhibits the signal in the slow sustained channel which carries information about the target. Metacontrast masking is said to result from such inhibition (Breitmeyer & Ganz, 1976).

Object substitution masking

A newly discovered from of masking has been said to challenge traditional accounts of visual masking. Object Substitution Masking (OSM) refers to the observation that the visibility of a target stimulus is reduced by the presence of a second, spatially non-overlapping and structurally dissimilar stimulus, the mask. Typically the masking stimulus may consist of just four dots (four dot masking – FDM) which surround but do not overlap with the target and may have a common onset with the target (common onset masking – COM). In a standard task, the common onset mask vanishes either along with the target (common offset, or control condition) or it lingers for some milliseconds after the termination of the target (trailing mask, or masking condition). The difference in performance between the two conditions defines the OSM effect.

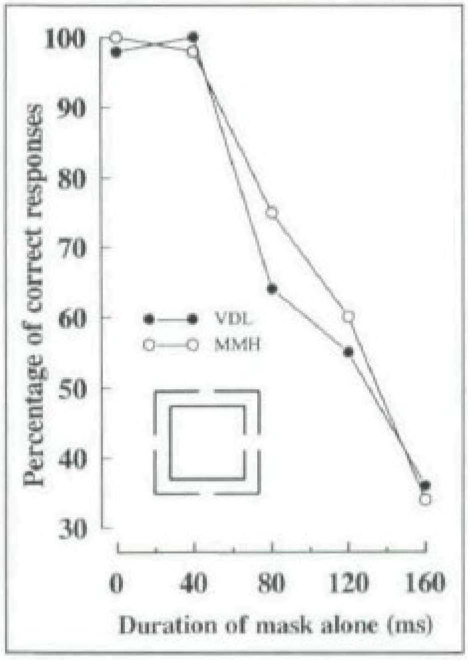

Figure 1.7*. Results from Di Lollo et al.' (1993) Experiment 2. The abscissa denotes the duration of the mask after the target offset in ms, and the vertical axis percentage of correct responses. The graph shows the results of two participants. In the common offset condition and for mask duration of 40ms observers had no difficulty reporting correctly the location of the gap in the target square. For longer mask durations, however, performance dropped dramatically and for mask duraiton of 160ms performance was close to chance (i.e. 25%). The inset shows the target and the mask.*

Early reports of OSM are found in the studies of Di Lollo, Bischof and Dixon (1993), and Bischof and Di Lollo (1995) in which they challenged the view that in metacontrast masking a minimum SOA is necessary for masking to occur. In Di Lollo et al.'s (1993) experiments the target stimulus was an outline square with a small gap at the centre of one of its sides. The mask was also a square frame and it had gaps at the centre of each side (Figure 1.7). Target and mask had a common onset (SOA = 0) and they were displayed for 1ms. The target was then turned off and the mask either disappeared simultaneously (common offset condition) with the target or it remained visible for up to 160ms (delayed offset condition). The observers' task was to report the location of the gap in the target square. The results showed that when the mask offset simultaneously with the target or when it outlasted the target for a very short time (40ms) observers had no difficulty reporting correctly the location of the gap. For longer mask durations, however, participants' performance dropped dramatically (Figure 1.7). The difference in performance between the common offset and the delayed offset conditions was taken to define the masking effect.

The study from Di Lollo et al. (1993) demonstrated that in metacontrast masking, a masking effect can be obtained if the SOA between the target and the mask is zero as long as the mask trails the target after the target offset. However, it could be argued that this was not really metacontrast masking as classically understood because there was always an appreciable gap between target and mask and because, unlike a disk target, the outline square target has both outer and inner contours. Werner (1935) proposed that in metacontrast masking the contour of the target disk was assimilated to the closely fitting inner contour of the mask and therefore the disk, because its only contour was not represented, could not itself be represented. These conditions do not apply to the early Di Lollo studies. In a later study, Enns and Di Lollo's (1997) showed that delayed offset masking can be obtained even with a mask that is comprised of only four dots. Furthermore, they showed that variation of the spatial separation between the mask and the target does not modulate the masking effect as is the case in metacontrast masking. In their experiments the masking stimulus was either four dots located at the corners of a notional square that surrounded the target (four dot mask) or a frame that fitted fairly snugly but did not touch the target (metacontrast mask). The target was a diamond with missing corner either to the left or to the right (see top of Figure 1.8 for target and mask stimuli). Target and mask had either common onset, or the mask onset before or after the target onset. In either case the mask duration was always 30ms. Furthermore, target and mask appeared either at the centre of gaze or in one of three horizontally arrayed locations (i.e. centre, left of centre and right of centre of gaze). When they appeared in one of three horizontal locations the two stimuli appeared either at the same location (e.g. target and mask on the left of the centre of gaze) or at different ones (e.g. target on the left and mask on the right of centre of gaze). Thus, in the different condition no masking was expected because target and mask were at different locations and therefore the target was not masked. The participants task was to report the side of the missing corner in the diamond. As can be seen in the graphs of Figure 1.8 a strong masking effect was obtained when the target was surrounded by a frame and when it was surrounded by four dots. This was surprising given that the contours of the four dots were neither substantial nor close enough to the target's contours to cause masking as metacontrast models would predict. In fact, when in a subsequent experiment the spatial separation between the target and the four dots varied the masking effect appeared insensitive to this manipulation.

Figure 1.8. *Top: Target and types of masks used in Enns and Di Lollo (1997) experiments. The graphs show identification performance as a function of SOA (horizontal axis) and target-mask location. The graphs show that there was a strong masking effect irrespective of the type of mask that was employed.*

Enns and Di Lollo (1997) took these findings as evidence that masking by four dots – and in contrast to other forms of masking – does not occur at early levels of visual processing and, therefore, it could not be attributed to sensory factors (e.g. target-mask spatial relationship). Instead, it was thought to take place at hierarchically higher levels of the perceptual system where the representation of the mask interferes with representation of the target. These representations were said to compete with each other in order to gain access to awareness. Enns and Di Lollo argued that masking with four dots does not occur as a result of interruption of the target processing in favour of the mask. This is because in masking by interruption the mask must spatially overlap the target for masking to occur; in masking by four dots the mask surrounded but it did not overlap with the target. Instead Enns and Di Lollo proposed that representations of the target object and the mask object come into conflict and that masking occurs when the representation of the mask substitutes that of the target. Thus, they termed the newly discovered form of masking object substitution masking (OSM).

The proposal that OSM occurs at higher levels of visual processing was later formalised in Di Lollo, Enns and Rensink's (2000) re-entrant account. This proposal was premised on the assumption of bidirectional communication between hierarchically organised brain areas (Felleman & Van Essen, 1991). According to the re-entrant hypothesis, stimulus onset initially triggers cell activity in the low level visual areas where a preliminary coding of the stimulus features and location takes place. The output of this coding is then sent as a feedforward sweep to high (extrastriate) levels of visual processing where one or more perceptual hypothesis is formed regarding the contents of the target location. The receptive field of these higher level cells, however, have poor spatial resolution and to distinguish between the competing perceptual hypotheses and resolve ambiguity as to the location of the stimuli, information is sent back to low level visual areas via re-entrant projections. If there is a match between the descending signals from the extrastriate visual areas and the current activity in the low level areas, one of the perceptual hypotheses is confirmed and a stable percept is achieved. In case of a mismatch, however, a new iterative loop commences based on the current visual input from the display and persisting activity in low level cells.

Four dot masking and the OSM/re-entrant account of it have attracted a great deal of interest in the last decade and more (Bachmann, 2005; Enns & Di Lollo, 2000; Gellatly, Pilling, Carter, & Guest, 2010; Gellatly, Pilling, Cole, & Skarratt, 2006; Guest, Gellatly, & Pilling, 2012; Kahan & Lichtman, 2006; Lleras & Moore, 2003; Luiga & Bachmann, 2007; Moore & Lleras, 2005). This reception can be explained in part by the fact that the FDM effect is so unexpected. Why should 4 dots that remain present for a fraction of a second impede perception of a target that would have been clearly visible if the dots had terminated at the same time as the target? In addition, the OSM/re-entrant account meshes well with much current thinking about the manner in which the visual system functions. As Nakayama and Martini (2011) described in their recent review of visual search, the last three decades have seen a gradual shift away from a view of vision as a strictly serial feed-forward system to one in terms of intercommunication between hierarchically different levels of visual processing (e.g. Desimone & Duncan, 1995; Di Lollo et al., 2000; Felleman & Van Essen, 1991; Lamme, Supèr, & Spekreijse, 1998).

To summarise, there are several characteristics that are claimed to distinguish FDM from other forms of masking. First, OSM is not sensory in its origin; local contour interactions between the target and the mask are not required for masking to occur. For instance, in metacontrast masking even small manipulations of the distance between the mask and the target stimulus modulates the strength of masking with larger gaps resulting in shallower masking functions (Werner, 1935). In OSM the spatial separation between the target stimulus and the masking dots has a negligible or no effect on the masking magnitude (Enns and Di Lollo, 1997). In the same vein, whereas other forms of masking require the masking stimulus to spatially camouflage the target (as in pattern masking) OSM does not exhibit such mask – target spatial interactions. The four dots not only are – at an image level – strikingly dissimilar to the target but they also do not overlap with the target. They are too sparse to play the role of a mask as this is defined by the principles of pattern masking and yet strong masking can be obtained. Furthermore, the temporal characteristics of OSM are noticeably different to those found in other forms of masking. Whereas in pattern and metacontrast masking the masking effect depends on SOA manipulations, OSM can be obtained even when the SOA is zero as long as the mask remains visible for some time after the target offset (e.g. Di Lollo et al., 1993).

Despite these claimed differences in the spatial and temporal characteristics of OSM, pattern masking and metacontrast masking these kinds of maskings are not entirely distinct from each other. Enns (2004) demonstrated that elements of OSM can be also found in other forms of backward masking. In a series of experiments he compared the masking effects when the target was masked by different types of masks, across a range of SOAs and set sizes. Among others, these masks included a metacontrast mask, a noise mask, a FDM and structure masks (Figure 1.9). In Experiment 1 Enns found that although the masking effects were almost equal for SOAs longer than 100ms, for shorter SOAs there were substantial differences (Figure 1.10). In Experiment 3, a peripheral pre-cue (a dot) presented near the target location appeared before the display onset. The results showed that under pre-cueing conditions a substantial masking effect was observed for all backwards masks except FDM when the SOA ranged between -50ms to 50ms. In other words the pre-cue had no effect on masking. For the four-dot masking, however, a pre-cue facilitation was observed for all SOAs; masking was eliminated and identification performance was nearly perfect. Enns suggested that collectively this pattern of results shows that all forms of backward masking, apart from the four-dot mask, have at least two components. One is associated with object formation (object formation masking) which is active at SOA range of 0-100ms. This process is thought to be involved in the segmentation of the target from the background and other nearby objects. The other component is associated with object substitution and involves the substitution of one perceptual object (i.e. the target) by another (i.e. the mask). This latter process has been purported to be influenced by the distribution of attention over space.

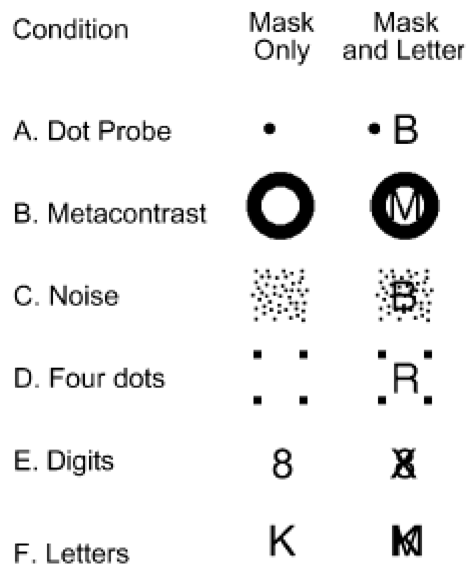

Figure 1.9. *The various types of masks used in Enns (2004). Image taken from Enns (2004, p. 1323)*

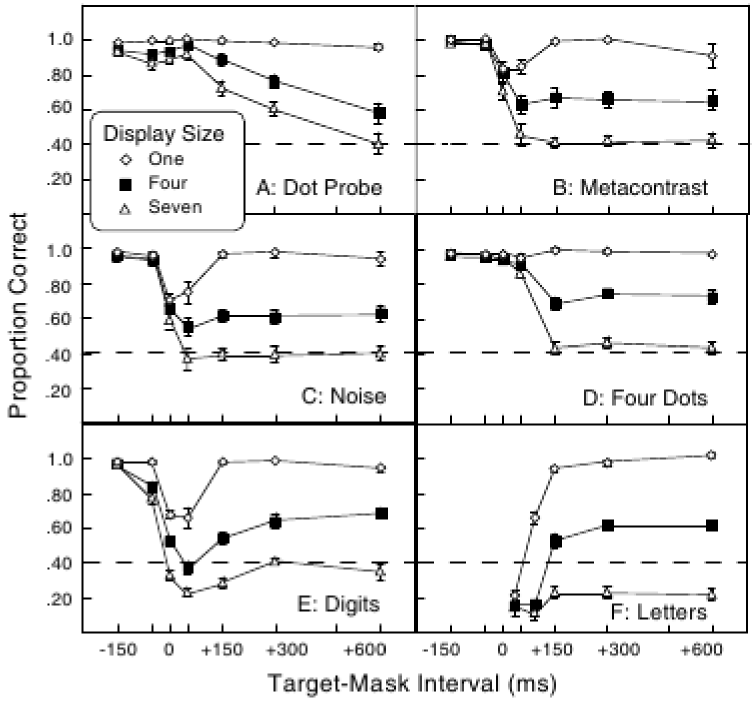

Figure 1.10. *Target identification performance as a function of target-mask interval (SOA – horizontal axis) and set size under different masking conditions. Image taken from Enns (2004, p. 1324).*

That attention has a paramount role in the effects observed in OSM has been central to most of the studies in the OSM literature. In particular, it has been claimed that OSM exhibits sensitivity to manipulations of attention, distinguishing it from other forms of masking. Such manipulations include variations of the number of items that are presented along with the target (set size), whether the target location is known in advance because of a pre-cue or whether the target pops out as a result of a unique characteristic. Furthermore, the proposal that attention plays a central role in OSM has inspired a number of accounts of OSM and the mechanisms that underlie this phenomenon.

In the next chapter it will be discussed that the re-entrant hypothesis has been the most influential account in the studies OSM and its main tenet is the purportedly predominant role of attention in OSM. Studies that support this position will also be described and their findings will be reviewed. Finally, this claim will be tested in a series of experiments in which the distribution of attention over the search display will be manipulated.

Chapter 2

Object substitution masking and attention in discrimination tasks

Introduction

In the Introduction it was reported that there are several characteristics that distinguish OSM from other “forms” of masking; OSM occurs even when the target and the mask onset simultaneously and the mask does not overlap with the target. Furthermore, OSM is insensitive to the spatial proximity between the target and the mask. But it was not only these characteristics that caused OSM to become the focus of much research. What was said to make OSM so different from other forms of masking was its purported dependence on the distribution of attention on the target display; OSM was said to occur under diffused attention conditions but not when attention was prefocused to the target location. Before discussing the studies that gave rise to and supported this claim it is important to discuss other studies which also claimed that other forms of masking, and in particular metacontrast masking, can be modulated by spatial attention (e.g. Averbach & Coriell, 1961; Ramachandran & Cobb, 1995; Shelly-Tremblay & Mack, 1999).

Averbach and Coriell (1961) investigated various properties of visual short term memory but their results are relevant to the present discussion. In their second experiment an array of letters was presented for 50ms which was then followed by a blank frame. The duration of the blank frame varied between trials. Next, another frame followed which contained a ring placed at the location that was previously occupied by one of letters and it served as a post-cue indicating the location of the to-be-reported target. The observers were asked to report the identity of the letter that was post-cued by the ring. Although the aim of Averbach and Coriell's study was to investigate various properties of VSTM with the ring serving as a post cue their task could be considered an example of metacontrast masking; a target followed by a blank frame for various durations (SOA) which was then followed by a ring at the target's location (i.e. mask). Their data on discrimination performance also followed the same pattern found in metacontrast masking studies; accuracy at reporting correctly the identity of the target was at approximately 75% for SOAs of 0ms but it dropped for SOAs of 100ms (about 25% correct responses) and then recovered when SOA was longer than 100ms resulting in a U-shaped curve. The important finding, and relevant to the present discussion, is that the U-shaped curve was present only when the target was surrounded by distractors. When the target was the only item in the display performance was perfect (i.e. 100%) across all SOAs. This is an important finding because it shows that the presence of distractors affected masking which in turn suggests that attention contributed to the masking effect. Another study that attempted to link attention to the effects of metacontrast masking comes from Ramachandran and Cobb (1995). These authors demonstrated in a series of experiments that when observers were required to perceptually group the target with items elsewhere in the display – a task that was said to require focused attention – the effect of metacontrast masking was reduced compared to when no such grouping of the target was required.

The findings from the above studies, however, are not conclusive and they provide only indirect evidence about the role of attention in metacontrast masking and the involvement of higher levels of visual processing. Ramachandran and Cobb's (1995) did not provide direct evidence that metacontrast masking is influenced by focused attention. In Averbach and Coriell's (1961) study the finding that set size interacted with SOA might be an artifact of performance being at ceiling when the target was the only item in the display. Namely, if performance was not constraint by the upper limit of the response scale then, perhaps, the two factors, SOA and set size, would have additive effects. As it will be discussed later in this Chapter, such artificial interactions can change the way we interpret results in visual masking studies.

Studies using the FDM paradigm, on the other hand, were said to demonstrate that OSM occurs only under conditions of diffuse attention and that it involves processes from higher levels of the visual system. According to Di Lollo et al. (2000), key evidence in support of the re-entrant hypothesis account (described in Chapter 1) comes from two sources. First is the fact that large masking effects are observed only with multi-element displays and relatively prolonged mask durations. They argued that this is because when the target is presented along with a large number of distractors, attention takes a longer time to arrive at the target's location. As a result this increases the likelihood that, before the target has been identified, the display will have changed from target plus mask to mask only. Secondly, when a target "pops out," or is the only item in the display, attention becomes focused upon it rapidly and a robust target representation can be established before the display changes to the mask only. If the mask lingers after target offset and the visual system has failed to confirm the initial hypothesis of target plus mask, then the representation of the mask alone will prevail in the perceptual system and only the mask will be consciously perceived. Di Lollo et al. instantiated their theory in a computational model (computational model of object substitution [CMOS]), of which a key parameter is the time for attention to contact the target item. A great deal of this thesis will be taken up with re-considering the above two sources of evidence that spatial attention modulates OSM.

A critical aspect of Di Lollo et al.'s (2000) theory is the emphasis on the interaction between search-array set size and mask duration. In their Experiment 3, the stimuli consisted of circles, each with a gap at the top, left, bottom or right. The target was cued by four dots which also served as a mask, and, the observers' task was to report the orientation of the gap of the target circle. The results showed that set size and mask duration (after target offset) interacted such that OSM was maximal for the largest set-size at relatively long mask durations (Figure 2.1).

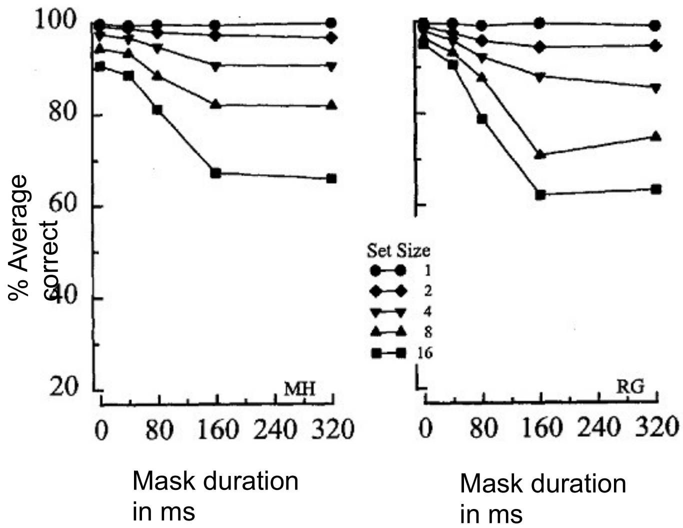

Figure 2.1. *Mean percentage correct identification of the location of the gap in the target as a function of set size and mask duration for two observers (copied from Di Lollo et al., Experiment 3).*

The claim that the magnitude of OSM is critically dependent on the joint effects of set size and mask duration can be called into question on the grounds that ceiling effects were evident in their results. For instance, in Experiment 3 performance for the small set sizes was close to or at 100% for all levels of mask duration. In addition, performance in the common offset condition was close to ceiling for all set sizes as indicated by the narrow vertical spread of the data when mask duration was 0 ms. These features of the data suggest performance for certain conditions may not have been fully revealed because it was compressed by the limits of the response scale. Di Lollo et al. noted that crowding acts to reduce the detectability of the target in larger set sizes. This means ceiling performance for larger set sizes could be less than 100%, so producing some vertical spread even at 0 ms mask duration (Di Lollo et al.'s term for the mask offsetting simultaneously with the target).

In fact, Di Lollo et al. themselves considered in relation to the data of their Experiment 1 whether the set size times mask duration interaction they obtained could be due to a ceiling effect. This experiment was the same as their Experiment 3, described above, except that the cue/mask was a circle rather than four dots. They argued (p.488) that a ceiling effect interpretation did not apply since performance for most set sizes at most mask durations was below ceiling, and they did not re-consider the possibility in relation to their subsequent experiments. However, they also argued that the data of their Experiment 1 showed the effect not just of high level substitution masking but also of a low level interaction between the closely fitting circular mask and the circular targets they employed. Indeed, in their Experiment 2 they repeated their Experiment 1 under conditions of dark adapted viewing intended to eliminate or reduce low level contour interactions. They once again observed an interaction of set size and mask duration but in the presence of ceiling or close to ceiling performance with smaller set sizes and for all set sizes at 0 ms mask duration (common offset). In fact performance was similar to that in their Experiment 3 (see Figure 2.1). In other words, to the extent that dark adapted viewing reduced low level contour interactions, it also served to undermine the argument against a ceiling level interpretation of the interaction.

Have other studies of OSM that independently manipulated both set size and mask duration obtained an interaction between the two factors? Although many studies have cited it as a signature feature of OSM, as it will be discussed below, few studies have sought to replicate the purported interaction between set size and mask duration and when this interaction was reported it was in the presence of ceiling and/or floor effects.

Another study for which a set size times mask duration interaction was reported comes from Goodhew and colleagues who compared set sizes one and nine across a range of mask durations. Although their experiments focussed on a separate issue, the authors reported interactions between set size and mask duration for most, though not all, of their experiments, and Goodhew et al. (2011a, p.590), citing Di Lollo et al. (2000), assert that “this interaction is the hallmark of OSM”. However, in all their experiments except the one that failed to produce a significant interaction, performance for set size one was well above 90% for all mask durations, and frequently close to 100%. As before, ceiling effects make it impossible to interpret the interaction, even when it is significant.

In this Chapter a series of experiments are reported which investigate whether the interaction is present when performance is not constrained by ceiling or floor effects. It is important to note that the first Experiment was an attempt to replicate Di Lollo et al.'s (2000) experimental procedure and results in order to be able to investigate other aspects of OSM such as whether OSM occurs selectively on particular target feature or on the whole target representation. However, as it will be reported – and to preview what is to come – neither in Experiment 1 nor in subsequent experiments did the interaction between set size and mask duration materialise. A discussion will then follow on the implications that the results from these experiments have on the validity of the re-entrant hypothesis as proposed by Di Lollo et al. (2000).

Experiment 1

The aim of the first experiment was to investigate if the finding that set size interacts with mask duration in OSM as initially reported by Di Lollo et al. (2000) can be replicated. The experiments were deliberately modeled on Experiments 1 – 3 of Di Lollo et al. (2000) with the following two differences: the stimuli were squares with gaps rather than circles and they were presented on the perimeter of a virtual circle rather than in a virtual square so that the distance of the target and the distractors from fixation was constant between trials. This experiment and all subsequent reported experiments had the approval of the University Research Ethics Committee of Oxford Brookes University.

Method

Participants were eleven (eight females) undergraduate and postgraduate students and members of the public with an average age of 22.2 years (s.d.= 4.4). They were all recruited via flyers posted in the OBU's psychology department. All participants reported normal or corrected-to-normal visual acuity. They gave informed consent and they received a small financial recompense. In the present and subsequent experiments participants were pre-warned that they should not take part if they had a medical history of epilepsy or of visual migraine caused by extended exposure to a television screen or flashing images.

In all the experiments reported in the present study, the stimuli were presented on a 20-inch CRT computer monitor running at 100Hz. They were black (0.35 cd/m2]) on a white background (97.25 cd/m2) and they were displayed at a viewing distance of 113cm in a dimly lit room. The experiments were written in and controlled by Matlab using the Psychophysics Toolbox extension (Brainard, 1997; Pelli, 1997).

On any given trial the display consisted of 4 or 16 squares. When there were 4 squares they were placed in the four cardinal positions of the circle. When there were 16 squares they were placed with equal space between them on the perimeter of the circle. Unless otherwise stated the same practice was followed for the rest of the experiments described in the present thesis even with different set sizes. Each square had a gap in the top, bottom, left or right side. The side of the gap was randomized. The centres of the squares were equally spaced around the circumference of a virtual circle with radius 2.98°. On each trial one of the items was surrounded by four dots (the mask), which also served as a cue to single out the target. The mask always onset simultaneously with the target and the distractors; these then either all offset together (blank frame) or the mask lingered for 60ms or 180ms (see Figure 2.2).

In units of visual angle, each side of the square subtended for 0.3°, the gap was 0.1° and the lines forming the square were of thickness 1.5 min arc. The thickness of each dot was 3 min arc and the distance between them was 0.5°.

Figure 2.2. *In each trial, four or sixteen squares with a small gap located randomly on one of their sides were presented in a circular array. Participants were asked to report the location of the gap of the square that was surrounded by four dots.*

Each participant underwent 240 trials which resulted from the factorial combination of 2 set sizes x 3 mask durations x 40 trials per condition. Twenty-four demonstration trials with extended frame durations (to ensure participants fully understood the task) and 48 practice trials preceded the main experiment. Every 60 trials the computer prompted the participants to have a brief break. The total duration of the experiment was approximately 25 minutes. At the beginning of each trial a fixation cross was presented for 500ms at the centre of the screen followed by a frame that contained the target, the mask and the distractors for 50ms. A subsequent frame was either blank – common offset condition - or contained only the trailing mask for 60 ms or 180 ms.

Participants were instructed to press one of four arrow keys on a computer keyboard if they thought that the gap was on the right, left, top or bottom side of the target-square. Participants were informed that accuracy, not speed of response, was of importance.

Results and Discussion

Figure 2.3 shows the mean percentage correct responses for each combination of set size and mask duration. Chance performance was 25% (four possible responses – left, right, top, bottom). The data were analysed in a two way repeated measures ANOVA. In this and all subsequent analyses, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity where appropriate. Results from the ANOVA showed significant main effects of set size $F(1, 10) = 14.28$, $p < .005$, partial $\eta^2 = .58$) and mask duration $F(1.3, 13) = 14.90$, $p < .005$, partial $\eta^2 = .59$). However, what was surprising in the present experiment – and in contrast to Di Lollo et al.'s (2000) findings – was the lack of an interaction between those two factors [$F(2,20) = .06$, $p > .05$].

A possible explanation for this lack of interaction could lie in the overall level of performance. In Di Lollo et al.'s (2000) study (Experiment 3) performance for all set sizes in the common offset condition was consistently high (on average above 90%), and even at longer mask durations performance for smaller set sizes varied between 70% and 100%. In Experiment 1, however, performance for the common offset condition was much lower, 56% for set size of four and 44% for set size of sixteen. Furthermore, performance for the larger set size and longest mask duration (32%) was not very far above the chance level of 25%. Although the group mean was significantly different from chance ($t(10) = 10.99$, $p < .001$), results for some participants may have been compressed by a floor effect. Certainly performance on our task was much lower than on Di Lollo et al.'s task, and it is possible that the relatively close to floor performance for the larger set size at the longest mask duration might have disguised the expected interaction.

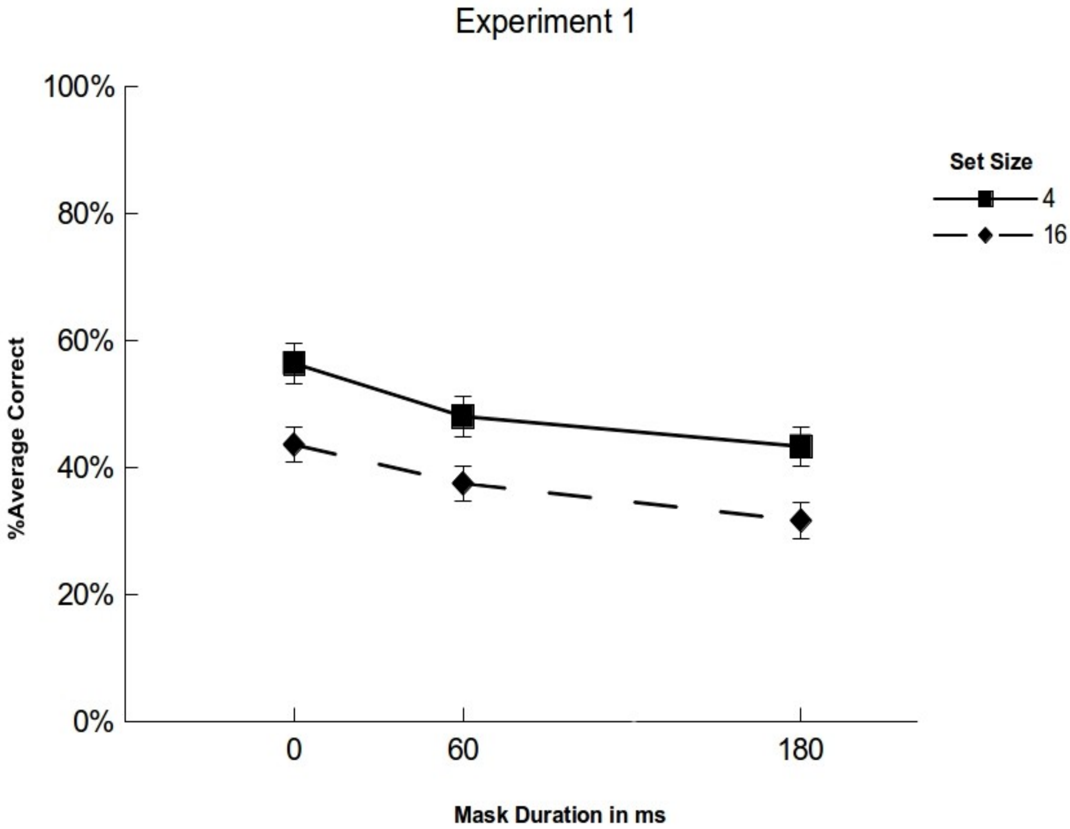

Figure 2.3. *Mean percentage correct identification of the location of the gap in the target. The horizontal axis denotes the mask duration and the lines denote the two set sizes.*

To test this possibility, a second experiment was carried out. The task was made easier for participants by completely omitting one side of each square instead of having just a gap. It was expected that this change would raise overall performance levels and eliminate the danger that a floor effect for the most difficult condition might be disguising the expected interaction.

Experiment 2

Method

There were 10 psychology undergraduate participants (8 females) with an average age of 30.8 years (s.d. = 13.2). They were recruited from the OBU Psychology Department Participants Panel and received course credits for taking part in the study. Stimuli were identical to those used in Experiment 1 except that instead of each square having a small gap in one of its sides, a whole side was missing. The procedure was identical to that in Experiment 1.

Results and Discussion

Figure 2.4 shows the mean percentage correct responses over set size and mask duration. As expected, the replacement of the small gap with a missing side markedly improved discrimination performance. A two way repeated measures ANOVA revealed a significant main effect of set size [$F(1,9) = 28.04$, $p < .001$, partial $\eta^2 = .76$] and of mask duration [$F(2,18) = 26.29$, $p < .001$, partial $\eta^2 = .75$]. However, as in Experiment 1, there was no interaction between these two factors [$F(2,18) = .86$, $p > .05$]. Increasing the size of the target gap had the desired effect of raising overall performance levels and also resulted in steeper masking functions but did not otherwise alter the pattern of results from those of Experiment 1. The interaction between mask duration and set size was not significant.

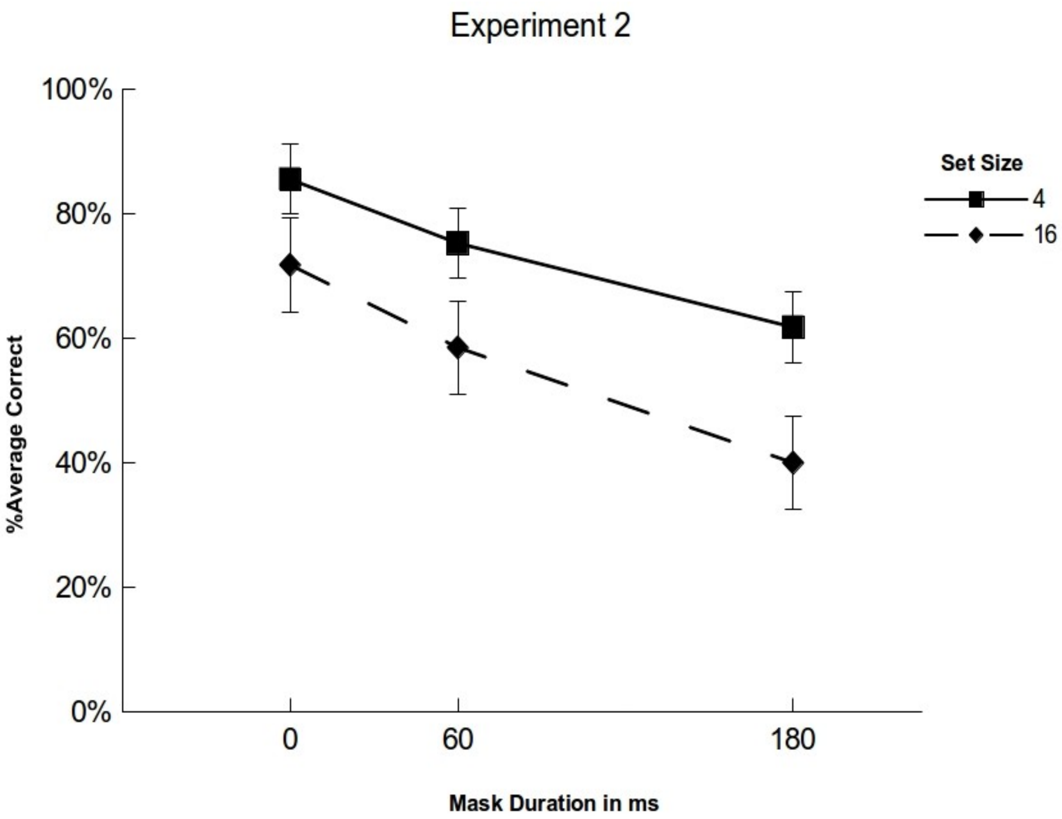

Figure 2.4. *Mean percentage correct identification of the location of the gap in the target. The horizontal axis denotes the mask duration and the lines denote the two set sizes.*

Experiment 3

In both the first two experiments, discrimination performance decreased with increasing set size and mask duration. However, contrary to Di Lollo et al. (2000) the two factors did not interact. The masking effect was not the product of an interaction between set size and mask duration but rather the additive result of the effect of each factor individually. One difference between our two studies and those of Di Lollo et al, is that we used only two set sizes whereas for their comparable experiments they used five. Possibly this might have led to participants employing different processing strategies. Furthermore, in their experiments the effect of mask duration for set size 4 lay somewhere between that for set sizes 1 and 16. Possibly I might find an interaction if I included more levels of the set size variable and a greater range of values of set size. In Experiment 3, therefore, I added two more set sizes of 1 and 8 items. However, employing a square with a missing side as the stimulus could result in performance always at ceiling when 1 item was presented. Conversely, a stimulus with too small a gap could conduce to performance close to chance levels for the larger set size and longest mask duration (as in Experiment 1). Consequently, in an effort to avoid ceiling and/or floor effects, the stimuli in Experiment 3 were constructed with larger gaps than in Experiment 1 but not with missing sides.

Method

There were 10 psychology undergraduate participants (7 females) with an average age of 22.7 years (SD = 5.17). They were recruited from the OBU Psychology Department Participants Panel for course credits. Stimuli were identical to those used in Experiment 1 except for the two following changes; instead of a small gap (0.1°) there was now a larger gap of 0.2°. Also, two extra set sizes of 1 and 8 items were added. As a result, the total number of trials was increased from 240 to 480 (from the factorial combination of 4 set sizes X 3 mask durations X 40 trials per condition). The procedure was identical to that of Experiment 1.

Results and Discussion

Figure 2.5 shows the mean percentage correct responses over the 4 set sizes and the 3 mask durations. Similar to Experiments 1 & 2, there were significant effects of set size [$F(1.5, 13.4) = 35.12$, $p < .001$, partial $\eta^2 = .79$ and mask duration [$F(2,18) = 34.02$, $p < .001$, partial $\eta^2 = .79$] but not an interaction between these two factors [$F(6,54) = .92$, $p > 0.05$]. The results of Experiment 3 are entirely consistent with those of Experiments 1 and 2. Increasing the number and range of set sizes did nothing to promote an interaction with mask duration.

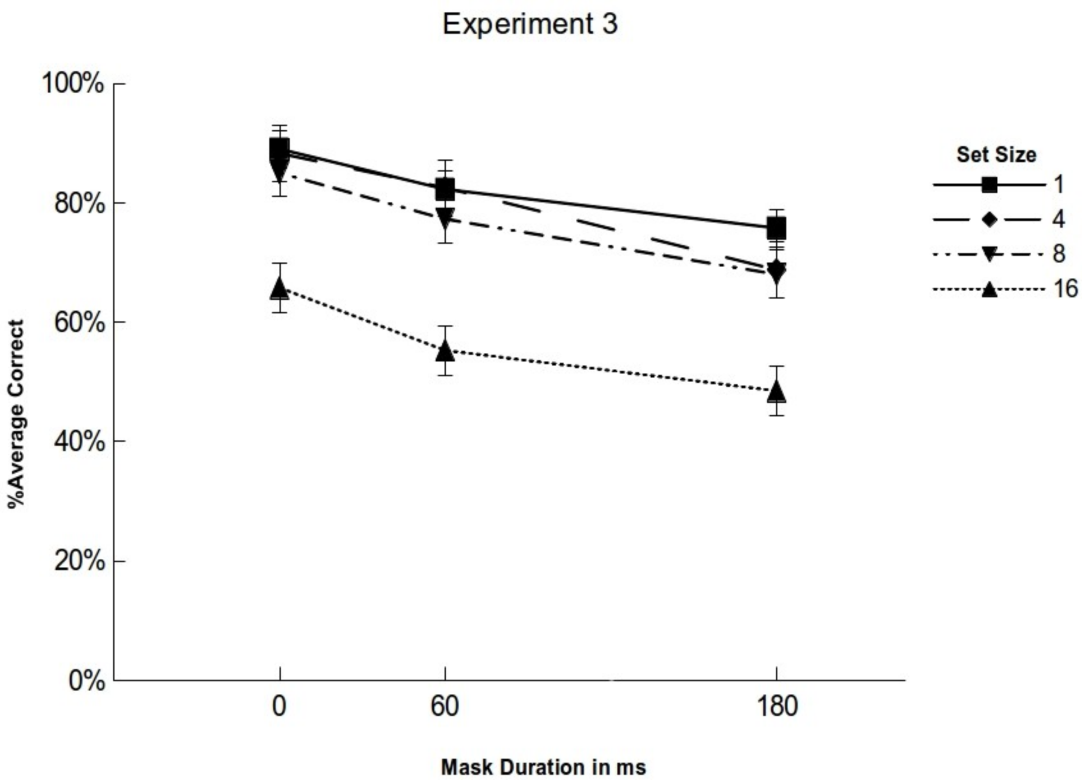

Figure 2.5. *Mean percentage correct identification of the location of the gap in the target. The horizontal axis denotes the mask duration and the lines denote the four set sizes.*

That OSM in Experiment 3 was just as strong for set size 1 as for the larger set sizes is a theoretically important finding. It shows that, contrary to what has been thought previously, it is not necessary for the target to be part of a multi-element display in order for OSM to be obtained. In contrast to the data of Di Lollo et al., the spread of the functions for set sizes 1, 4 and 8 is very small, with the main difference being between 8 and 16 items. Di Lollo et al. remarked on the role crowding plays in reducing performance for larger set sizes and a likely explanation for why such a large difference was found between set sizes

8 and 16 of Experiment 3 is that in our circular displays of equally spaced items crowding may have come into play only for the latter displays. I will be reporting investigations of the relationships between set size, mask duration and crowding effects in a later chapter.

An argument that might be made about the first three experiments is that each of them employed a relatively small number of participants, and that perhaps an interaction would have emerged if larger number of participants had been employed. Because, despite the differences in gap size in each experiment, all three studies were very similar and all included set sizes 4 and 16, I entered the relevant data into a single 3 x 3 x 2 mixed ANOVA, with one between participants factor (experiment) and two within participant factors (mask duration and set size). There were main effects of Experiment [$F(2, 28) = 15.03$, $p < .001$, partial $\eta^2 = .52$], mask duration [$F(2, 56) = 63.21$, $p < .001$, partial $\eta^2 = .69$] and set size [$F(1, 28) = 99.86$, $p < .001$, partial $\eta^2 = .78$]. Experiment interacted significantly with set size [$F(2, 28) = 3.96$, $p < .05$, partial $\eta^2 = .22$] reflecting a larger set size effect in Experiment 3 (mean = 23%) compared to Experiment 1 (mean = 11%), ($p<0.05$). The interaction between Experiment and mask duration approached significance [$F(4, 56) = 2.27$, $p < .1$, partial $\eta^2 = .14$] with the effect of mask duration being larger in Experiment 2 (mean = 28%) compared to Experiment 1 (mean = 16%). Most importantly, there was not an interaction between set size and mask duration [$F(2, 56) = .63$, $p > 0.05$, partial $\eta^2 = .02$], nor a 3-way interaction [$F(4, 56) = .85$, $p > 0.05$, partial $\eta^2 = .06$]. Thus even with a total of 31 participants, there was no hint of an interaction between set size and mask duration.

General discussion

The aim of Experiment 1 was to replicate the findings from Di Lollo et al. (2000) and then to investigate further aspects of OSM. A surprising finding was that in contrast to Di Lollo et al.'s reports that set size and mask duration interact in OSM, the results in Experiment 1 showed that there was not an interaction between the two factors; longer mask durations did not result in a larger masking effect when set size increased from 4 items to 16 items although both main effects were individually significant. The next two Experiments further probed the lack of an interaction between these two factors. The task in Experiment 2 was identical to Experiment 1 but with the critical feature increased in salience to avoid possible floor effects in some conditions. Although the overall performance increased there was again no evidence of an interaction between set size and mask duration. In Experiment 3 the ranges of both set size and mask duration were increased and the size of the critical feature was midway in size between those used in the previous two experiments. Once again, there was no sign of an interaction between two factors. In a subsequent analysis the data from all three experiments for set size of 4 and 16 were combined to increase the power of the analysis but set size did not interact with mask duration.

What are the implications of these findings for the re-entrant account as originally proposed by Di Lollo et al. (2000)? In the re-entrant processing account the speed with which spatial attention is focused on the target was said to be the crucial factor in determining the magnitude of OSM. When the target can be rapidly located because it is the only item or one of few items in the display, interference from involuntary processing of distractors is thought to be minimal. Because spatial attention focuses more rapidly on the target, processing of it will be more advanced by the time it offsets. As a result the target representation will be more developed and less likely to be substituted by a representation of the mask object in the course of continuing iterative reentrant processing. The likelihood that the representation of the target will be substituted by that of the mask is also increased by prolonged mask durations. The two factors supposedly have multiplicative effects on the probability of substitution so causing an interaction. The present data show that set size and mask duration do not, in fact, interact. These data may have important implications on how we think attention affects OSM. The finding that set size does not interact with mask duration in OSM suggests that attention, when it is modulated by varying the number of distractors, does not have an effect on OSM. This is in contrast to the claim that the OSM effect is attention dependant.

The tasks employed in Experiments 1 – 3 were deliberately modelled on Di Lollo et al.'s Experiments 1 – 3 in which the participants were required to discriminate a particular target feature. The most likely explanation for the difference in results with respect to an interaction is that in the present studies ceiling and floor effects were generally avoided whereas in the earlier studies they were strongly present. However, in other experiments by Di Lollo et al.

large interactions were observed when the task involved detection of the presence (or absence) of the target. It might be that the interaction will more readily appear in this type of task. Alternatively, it may be that ceiling of floor artefacts were present also in Di Lollo et al.'s target detection tasks. In the next chapter these possibilities will be investigated.

Chapter 3

Object substitution masking and attention in detection tasks

Introduction

In the previous chapter it was argued that the interaction between mask duration and set size in OSM as reported for a number of studies might have been an artefact of ceiling effects. Across three 4 AFC experiments I showed that when performance is held below ceiling mask duration and set size were both significant but their interaction was not. This finding suggests that in OSM attention - set size mediated - may not be the important factor as was originally suggested by Di Lollo et al. (2000).

It is possible, however, that the interaction between the two factors could appear under different task demands, namely when participants are required to perform a detection rather than a discrimination task. Di Lollo et al. (2000) found an interaction between the two factors when the participants were required to perform a detection task. For instance, in their Experiment 4, the target and distractors were closed circles and half of them had a vertical line segment through them while the other half did not. The observers had to report whether or not the target contained the vertical segment. In keeping with their Experiment 3, a significant interaction was obtained with the masking effect becoming multiplicatively stronger with increasing number of distractors and longer mask duration (Figure 3.1).

However, similar to their Experiment 3 the results of their Experiment 4 were not impervious to challenge. Although data for trials in which the target contained a vertical bar show a clear interaction between set size and mask duration (Figure 3.1), for trials in which the bar was absent, Di Lollo et al. reported that "…accuracy was at ceiling except at a mask duration of zero, when the results were comparable to those obtained when the vertical segment was present." (p.493). It is, therefore, possible the interaction between set size and mask duration for target present trials reflects a bias to respond "absent" even on trials in which the critical feature was present. The fact that performance for bar absent trials was at ceiling for almost all mask durations indicates that participants set a high criterion for reporting having seen the target. If the criterion varied with set size – a not unreasonable conjecture – such that it was even higher for larger set sizes, this would have produced the observed interaction.

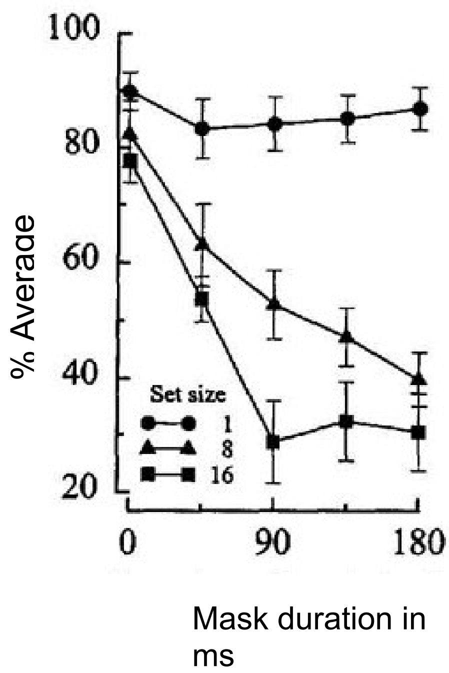

Figure 3.1. *Mean percentage correct target identifications, when the target contained a vertical segment, as a function of set size and mask duration (copied from Di Lollo et al., Experiment 4).*

A similar study was conducted by Kotsoni et al. (2007) but their results were less than fully conclusive. In two experiments they employed circles with or without a vertical segment and with set sizes one and nine and trailing mask durations of zero or 93 ms. Target duration was 13 ms in Experiment 1 and 40 ms in Experiment 2, and both sets of data were analyzed in terms of d-prime values. Both sets showed a trend towards the interaction but this was significant only for Experiment 2. However, group mean performance for the set size one and common offset condition was at 93% and 95% in the two experiments, suggesting that for many participants performance in this condition, and thus the extent of the OSM effect for set size one, was being artificially reduced by a ceiling. Moreover, even though chance was 50%, mean performance on the set size 9 and 93 ms trailing mask condition was 33% and 38% in the two experiments, indicating that a strong response bias to respond “target absent” affected the results for that condition in both experiments. Collectively, the results of Kotsoni et al.'s study are not conclusive regarding the interaction between set size and mask duration. Namely, performance for set size of one might not have been fully revealed because it was compressed by the limits of the response scale. Thus, the interaction between the two factors might have been artificially produced by performance being at ceiling in some conditions.

In all three experiments reported in Chapter 3, the target and the distractors were squares and observers had to report the orientation either of a gap or a missing side. As noted, however, in some of Di Lollo et al.’s (2000) experiments and in Kotsoni et al.’s (2007) studies the stimuli consisted of circles, and participants had to report whether or not the target contained a vertical segment. For the next three experiments I adopted similar stimuli to see if a change of task and stimuli would lead to the expected interaction.

Experiment 4

Method

There were 18 psychology undergraduate participants (15 females) with an average age of 19.5 years (s.d. = 1.3). They were recruited from the OBU Psychology Department Participants Panel for course credits.

The present and subsequent two experiments were designed to resemble Di Lollo et al.'s Experiment 4. Circles were employed and observers had to report whether the target contained a bisecting vertical bar (Figure 3.2). The decision to employ a bisecting vertical bar (instead of a shorter vertical segment as in Di Lollo et al.’s study) was based on results from a pilot study which showed that observers performed at or around chance level when stimuli contained a short vertical segment. But, when the segment was extended upwards to intersect with the circumference of the circle dividing it into two equal parts, measurable performance was obtained. The stimuli consisted of 1, 8 or 16 circles half of which had a bisecting vertical bar. The common onset mask either offset simultaneously with the target and the distractors or it lingered for 60ms or 180ms. On average, on half of the trials the target contained a vertical bar and on the other half it did not (hereafter, bar present/absent conditions).

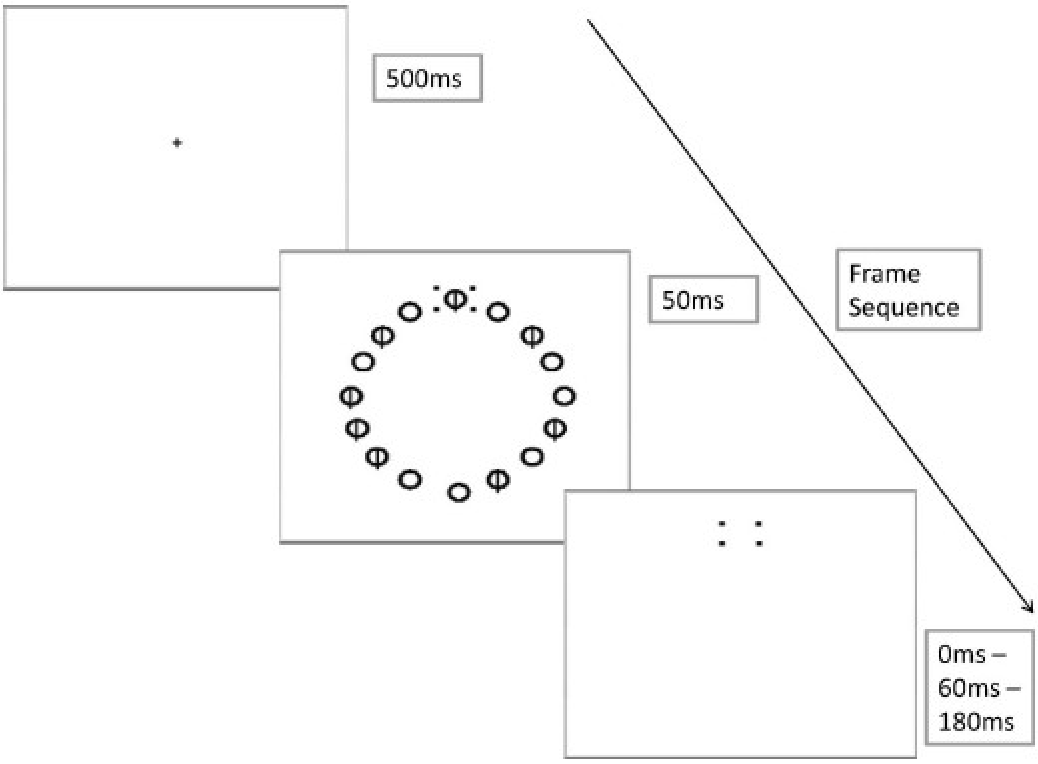

Figure 3.2. *In each trial one, eight or sixteen circles were presented in a circular array. On average, on half of the trials, the target circle contained a bisecting vertical bar. Participants were asked to report whether the target circle contained the bisecting vertical bar.*

In units of visual angle, the radius of the annular array was 2.98° and of each circle was 0.15º. The bisecting vertical bar subtended for 0.38° and its thickness was 1.5 min arc. The distance between the dots was 0.5° and each dot had a thickness of 3 min arc. Luminance values of stimuli and background were as in the previous experiments.

Each participant contributed to 540 trials resulting from the factorial combination of 2 bar present/absent conditions x 3 set sizes x 3 mask durations x 30 trials per condition. Every 60 trials the programme prompted observers to have a brief break. The total duration of the experiment was approximately 45 minutes. Similarly to the previous experiments, a session of 12 demonstration trials with extended frame durations and 36 practice trials preceded the main experiment.

At the beginning of each trial a cross was presented in the centre of the screen for 500ms on which participants were told to fixate. Immediately after the cross offset, the target, the distractors and the mask were flashed for 50ms followed by either a blank frame or a frame containing the trailing mask. Participants were informed that, on average, half of the times the target would contain a bisecting vertical bar and the other half it would not. They were instructed to press the “Y” key on a standard computer keyboard if they thought that the circle contained the vertical bar or the “N” key if they thought it did not. They were also informed that accuracy of rather than speed of response was of importance.

Results and Discussion

Illustrated in Figure 3.3 are mean percent correct responses as a function of set size and mask duration. For target present trials (right side of the graph) a two-way repeated measures ANOVA showed significant main effects of both set size,[$F(2,34) = 39.24$, $p < .001$, partial $\eta^2 = 0.69$] and mask duration [$F(2,34) = 46.43$, $p < .001$, partial $\eta^2 = 0.73$] and, most importantly, a significant interaction between the two factors [$F(4,68) = 2.82$, $p < .05$, partial $\eta^2 = 0.14$]. The effect of set size was stronger for longer mask durations and, conversely, mask duration had its greatest effect at larger set sizes. For target absent trials (left side of the graph) mask duration had a significant effect [$F(1.4, 20.7) = 12.87$, $p < .005$, partial $\eta^2 = .46$] but neither set size [$F(1.3, 20.12) = .55$, $p > 0.05$] nor the interaction between these two factors [$F(4, 60) = 1.2$, $p > 0.05$) were significant.

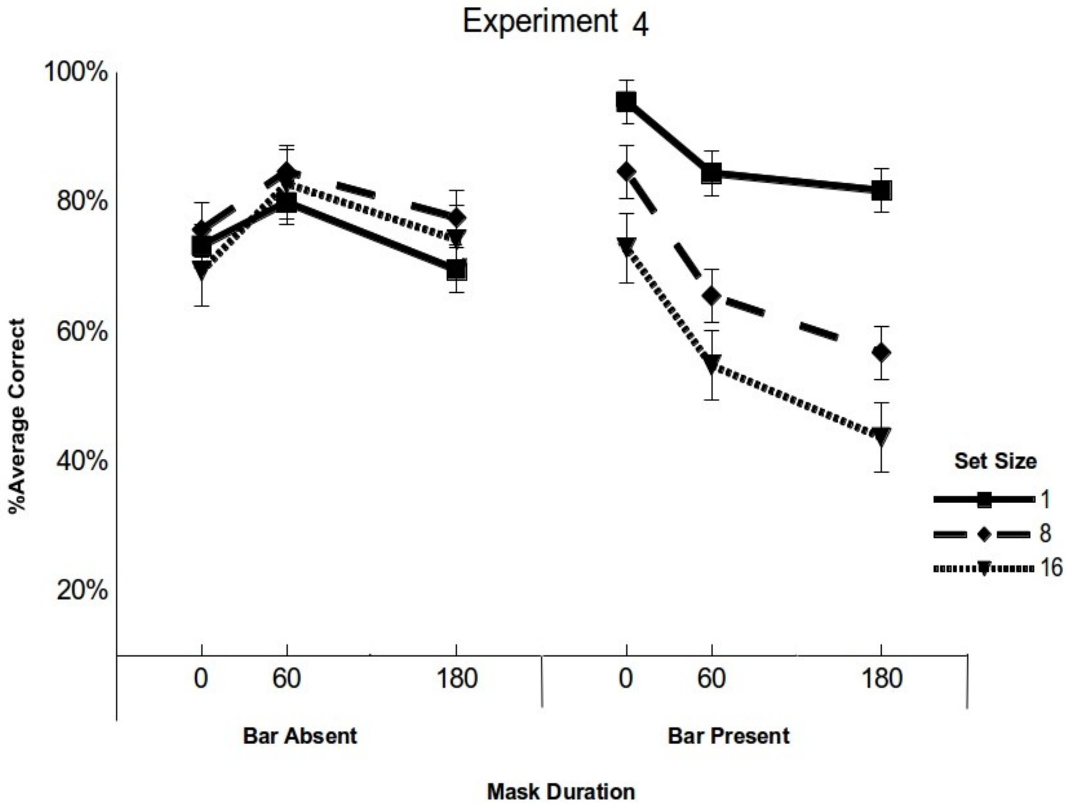

Figure 3.3. *Mean percentage correct reporting of presence/absence of the bisecting vertical bar in the target circle. The horizontal axis denotes the mask duration and it is divided into scores for trials in which the target circle did not contain the bisecting vertical bar (bar absent trials, left part of the graph) and scores in which the target circle contained the bisecting vertical bar (bar present trials, right part of the graph). The lines denote the three set sizes.*

In the bar present trials, the pattern of the data resembles that of Di Lollo et al. in that there was an interaction between set size and mask duration. In the bar absent trials, the first feature of the data that needs to be noted is that performance when target and mask had a common offset was lower than or comparable to that for the delayed offset conditions. This pattern was also reported by Di Lollo et al. and shows that observers were more likely to report that the target contained a bar when it did not in the control condition compared to the mask delayed trials. Most important, however, was the finding that high false alarm rates were observed in the target absent trials. This finding suggests that observers adopted a rather low criterion for reporting having seen the vertical bar. Namely they were more likely to respond that the target was present than that it was not in the bar absent trials. This is in striking contrast to the data that were obtained under the same conditions in Di Lollo et al.'s study in which "On trials in which the target did not contain the vertical segment […], accuracy was at ceiling except at mask duration of zero..." (p. 493). One way to overcome the problem with the high false alarm rates in the present experiment is to perform a guessing correction by subtracting false alarms in the bar absent condition from correct detections in the bar present condition. Figure 3.4 illustrates the results of this procedure. When the data were entered into a 3 (set size) by 3 (mask duration) ANOVA, there was a main effect of set size [$F(1.46, 21.9) = 24.99$, $p < .0001$, partial $\eta^2 = .63$] and of mask duration [$F(2,30) = 32.48$, $p < .001$, partial $\eta^2 = 0.68$] but the interaction was not significant [$F(4,60) = .74$, $p > 0.05$]. The same total absence of interaction was found with A-prime analysis ($F(2.62, 39.74) = 1.52$, $p > .05$).

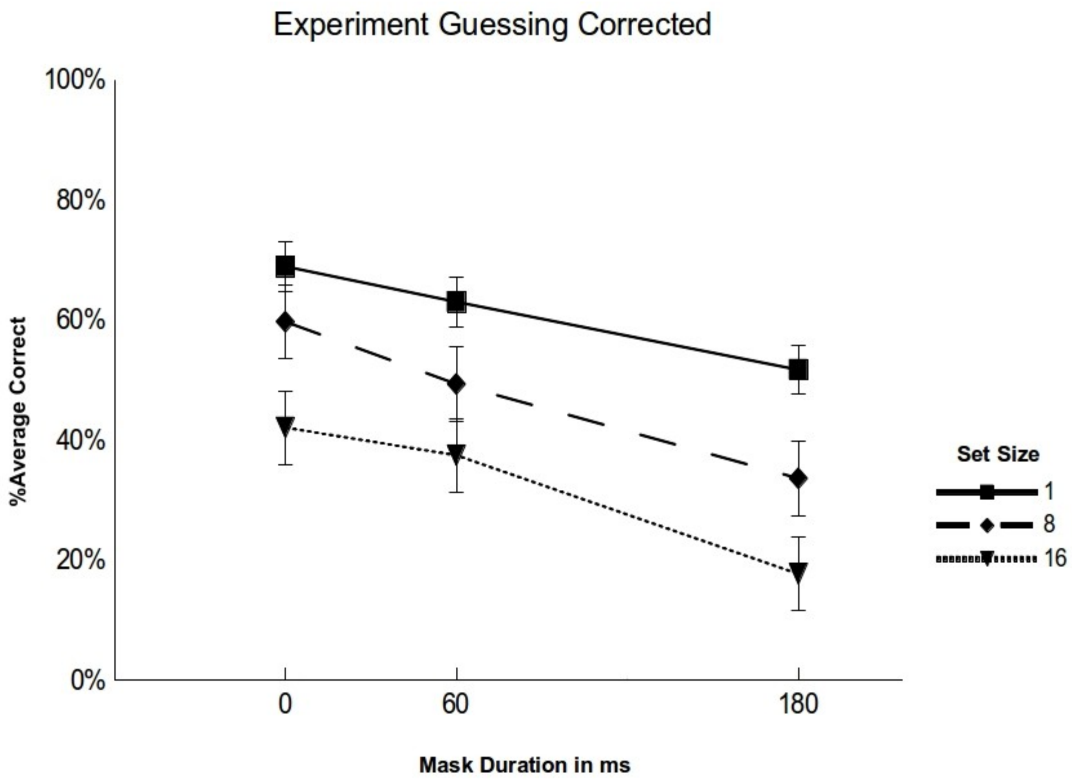

Figure 3.4. *Guessing corrected analysis. Each data point was computed by subtracting the false alarms from the correct responses.*

The failure to find a significant interaction cannot readily be attributed to stimulus presentation differences (a square matrix in Di Lollo et al. versus an annular array in the present study). When Di Lollo et al. analyzed their results based on the degree of eccentricity (Experiment 1) they found that although a stronger masking effect was present at greater eccentricities, the pattern of results remained similar across eccentricities. Moreover, the eccentricity of the annular array of the present experiment was deliberately very similar (3°) to that of the outer positions of their matrix (2.8°). However, the size of the circles differed considerably between the two studies (0.15° in our experiment, 0.4° in Di Lollo et al.). Conceivably, this might have resulted in higher false alarms rates. For this reason, and to ensure the reliability of the findings, I conducted a further experiment.

Experiment 5

The present experiment was identical to Experiment 4 apart from the following changes. First, the eccentricity of the annular array was decreased from 2.98° to 1.77°. This change was expected to produce an improvement in overall discrimination performance. Secondly, an additional mask duration of 360 ms was employed. Although Di Lollo et al. found that the effect of mask duration reached a plateau by 180 ms or sooner, it is possible that in the conditions of our experiments the main effect might operate over a longer duration. Similarly, although I have failed to obtain an interaction with set size in any of our first four experiments, it is possible that one might emerge at a mask duration longer than those I used previously.

A further twist to Experiment 5 is that I ran two versions of it. In discussing the results of their Experiment 4 (see Figure 3.1), Di Lollo et al. noted that "… the lower limit of accuracy is more properly regarded as being zero rather than the 50% chance level. This is because the observers indicated whether they had seen the vertical segment in the target. Thus, a score below 50% would indicate that the vertical segment, although present, was not seen because it had been masked. On trials on which the target did not contain the vertical segment ….accuracy was at ceiling except at a mask duration of zero….Ceiling effects for accuracy on target absent trials are commonly found in visual search experiments because observers are reluctant to guess that a feature they did not see was actually present". Another way of expressing the last point is to say that observers set a high criterion for reporting target presence. Although Di Lollo et al. do not report the precise instructions given to their participants, the ceiling level performance on target absent trials indicates that participants so interpreted the instructions that they did indeed set a high criterion for reporting having seen a line segment in the target circle. This contrasts with the results of the present Experiment 4 (see Figure 3.3) in which false alarms on target absent trials averaged around 25%. I therefore ran two versions of Experiment 5 with different experimental instructions. For Experiment 5a, the instructions were exactly as for Experiment 4, making Experiment 5a a replication and extension of Experiment 4. For Experiment 5b, participants were instructed to press yes only if they were certain that the target contained the bisecting vertical bar, otherwise to press no. My intention was to see whether the different instructions would influence performance level by changing participants' criterion, and how this might affect the appearance of an interaction between set size and trailing mask duration.

Method

For Experiment 5a there were 13 psychology undergraduate and postgraduate students and members of staff (11 females) with an average age of 30.43 years (SD = 9.85). For Experiment 5b there were 16 psychology undergraduate participants (all females) with an average age of 19.61 years (SD = 1.75). Participants were either unpaid volunteers or were recruited from the OBU Psychology Department Participants Panel for course credits. The stimuli were the same as those in Experiment 4 except for the differences described above. Additionally, in order to retain an analogous spatial relationship between the target-circle and the masking dots, the distance between the dots decreased from 0.5° to 0.4°. An additional mask duration of 360ms was added and the number of trials remained at 30 per condition. As a result each participant contributed a total of 720 trials.

Results and discussion

The results for Experiments 5a and 5b are shown in Figure 3.5 and 3.6, and Figures 3.7 and 3.8 respectively. Figure 3.5 illustrates the average percent correct as a function of bar absent/bar present conditions, set size and mask duration in Experiment 5a. The data of 5a were submitted to two separate repeated measures ANOVAs for the bar absent and bar present conditions. For the former conditions, there were main effects of set size [$F(2,24) = 5.62$, $p < .05$, partial $\eta^2 = .31$] and mask duration [$F(1.4, 1.7) = 7.66$, $p < .05$, partial $\eta^2 = .39$] and a significant interaction between them [$F(6, 72) = 5.48$, $p < .005$, partial $\eta^2 = .31$]. For trials when the target included a bar, there were again main effects of set size [$F(2, 24) = 21.26$, $p < .0001$, partial $\eta^2 = .64$] and mask duration [$F(1.8, 22) = 27.27$, $p < .0001$, partial $\eta^2 = .69$] and also a significant interaction between them [$F(6,72) = 6.17$, $p < .005$, partial $\eta^2 = .34$].

Although the set size points for common offset trials are close together in the bar present condition they were somewhat spread apart for the bar absent condition. This pattern is reversed for the 360ms mark duration condition with the set size points being far apart for bar present trials but very close together for bar absent trials. In other words participants' readiness to make false positive responses did not differ with set size for 360ms mask duration but did do so for the common offset condition. This clearly demonstrates the need to apply a guessing correction to the target present data.

As for Experiment 4, the target present and target absent data of Experiment 5a were combined in a guessing correction procedure, the results of which are shown in Figure 3.6. The individual scores were entered into an ANOVA, which yielded significant main effects of set size [$F(2,24) = 36.74$, $p < .001$, $\eta^2 = .75$] and mask duration [$F(3,36) = 53.60$, $p < .001$, $\eta^2 = .81$] but no interaction between these factors [$F(6,72) = .71$, $p =$ n.s., $\eta^2 = .05$]. Once again A-prime analysis showed a lack of an interaction between the two factors ($F(3.04, 36.46) = 1.29$, $p > .05$).

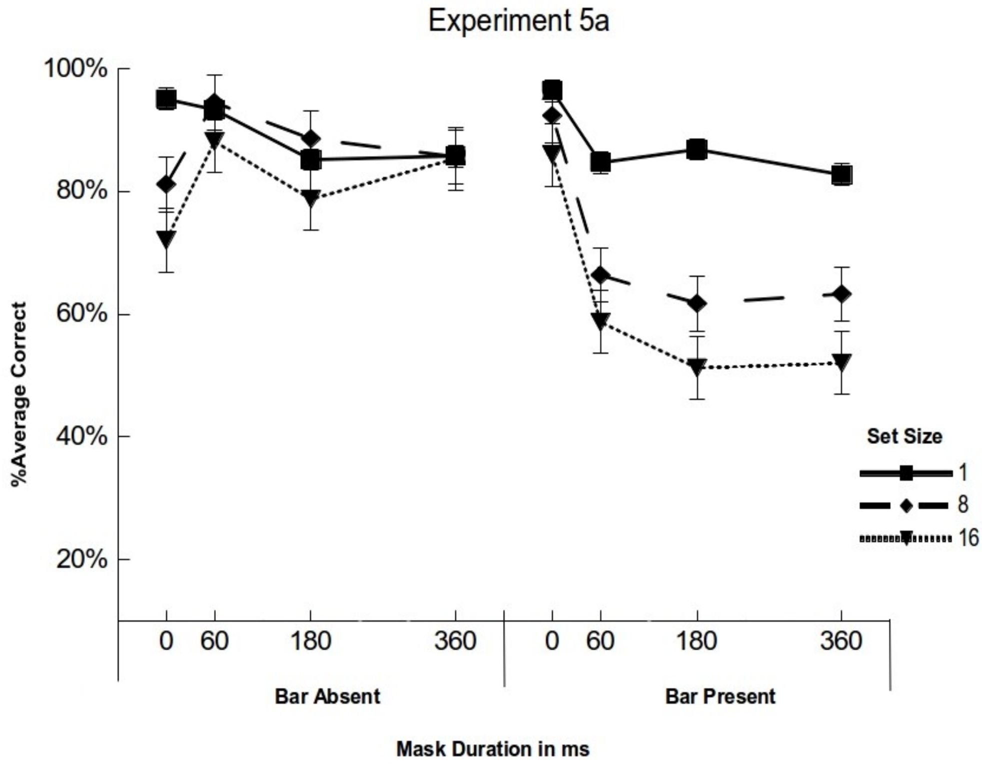

Figure 3.5. *Mean percentage correct detection of the presence/absence of the bisecting vertical bar in the target circle. The horizontal axis denotes the mask duration and it is divided into scores for trials in which the target circle did not contain the bisecting vertical bar (bar absent trials, left part of the graph) and scores in which the target circle contained the bisecting vertical bar (bar present trials, right part of the graph). The lines denote the three set sizes.*

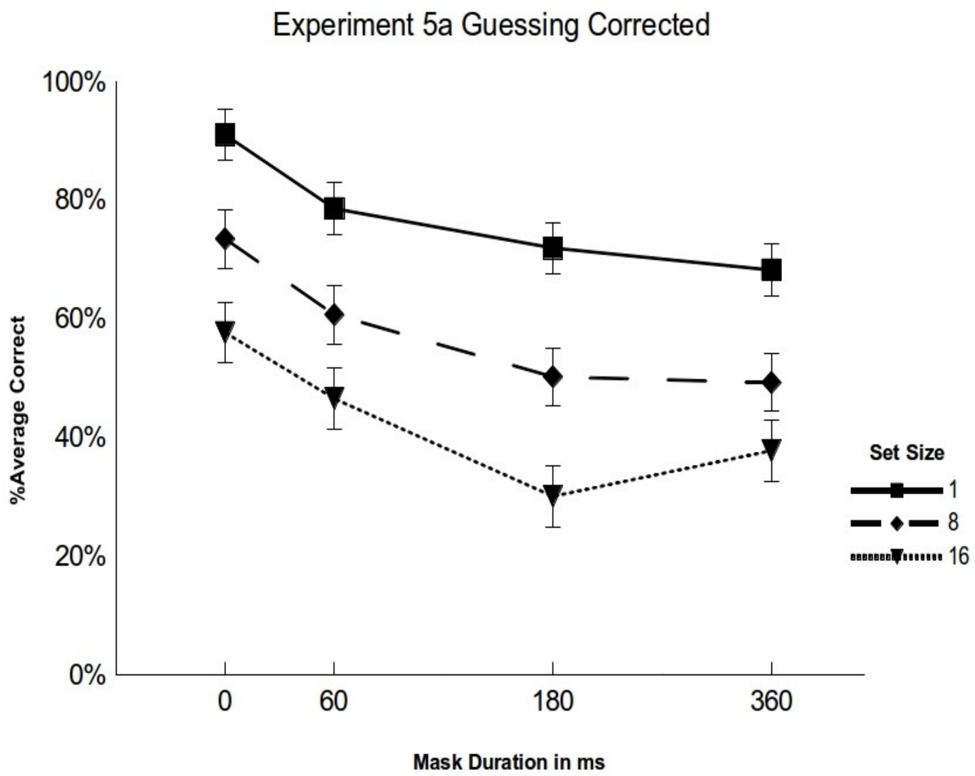

Figure 3.6. *Guessing corrected analysis. Each data point was computed by subtracting the false alarms from the correct responses.*

Figure 3.7 shows the data of Experiment 5b for bar absent (left part of the graph) and bar present trials (right part of the graph). A visual comparison between the Figures 3.5 and 3.7 shows that for target present trials the pattern of the data is similar between Experiments 5a and 5b. In Experiment 5b the spread of the set size data points in the common offset trials is greater than in Experiment 5a. This difference is presumably because of the change in the experimental instructions in Experiment 5b which led the participants to adopt a more conservative criterion. Namely, they were more likely to report "no" that the bar was not present although it was. The consequences of adopting such criterion are more profound in the bar absent trials. In Experiment 5b performance at reporting the target was close to ceiling in the majority of conditions meaning false alarm rates were generally very low.

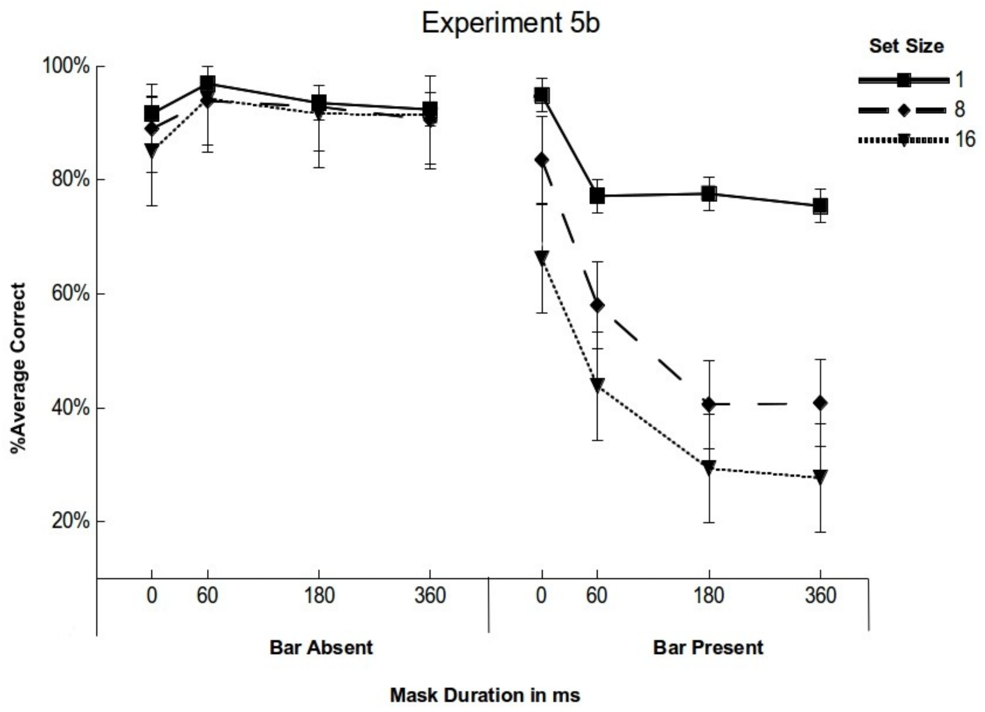

Figure 3.7. *Mean percentage correct detection of the presence/absence of the bisecting vertical bar in the target circle. The horizontal axis denotes the mask duration and it is divided into scores for trials in which the target circle did not contain the bisecting vertical bar (bar absent trials, left part of the graph) and scores in which the target circle contained the bisecting vertical bar (bar present trials, right part of the graph). The lines denote the three set sizes.*

The data of Experiment 5b were submitted to two separate repeated measures ANOVAs for the bar absent and bar present conditions. For the bar absent trials, the ANOVA revealed a significant main effect of mask duration [$F(1.9, 28.7) = 5.45$, $p < .05$, partial $\eta^2 = .27$] but not one of set size [$F(2, 30) = 2.08$, $p>.05$, partial $\eta^2 = .12$] and nor an interaction between set size and mask duration [$F(3.5, 51.8) = 1.02$, $p>.05$, partial $\eta^2 = .06$]. For the bar present trials, there were significant main effects of set size [$F(1.3, 19.7) = 62.9$, $p < .0001$, partial $\eta^2 = .81$] and mask duration [$F(1.8, 26.6) = 39.65$, $p < .0001$, partial $\eta^2 = .73$. In addition, the interaction between mask duration and set size reached statistical significance [$F(6,90) = 7.07$, $p < .001$, partial $\eta^2 = .32$].

As for Experiment 4, the target present and target absent data of Experiment 5b were combined in a guessing correction procedure, the results of which are shown in Figure 3.8. An ANOVA confirmed the main effects of set size [$F(1.4, 20.8) = 88.88$, $p < .0001$, partial $\eta^2 = .86$] and of mask duration [$F(1.7, 25.8) = 32.54$, $p < .0001$, partial $\eta^2 = .69$] and also of the interaction between them ($F(6, 90) = 5.23$, $p<.0001$, partial $\eta^2 = .265$). Thus Experiment 5b finally replicated the elusive interaction between set size and mask duration, but only because a deliberately induced response bias lead to near ceiling performance on all target absent trials. Because of this near to ceiling performance, the guessing correction procedure could do little to modulate the data pattern for target present trials.

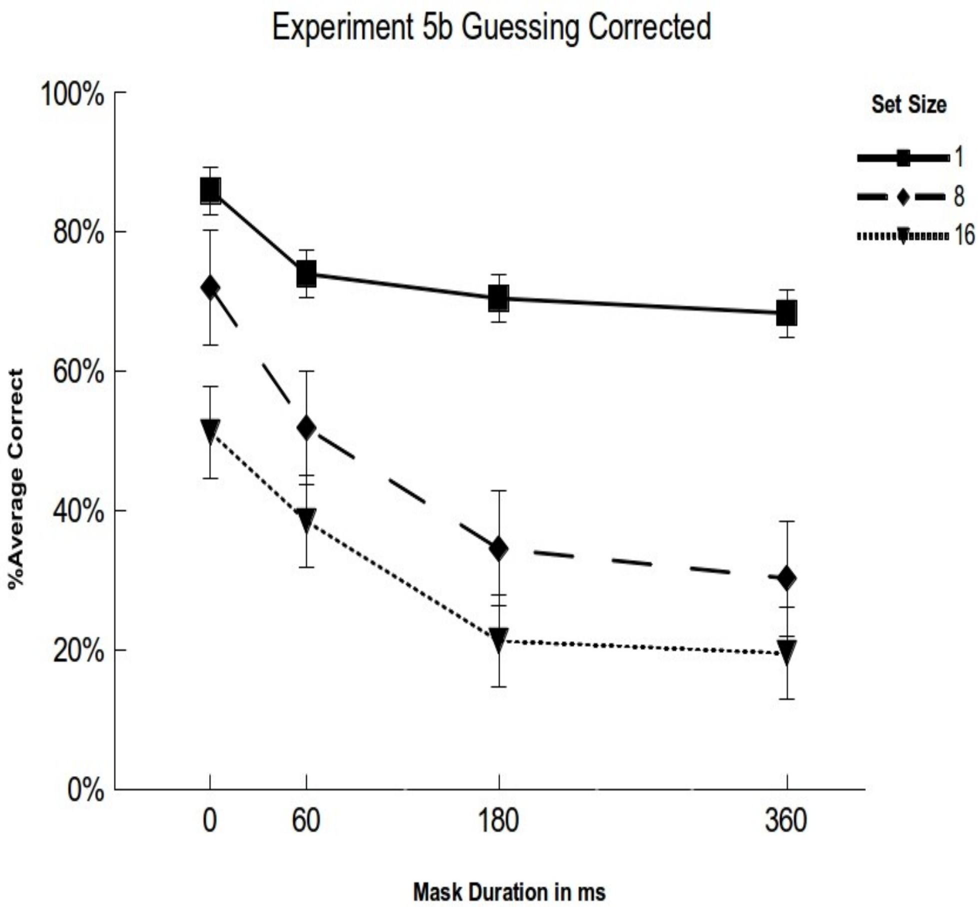

Figure 3.8. *Guessing corrected analysis. Each data point was computed by subtracting the false alarms from the correct responses.*

Discussion

I begin by comparing the results of Experiment 5a with those of Experiment 4, since the latter was a replication with extensions of the former. Reducing the eccentricity of the stimulus display in Experiment 5a had the desired effect of raising accuracy levels for both target absent and target present trials. However, the pattern of results is very similar in the two studies. For target absent trials, eight of the first nine data points (i.e. ignoring the 360 ms mask duration) are in the same configuration. For target present trials the same is true for all nine points that are common to both experiments, the only difference being a slight bunching of the zero mask duration points in Experiment 5a, which is attributable to the higher overall accuracy level bringing these points up against ceiling. Turning to the guessing corrected results (Figures 3.4 and 3.6) the similarity between the two sets of data is again striking despite the difference in absolute levels of accuracy. Furthermore, although in both graphs the spread of points is slightly greater for the 180 ms than for the zero trailing mask duration, the spread reduces again for the 360 ms duration in Experiment 5a. Lengthening mask duration does not cause an interaction to emerge.

If I now compare Experiments 5a and 5b, then, as expected, the contrasting instructions resulted in higher performance on target absent trials for the latter than the former and the reverse for target present trials. As intended, participants appear to have set a higher criterion for reporting a target segment in 5b than in 5a. For the target present trials the change in the experimental instruction had a large effect on set sizes of 8 and 16 but much less effect on set size of 1. This difference in the set size effects may be attributed to the way response bias works for different set sizes. It, therefore, lends support to the conjecture that participants in Experiment 4 of Di Lollo et al. may have varied their criterion for reporting target presence according to set size. In general, however, the patterns of results are very similar for target present trials in the two Experiments, with both closely resembling the corresponding data of Experiment 4. All three studies show an interaction between set size and target duration when target present trials are viewed alone but for Experiments 4 and 5a the interaction vanishes when a guessing correction is undertaken. Only in Experiment 5b does the interaction survive guessing correction but that is clearly due to ceiling level performance on target absent trials rendering the procedure ineffective. The overall consistency across the three experiments can only increase confidence in conclusions drawn from them.

The results from Experiments 4, 5a and 5b are consistent not only with each other but also with the studies of Di Lollo et al.(2000). For Experiments 5a and 5b the effect of mask duration reaches a plateau by 180 ms, just as observed in Di Lollo et al.'s Experiments 1, 2 and 3. Such similar patterns of temporal dynamics across two sets of studies, undertaken in different laboratories more than ten years apart and with different target durations, is impressive. For target present trials in Experiments 4, 5a and 5b and for Di Lollo et al,'s Experiment 4, set size and mask duration significantly affect performance accuracy and also interact with each other. However, as it has been now shown, these interactions disappear for Experiments 4 and 5a when a guessing correction is applied.

General Discussion

According to Di Lollo et al. (2000, p. 488), accounting for the interaction between set size and mask duration in terms of the time needed for spatial attention to focus on the target location is "…an essential part of the re-entrant-processing account that we favour…" for explaining OSM. The experiments reported so far question the reality of that interaction. Experiment 4 employed a present/absent decision based closely on the task in Experiment 4 of Di Lollo et al., but with performance calibrated to be below ceiling in all conditions. An interaction was present for target present trials but when target absent trials were taken into account by applying guessing correction the interaction disappeared. Experiments 5a and 5b were then conducted with stimuli presented at a reduced eccentricity and with instructions that were expected to affect the criterion with which participants reported the target. The instructional manipulation yielded differing levels of performance. However, the pattern of results for target present trials in the two studies was highly similar in each case and to that of Experiment 4. Similar to Experiment 4, in Experiment 5A, the interaction was abolished by a guessing correction. This was not the case for Experiment 5B because, similar to Di Lollo et al.'s (2000) Experiment 5, guessing correction was not applicable because of ceiling level accuracy on target absent trials. At this point it is worth noting that by contrast to the uneven spread of set sizes in Experiment 3 in Chapter 2 (see Figure 2.5) the spread of set sizes in Experiments 4, 5a and 5b is fairly even at least when a guessing correction analysis was performed. This difference perhaps can be attributed to the size of the stimuli, the space between them and to the fact that in Experiments 4-5b only half of the distracters had the critical feature. In summary, across 3 experiments I found no evidence for an interaction between set size and mask duration if performance levels were constrained below ceiling, even though each of these variables always produced an independent significant effect.

These results replicate and extend the findings of Experiments 1-3; when performance is not constrained by ceiling the interaction between set size and mask duration is not significant regardless of whether the observers have to detect or discriminate a target. It is, of course, possible that under conditions different from those tested in the present experiments an interaction between these two factors can be found. But the results indicate that the interaction is certainly not a hallmark of OSM and, therefore, it need not be an essential part of any theoretical account of how OSM is produced.

At this juncture it is worth commenting on a study that shows an interaction between set size and the asynchrony between target and mask onsets. In their Experiment 3, Enns & Di Lollo (1997) presented for 30 ms one or three diamond shapes that lacked either a left or right corner. Appearing around the target shape for 30 ms – and designating it as the target – were four dots that could onset between 300 ms before or after target onset. The dots had relatively little effect when only a single shape was presented. However, when three shapes were presented the dots interfered with reporting of the target at even the longest stimulus onset asynchronies (SOAs) for parafoveal locations and also impaired reporting of a centrally located target at intermediate SOAs. This result amounts to an interaction between set size and SOA because SOA affects performance with three shapes but not with one. However, the variable SOA of a brief 30 ms mask is not the same as the variable duration of a mask which onsets simultaneously with the target, as in the present studies and those of Di Lollo et al. (2000) and many other investigators (e.g. Goodhew et al., 2012, 2011a; Kotsoni, Csibra, Mareschal, & Johnson, 2007). In the SOA case, the dots may due to their abrupt onset cause processing of the target to be terminated by capturing attention towards themselves. Indeed, Enns & Di

Lollo (1997) reported that their data could be partly explained by attentional capture. Attentional capture, however, is different to the re-entrant processing account proposed by Di Lollo et al. (2000). Other authors have also argued that four dot masking can result from attentional capture by the mask (Neill, Hutchison, & Graves, 2002; Tata & Giaschi, 2004), or that attentional capture may be one of several mechanisms by which four dot masking may come about (Bischof & Di Lollo, 1995; Guest et al., 2012; Kahan & Lichtman, 2006; Tsotsos, 1990).

What are we to make of our failure to find an interaction of set size and mask duration with common onset four dot masking? In the original re-entrant processing account of Di Lollo et al., the crucial factor in determining OSM is held to be the speed with which two dimensional spatial attention can be focused on the target. When the target can be rapidly located because it is one of very few items, or even the only item, in the display, there is said to be little interference from involuntary processing of distractors. Because spatial attention focuses more rapidly on the target, processing of it will be more advanced by the time it offsets, so the representation of it will be more developed and less likely to be substituted by a representation of the mask object in the course of continuing iterative re-entrant processing. The two factors supposedly have multiplicative effects on the probability of substitution during this period, so causing an interaction. The present evidence is that set size and mask duration do not interact except when performance is compressed by a ceiling (or floor) effect. In fact, what my results show is that the two factors have additive rather than multiplicative effects which suggests that something is incorrect in the re-entrant processing account of OSM.

At this juncture, it is worth noting that supporting the idea that attention interacts with mask duration to determine the extent of OSM, and counting against the assumption of additivity, are reports that OSM is absent or greatly reduced when, as the result of a local cue, spatial attention can be pre-focused on the location of the target (Di Lollo, et al., 2000, Experiment 6; Enns, 2004, Experiment 3; Luiga & Bachmann, 2007, Experiments 1 and 2; Tata, 2002, Experiments1 and 2). In Chapter 5 I will investigate this possibility by having a radial line cueing the target.

The object updating account

An alternative to the original re-entrant processing account of OSM by Di Lollo et al (2000) is the object updating account first proposed by Lleras & Moore (2003) and since supported by a range of other findings (e.g. Guest et al., 2012). According to the updating account, in experiments in which OSM is observed the trailing mask is thought to be perceived as a transformation, or updating, of the target rather than as a new and different object that replaces it. Under common onset conditions, the mask and target are not initially individuated as separate objects but are represented as a single object because of their close spatio-temporal proximity. The offset of the target is treated as a transformation of this single object. The longer the mask remains present after target offset, the more likely it is that the features of the original target-plus-mask will be overwritten by those of the mask alone. The updating, or individuation, account, like the original re-entrant account, emphasises the dynamic nature of visual representations. Visual features from the lower levels of the system are fed forward to higher levels, where they either confirm an already activated object/event representation or, if sufficiently discrepant with that, they trigger the creation of another representation. However, the emphasis in updating is somewhat different from in the original account, and although spatial attention has been held to modulate the process of updating (Oriet & Enns, 2010), this may not necessitate commitment to an interaction between set size and mask duration. A finding of relevance to the present argument is that pre-view of the search display before the target item is indicated by onset of the 4DM (or square mask) reduces OSM (Guest et al., 2012; Tsotsos, 1990). The same is true for pre-view of the mask. These findings can be accommodated by the updating account in that a temporal disparity between target onset and mask onset increases the probability the target and mask will be individuated, and so represented as separate objects rather than as a single object. This in turn means that offset of the target will not be processed as a transformation of a single continuing object, and the target features will not be subject to over-writing by features of the mask.

A final study of relevance to the issue of how attention does or does not affect OSM when it is set size modulated was reported by Dux et al. (2010). Their experiment was concerned with whether engaging anterior brain regions, thought to play a role in re-entrant processing, would impact on the extent of OSM. Participants saw a sequence of four digits presented at fixation for 500 ms each, with an inter-stimulus interval of 500 ms. After a further 100 ms or 600 ms, a circle with a gap surrounded by four dots also appeared at fixation for 10 ms, and the dots either offset simultaneously with the single circle or trailed it for 200 ms. In blocked trials, participants either did an arithmetic calculation on the digits before reporting the orientation of the target gap or reported only the latter. Relative to simultaneous mask offset, delayed mask offset reduced performance in all conditions, an OSM effect. The surprising finding, however, and relevant to the present discussion is that a masking effect was obtained even when only a single target was presented, and that at fixation. This means that contrary to what Di Lollo et al. (2000) reported OSM in Dux et al.'s study did not require diffuse attention. This is consistent with the data from Experiments 3-5b in which OSM was obtained even for a single item although this was not at fixation as it was in Dux et al.'s study.

Conclusion

Across six experiments (including those from Chapter 2), I have presented evidence that set size and mask duration do not interact to produce OSM. I suggest that previously reported interactions of these two factors have resulted from ceiling level accuracy having compressed the data for some conditions. If the effect of set size indexes the speed with which attention reaches the target location, then the absence of an interaction with mask duration suggests that speed of attention to the target is not a critical factor in determining OSM, as supposed in the original re-entrant processing account of Di Lollo et al. (2000). It is often thought that the literature on OSM provides two lines of evidence for the importance of speed of attention to the target, one concerning the interaction of set size and mask duration, the other concerning the effect of pre-focusing attention on the target. I will return to consideration of the second of these in Chapter 5. With regards the former, my detailed review of the relevant literature and the results of the five experiments that have been reported reveal the supposedly supporting evidence to be either weak or open to alternative interpretation. More generally, the analysis of the literature and my experimental findings demonstrate how important it is to take ceiling effects into account when interpreting data on visual cognition.

Although the contrary has been widely assumed in regard to OSM, it could be that the set size effect does not reflect time for attention to locate the target but is, in fact, solely a function of crowding, the effect of which might well be additive with the effect of mask duration (Argyropoulos, Gellatly, & Pilling, 2013). Di Lollo et al. considered that the spread of set size points at zero trailing mask duration (see Figure 3.1) was due to crowding but argued that the increase in spread as mask duration was made longer indexed the interaction of mask duration with the delayed arrival of attention at the target for larger set sizes. However, if, as seems likely, the spread at zero mask duration is compressed by a ceiling effect, then the statistical interaction they obtained is an artefact. Assuming additive effects of set size (mediating crowding) and mask duration would seriously undermine the re-entrant processing account, and particularly its computer model instantiation, CMOS, which dictates an interaction between the two factors. In the next chapter I will investigate if the set size effect in OSM is in fact due to crowding.

Chapter 4

Crowding

Introduction

In Chapters 2 & 3 it was shown that, contrary to what has been previously reported, set size did not interact with mask duration; increments of the number of displayed items did not affect the magnitude of masking. An interpretation of this finding was that attention (as mediated by set size) might not play a role in OSM. This interpretation was based on the assumption that set size stands as a proxy for the speed with which attention is deployed towards the target (Di Lollo et al. 2000). This assumption itself could be faulty; perhaps what modulates the speed of attention is not the number of distractors in the search display but rather how close or far these are from the target. If distractors are positioned close to the target it may take longer for attention to separate and isolate the target from the nearby distractors compared to when the distractors are positioned further away from the target. Thus, it may be the spatial proximity between the target and the distractors that affects the speed with which attention is deployed towards the target and thus affects OSM. That the spatial proximity between the target and the distractors affects target perceptibility when these are presented in the peripheral visual field is a phenomenon called crowding (Bouma, 1970, 1973; Levi, 2008; Pelli, Palomares, & Majaj, 2004; Whitney & Levi, 2011).

In this chapter the role of crowding in OSM will be investigated. It will start with a description of what crowding is, what are the factors that influence its magnitude and how it has been used to explain some of the effects observed in OSM studies (e.g. Di Lollo et al., 2000). A series of experiments will follow in which the role of crowding in OSM will be explored. Finally, the findings from these experiments will be discussed in relation to the role of attention in OSM.

Crowding

Crowding generally refers to the detrimental effect of stimuli that flank a target at close distance when they (target and flankers) are presented to the peripheral visual field[4]. Its defining characteristic is the spatial interactions between the target and the flankers. In his seminal work, Bouma (1970) varied target eccentricity and the space between the target and two flankers presented peripherally in the visual field. Bouma reported that letter identification accuracy decreased when the distance between the flankers and the target was approximately half the distance between the target and the fixation point (0.5E where E = Eccentricity). Thus, to identify correctly a target presented at 3° eccentricity, no other items should be present within 1.5° distance from it. Although there are small variations between studies about the distance between the target and the flankers relative to the target eccentricity ((e.g. Andriessen & Bouma, (1976) and Wilkinson, Wilson and Ellemberg (1997) reported a distance of 0.4E whereas Pelli, Palomares and Majaj (2004) reported that in some of their data the distance dropped to 0.3E)), the existence of a “critical spacing” between the target and the flankers has been a constant finding in crowding studies and it is often known as Bouma’s law (Latham & Whitaker, 1996; Levi et al., 2002; Strasburger et al., 1991; Tripathy & Cavanagh, 2002; but also see Whitney & Levi, 2011).

Once crowding is obtained, its magnitude depends on a number of factors.

[4] Whether crowding occurs in fovea has been an issue of debate; a number of studies have shown that crowding does occur in foveal vision (but only at distances as small as 4-6 arc min, e.g. Flom, Heath, & Takahashi, 1963; Liu & Arditi, 2000; Toet & Levi, 1992) but others have questioned if crowding in fovea is genuine (Levi, Hariharan, & Klein, 2002; Levi, 2008) and Strasburger, Harvey and Rentschler (1991) argued that crowding does not operate in fovea at all.

For instance, the location of flankers relative to the fovea has been found to modulate the crowding effect such that letter flankers that are positioned further away from the fovea exert more crowding than letter flankers closer to it (Bex, Dakin, & Simmers, 2003; Bouma, 1970, 1973; Chastain, 1982). The level of similarity between target and flankers is also a well established factor in crowding. For instance in Kooi, Toet, Tripathy and Levi's (1994) experiments the target was matched to the flankers on a number of dimensions. When target and flankers were identical in shape, depth or contrast polarity crowding was stronger and more extensive than when they were different. A similar effect was obtained with manipulations of colour but this was not present for all participants. Also, supporting the idea that target – flanker similarity leads to impaired performance are studies that showed an enhanced crowding effect when the two types of stimuli were matched in orientation (Andriessen & Bouma, 1976; Hariharan, Levi, & Klein, 2005; Leat, Li, & Epp, 1999; Levi et al., 2002) or spatial frequency (Chung, Levi, & Legge, 2001).

There have been a number of suggestions as to what causes crowding. One suggestion has been that the activity of neurons that detect a visual item (e.g. a target) can be suppressed by the presence of similar stimuli in nearby spatial locations (e.g. flankers) (Cavanagh, Bair, & Movshon, 2002; Chao-Yi & Wu, 1994). An alternative account is based on the concept of feature integration. A feature is the most elementary component of a visual item such as a line, a dot or a colour (Graham, 1980) the detection of which is carried out by specialised independent neurons or groups of neurons called feature detectors (Hubel & Wiesel, 1962). Each feature detector has its own receptive field, the size of which varies; detectors that respond to stimuli located further into peripheral vision have larger receptive fields than those that respond to stimuli that are at or closer to the fovea. When an isolated target stimulus is presented in peripheral vision its individual components are very likely to be "captured" successfully by the receptive fields of the corresponding feature detectors. In crowded conditions, however, because their receptive fields are large (and so with poor spatial resolution) these detectors will also capture components from the nearby flankers which are then combined to form an amalgam of features from both the target and its surrounding flankers. This feature assimilation is accomplished over a region called the integration field (Pelli et al., 2004), the size of which varies with target eccentricity but not with target size and it has as its centre the target (Toet & Levi, 1992). Importantly, in such conditions it is not that the target signal is lost or overwritten by that of the flankers but rather that the flankers' features integrate with those of the target. Thus, in crowding, although the target is detectable, discriminatory identification of it suffers due to imprecise segregation and binding of its individual components. Or, in other words, although a token representation of the target is established there is a failure to bind appropriate features to it to produce an accurate representation.

With these crowding characteristics in mind one may be tempted to draw parallels between crowding and masking. After all, both phenomena reflect the failure of the visual system to discriminate a target in the presence of irrelevant stimuli in the visual field. Despite the fundamental difference that masking at least sometimes affects both target detection and discrimination whereas crowding is observed mostly in tasks that involve target identification (Levi et al., 2002; D G Pelli et al., 2004; but also see Põder, 2008, who reported crowding effects in a detection task when there were enough flankers), there are indeed striking similarities and analogies between the two phenomena. For instance, as was mentioned earlier, one of the ways that backward visual masking operates is through the integration of the mask's and the target's properties into one percept. This is not very different from the signal averaging hypothesis of crowding in which the target's and flankers' signals are combined rendering the target indiscriminable. Also, both phenomena appear to exhibit both spatial frequency and contrast sensitivity (Chung et al., 2001). There is also an anisotropic analogy (inward – outward flanker asymmetry) in OSM; a four dot mask positioned peripherally to a target (and thus further from the fovea) exerts larger masking than a mask positioned centrally relative to the target (closer to the fovea) (Jiang & Chun, 2001a).

Given the similarities between the two phenomena it is worth considering whether crowding may sometimes be observed in visual masking tasks, especially in tasks that exert OSM. Di Lollo et al. (2000) did consider, in reporting the results of their Experiment 1, that crowding might have been a contributing factor. They argued that in larger set sizes the target was more likely to be crowded. This would result in the visual system being unable to accurately process the target without processing the nearby distractors. They argued that in their common offset conditions the spread of the data points for the different levels of set size reflected a decrement in performance attributable to crowding. But they also argued that the increasingly large effect of set size that was observed as mask duration increased could not be explained solely by crowding. However, as pointed out in Chapter 2, because in the common offset condition performance was at or close to ceiling for all set sizes, the spread of the data points was compressed. It is therefore possible that in Di Lollo et al.'s experiments the difference in performance between set sizes in the common offset condition should actually have been larger than what Di Lollo et al. observed. As we saw in the previous two chapters, when care is taken to avoid ceiling and floor limits on performance the effect of set size is constant across mask duration. However, since larger set sizes are, as Di Lollo et al. observed, likely to be associated with an increased probability of crowding, there is the possibility that crowding is actually the cause of the set size effect.

Before I proceed to consider this possibility further, it is necessary to address the question of whether Di Lollo et al.'s experimental set up was indeed susceptible to crowding. In their experiments the items were presented in a 4x4 matrix with a radius of 2.8°. This means that for the largest set size (i.e. sixteen items) the stimuli occupied all the sixteen positions of the matrix with an inter-stimulus spacing of 1° horizontally and vertically and 1.4° diagonally. Therefore, in this condition the target was always flanked by at least 3 items that were falling within half the target eccentricity causing crowding. For smaller set sizes (even for set size of two), however, it is difficult to know whether crowding occurred; there were perhaps trials in which the distractors have been positioned at locations such that they were causing crowding whereas in other trials the distractors might have been located further away from the target and therefore they did not interfere with the target.

Having shown that targets in Di Lollo et al.'s experiments were likely subject to crowding (at least for the largest set size) an analysis that Di Lollo et al. performed on their Experiment 1 can now be reviewed. In that analysis they divided the 4x4 matrix into three concentric parts with the inner part having a radius of 0.7°, the middle 1.6° and the outer one (the four corners of the matrix) 2.8°. When they ran an analysis with eccentricity as a factor they found that eccentricity interacted with masking such that when the target was presented further from the fovea steeper masking functions were observed. One could argue that this result just confirms the well established eccentricity effect in visual search (Carrasco, Evert, Chang, & Katz, 1995; Wolfe et al., 1998). However, another way to see it is that increments of eccentricity resulted in the critical space between the target and the flankers becoming larger (i.e. for the equation “Critical Spacing = 0.5*E”, a larger eccentricity (E) increases the critical spacing between target and flankers). Thus, two items flanking a target at a given distance in the inner circle may result in little or no crowding. If however the same target – flankers configuration (and their separation) is presented in the outer circle then it may be likely that they (the distractors) will fall within the critical distance of 0.5E and exert crowding. In other words, in Di Lollo et al.'s experiments, set size may have not been a proxy for the speed with which attention becomes focussed on the target. Instead, it may have been a proxy for the likelihood that a distractor(s) will fall within the critical space and produce crowding of the target. If that were the case, then the absence of an interaction between set size and mask duration might be uninformative about the role of attention in OSM.

At this juncture it is worth commenting on a study which although focused on a separate issue – namely, whether the masked target could be recovered from OSM with prolonged mask durations – produced findings which suggest that set size is in fact a proxy for crowding. In Goodhew, Visser, Lipp and Dux’s (2011a) Experiments 1A and 1B the target – a Landolt C – was presented either in isolation or along with 15 Landolt C distractors for 10ms. Each Landolt C had the gap either to the left or to the right. A common onset FDM that cued the target disappeared either along with the target or it lingered for up to 640ms (in Experiment 1A) or for up to 1000ms (in Experiment 1B) after the target offset. The task was to report the location of the target's gap (i.e. left or right). The data replicated the purported interaction between set size and mask duration. But, similarly to Di Lollo et al.'s (2000) data, scores for target alone trials (i.e. set size of one) in the common offset condition were at or close to 100%. For set size of sixteen performance was also close to ceiling in the control condition. It is therefore possible that – once again – the scores for both set sizes were compressed by a ceiling obscuring a potentially wider spread of the set size data points in the common offset condition. Evidence in favour of this interpretation comes from their Experiments 2A and 2B. In their Experiment 2A the participants were untrained and naive to the purpose of the study. This experiment was identical to their Experiment 1A except that the target display duration was now 100ms. Their data showed that scores in the control condition (common offset) dropped below 70% when the target was flanked by distractors. The authors did not consider that crowding mechanisms might have caused the low scores in the latter condition. Instead this performance was attributed to the task difficulty with set size 16, and when, in their Experiment 2B, the number of flankers was reduced from 15 to 8 to make the task easier for the observers performance was increased. But this improvement in performance may not be due to the smaller set size employed in that experiment. Instead, it may well be that the smaller set size resulted in an increased spacing between target and flankers (a feature of the experimental set up which the authors also reported) and, thus, the release of the target from crowding (or that it was less crowded). However, because not enough information was provided about the distance of the stimuli from fixation and the inter-stimuli spatial properties it is difficult to draw any firm conclusions as to when and how crowding may have been involved and if set size and crowding were confounded.

In summary, it is not clear from Di Lollo et al.'s study to what extent crowding is involved in OSM. This is because in their experiments crowding was confounded with set size and could even have caused the observed set size effect. Indeed, the effect of set size in visual search is influenced both by attentional and sensory factors (Palmer, 1994). Sensory factors include multiple eye fixations in displays with many items (Irwin, 1991; Rayner & Fisher, 1987), eccentricity effects (Yager & Davis, 1987) and crowding (Verghese & Nakayama, 1994). For instance, Verghese and Nakayama (1994) probed target detection performance as a function of target discriminability, display duration and set size. In each of three Experiments the target differed from the distractors on one unique dimension; the target was either a vertical line (among non vertical lines), or a green square (among non-green squares) or a grating with a unique (relative to the distractors) spatial frequency. In each trial the target appeared in one of three concentric rings; the first ring comprised of 6 items, the second of 12 items and the third of 18 items. After various target display durations, masks appeared at every item's locations for either 60ms or 120ms. The task was to report the presence of the target item in the display. The researchers found large set size effects for orientation and spatial frequency differences but a very small effect in the colour task when the colour difference between the target and the distractors was a small one (i.e. that target was less discriminable from the distractors). For the latter dimension difference the authors repeated the task but this time they manipulated the inter-stimulus spacing as well as the presence of distractors. The data showed that there was a main effect of inter-stimulus spacing and a larger (compared to the initial colour task) set size effect when the target colour was not very different from that of the distractors. Palmer, Verghese and Pavel (2000) argued that this result showed that the inter-stimulus spacing (i.e. crowding) interacted with set size when compared with the initial colour task; decreasing the spacing between the target and the distractors resulted in larger set size effects. I will return to this theme in the Discussion section.

Finally, it is worth noting that the results of Experiment 3 provide a strong hint that the set size effect may at least sometimes be reducible to crowding. In that experiment, performance differed only a little for set sizes 1,4 and 8 but was some 20% lower with 16 items (although as noted in the discussion of Chapter 3 set sizes in Experiments 4-5b were more evenly spread than in Experiment 3). This suggests that only in the latter condition were adjacent stimuli within the critical distance required to produce a reliable crowding effect.

In the experiments that will follow, set size was manipulated while controlling for crowding. For each set size, on some trials the target is crowded and on others it is not. It is predicted that performance will be worse for crowded targets than for uncrowded targets. Furthermore, if the set size effect is in fact due to crowding then a set size effect should not be observed in such a task in which crowding is kept equivalent for different set sizes. A major point of interest is whether either crowding or set size will interact with mask duration. Given that an interaction between set size and mask duration was found in Experiments 1 – 5b only when a ceiling effect was present the expectation is that the present experiments will replicate and confirm these earlier findings. Similarly, if the set size effect is actually caused by greater crowding with larger set sizes, then crowding also should not interact with mask duration.

Experiment 6

The present experiment employed a four alternative discrimination task and it was very similar to Experiments 1 to 3 of the present paper. The stimuli were presented in a virtual circle so target and flanker eccentricity was constant. The critical manipulation was that across all levels of set size, on half of the trials the target was flanked by two distractors and on the other half it was not (henceforth termed the crowded and uncrowded conditions, see Figure 4.1).

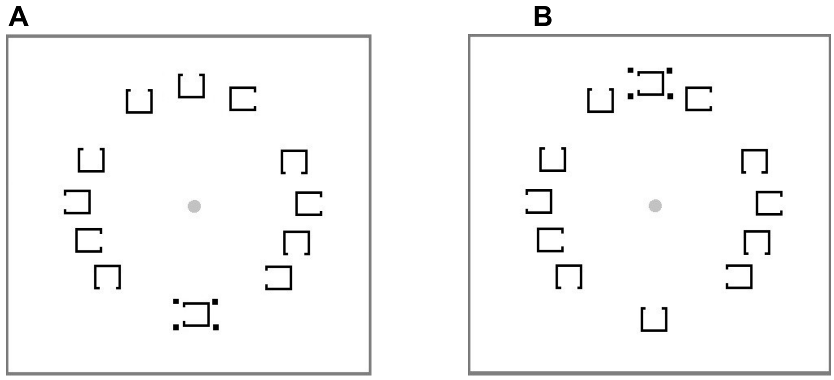

Figure 4.1: S*chematic representation of the uncrowded and crowded trials in Experiment 6 for set size twelve. A) Example of an uncrowded trial. The target (as marked by the four dots) was presented in isolation and three distractors were always positioned opposite the target on the circular array with the positions adjacent to them being left blank. B) Example of a crowded trial. The target was flanked by two items and a third one was presented opposite the target in the circular array. The positions adjacent to the distractors that were crowding the target were left blank as well as the positions adjacent to the distractor opposite the target.*

Method

Participants were 14 undergraduates (11 females) with an average age of 19.1 years (s.d.= 1.8). All participants reported normal or corrected-to-normal visual acuity. They were recruited from the OBU Psychology Department Participants Panel and received course credits for taking part in the study.

On any given trial, the display consisted of 4, 8 or 12 squares occupying 16 possible positions on a circular array. Each square had a gap in the top, bottom, left or right side. The side of the gap was randomised. The centres of the squares were equally spaced around the circumference of a virtual circle with radius 2.98°. On each trial one of the items was surrounded by four dots (the mask), which also served as a cue to single out the target. The mask always onset simultaneously with the target and the distractors; all these stimuli then either offset together (blank frame) or the mask lingered for 60ms or 180ms. In each trial the target could either be crowded or uncrowded. In the uncrowded trials three of the distractors were always presented opposite to the target on the circular array and on trials in which there were more than four items, the rest of the distractors were occupying some of the remaining 12 positions on the array with the restriction that the positions either side of the target as well as the positions immediately next to the distractors opposite the target were left blank (see Figure 4.1A for example of an uncrowded trial with set-size 12). In these trials the centre of the nearest distractor square was at least 2.03° away from the centre of the target square. In the crowded trials the positions immediately to the left and to the right of the target were always occupied by a distractor and there was always as a single uncrowded distractor opposite to the target. The positions next to the distractors flanking the target as well as the positions immediately before and after the distractor opposite to the target were left blank when there were more than 4 items in the display. On these trials, the centres of the nearest distractor squares were 1.01° away from the centre of the target square (see Figure 4.1B for an example crowded trials with set-size 12).

The spatial properties of the stimuli were identical to those in Experiments 1 – 3 with the exception of the gap in each square which was 0.15° (this was midway in size between those of Experiment 1 and 3); this size was selected, on the basis of the data of those studies, in an attempt to avoid floor performance in the crowded trials and ceiling effects in the uncrowded trials.

Each participant underwent 540 trials which resulted from the factorial combination of 3 set sizes (4, 8, 12 items) x 3 mask durations (0, 60ms, 180ms) x 2 crowding conditions (crowded / uncrowded) x 30 trials per condition. 18 demonstration trials with extended frame durations (to ensure participants fully understood the task) and 36 practice trials preceded the main experiment. Every 60 trials the computer prompted the participants to have a brief break. The total duration of the experiment was approximately 50 minutes. At the beginning of each trial a gray disk (luminance level of 18.95 cd/m2) appeared in the centre of the screen with a radius of 0.1° for 500ms. The disk then appeared bigger in size (radius 0.4°) and it immediately shrank to its original size over the course of 800ms and remained on the screen as such until the end of the trial. This method was expected to capture participants' attention to the centre of the screen (and hence of the circular array) and control eye movements at the beginning of each trial. The target and the distractors then appeared on the screen followed by a frame that was either blank – common offset condition - or contained only the trailing mask for 60 ms or 180 ms. Participants were instructed to press one of four arrow keys on a computer keyboard if they thought that the gap was on the right, left, top or bottom side of the target-square. Participants were informed that accuracy not speed of response was of importance.

Results and Discussion

Illustrated in Figure 4.2 are mean percent correct responses as a function of set size and mask duration when the target square was uncrowded (left side of the graph) and when it was crowded (right side of the graph). Chance performance is 25% correct. The data were analysed in a three way repeated measures ANOVA with set size, mask duration and crowding as within subjects factors. Results from the ANOVA showed significant main effects of crowding ($F(1, 13) = 44.1$, $p < .0001$, partial $\eta^2 = .77$) and mask duration ($F(2, 26) = 47.05$, $p < .0001$, partial $\eta^2 = .78$) but not of set size ($F(2, 26) = 1.87$, $p > .05$). None of the interactions between crowding and set size, set size and mask duration ($F < 1$, $p > .05$ in both cases) nor the three way interaction between these factors ($F(4, 52) = 1.43$, $p > .05$) was significant. The interaction between crowding and mask duration approached but did not reach significance ($F(2, 26) = 2.6$, $p = 0.9$).

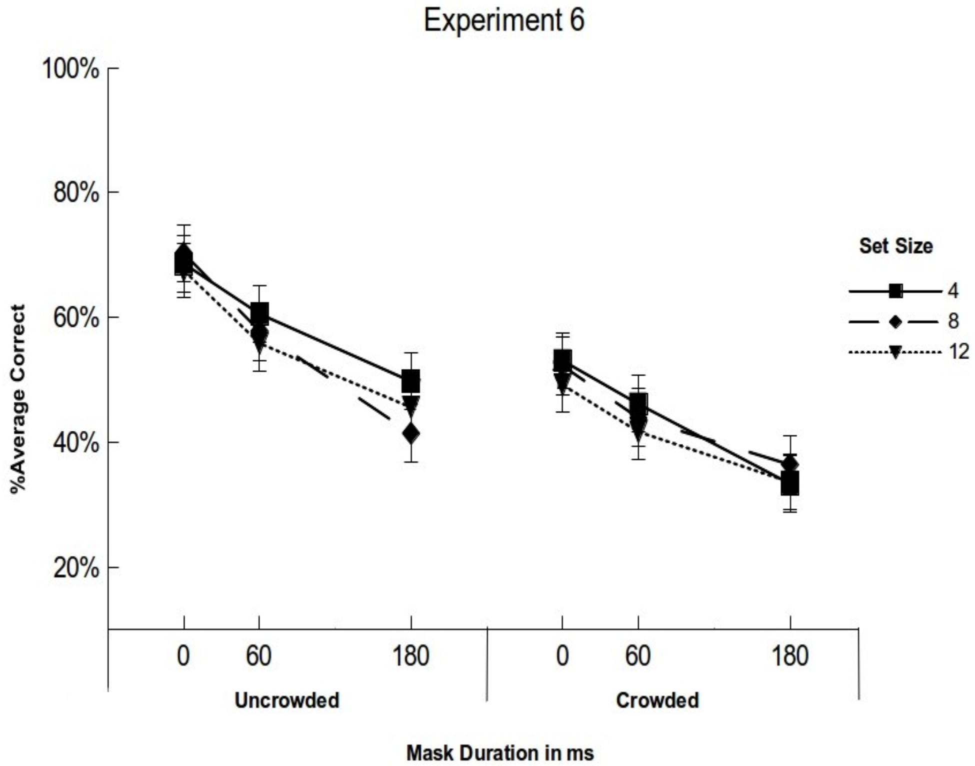

Figure 4.2. *Mean percentage correct identification of the location of the gap in the target in Experiment 6. The horizontal axis denotes the trailing mask duration and it is divided into scores for trials on which the target square was uncrowded (left part of the graph) and scores for trials on which the target square was crowded (right part of the graph). The lines denote the three set sizes.*

Although none of the participants scored more than 87% in any condition there were participants whose average performance was close to floor (i.e. 25%). To ensure that floor effects were not having an influence on the results, the data from participants who scored was less than 33% on any condition were excluded from a further analysis. An ANOVA on the data of the remaining 12 participants showed the same pattern of findings; there were significant main effects of crowding ($F(1, 11) = 60.72$, $p < .0001$, partial $\eta^2 = .85$) and mask duration ($F(2, 22) = 44.38$, $p < .0001$, partial $\eta^2 = .80$) but not of set size ($F(2, 22) = 1.94$, $p > .05$). There were also no significant interactions between crowding and set size, set size and mask duration ($F < 1$, $p > .05$ in both cases) or a three way interaction between these factors ($F(4, 44) = 1.18$, $p > .05$). The interaction between crowding and mask duration approached but it did not reach significance ($F(2, 22) = 2.27$, $p > .05$).

The first thing to be observed is the significant difference in performance between crowded and uncrowded trials such that observers were better at discriminating the target when it was uncrowded (55% overall performance collapsed across mask durations and set sizes) than when it was not (41%). This is in line with the crowding literature confirming that when a target is flanked by distractor items it becomes difficult to identify, and it demonstrates that the crowding manipulation employed here was highly effective. The most important finding however was that variation in the number of distractors did not affect discrimination performance. When crowding was controlled, the set size effect vanished for both crowded and uncrowded trials, which supports the conjecture that the set size effect in tasks that exert OSM is actually due to crowding, which would be tightly correlated with set size. This finding has important implications for the interpretation of the results of Experiments 1 – 5b. Earlier, I suggested that the absence of an interaction between set-size and mask duration could be taken to indicate that, contrary to previous claims, attention does not play a role in OSM. However, this interpretation assumed, along with previous authors, that set size can be regarded as a proxy for the speed with which attention contacts the target. However, if as it turns out set size seems to be a proxy for crowding then the absence of an interaction with mask duration says nothing about the possible involvement of attention in OSM. We return to this theme in the next chapter. However, before embracing the conclusion that set size is a proxy for crowding, it is necessary to consider a part of the data that may offer the grounds to question the validity of that inference. On crowded trials, performance was low and at 33% for the longest mask duration, it was close to chance level irrespective of set size and despite the fact that the gap size was chosen to avoid such an effect. This close to floor performance may have obscured further patterns (i.e. a set size effect or even interactions between factors) that might otherwise have been observed and could challenge the conclusion that crowding is the main contributor to OSM. A further important aspect of the data is that mask duration did not interact with crowding, although the interaction's F-ratio did approach significance. It appears that whether or not the target was flanked by distractors did not have an effect on the magnitude of masking. However, because this would be an important finding, it is worth seeing if it is one that replicates.

Experiment 7

Experiment 7 was identical to Experiment 6 except that it used a larger stimulus gap in order to raise the level of performance well clear of “floor”. As in Experiment 2, a whole side was missing from each square item. Furthermore, the number of participants was also raised to increase the power of the experiment relative to Experiment 6.

Method

There were 23 psychology undergraduate participants (19 females) with an average age of 23.1 years (s.d. = 8.9). They were recruited from the OBU Psychology Department Participants Panel and received course credits for taking part in the study. Stimuli were identical to those used in Experiment 6 except that instead of each square having a small gap in one of its sides, a whole side was missing. The procedure was identical to that in Experiment 6.

Results and Discussion

Figure 4.3 shows mean percentage correct responses for each combination of set size and mask duration when the target square was uncrowded (left side of the graph) and when it was crowded (right side of the graph). None of the participants had a score for any condition above 90% or below 33%. The data were analysed in a three way repeated measures ANOVA with set size, mask duration and crowding as within subjects factors. Results from the ANOVA showed significant main effects of crowding $F(1, 22) = 218.93$, $p < .0001$, partial $\eta^2 = .91$), set size ($F(2, 44) = 33.30$, $p < .0001$, partial $\eta^2 = .60$) and mask duration $F(2, 44) = 130.51$, $p < .0001$, partial $\eta^2 = .86$). The interactions between crowding and mask duration ($F(2,44) = 1.87$, $p > .05$), set size and mask duration ($F(4,88) = .82$, $p > .05$) and the three way interaction between these factors ($F(4,88) = 1.63$, $p > .05$) were non-significant. The interaction between crowding and set size only approached but did not reach significance ($F(2,44) = 2.91$, $p = .07$).

Collectively, the data show that the omission of a whole side resulted in an increased performance relative to Experiment 6 for both when the target was crowded and when it was uncrowded. Discrimination scores for the longest mask duration in the crowded condition was not any more near to floor but this did not alter the main pattern of results found in Experiment 6. Furthermore, the interaction between crowding and mask duration, which was approaching significance in Experiment 6 with small number of participants, was still well short of significance with a larger number of participants in Experiment 7. Importantly, what was markedly different between the results of Experiments 6 and 7, was that for Experiment 7 there was a significant effect of set-size; overall discrimination performance was better with small set sizes than with large set sizes.

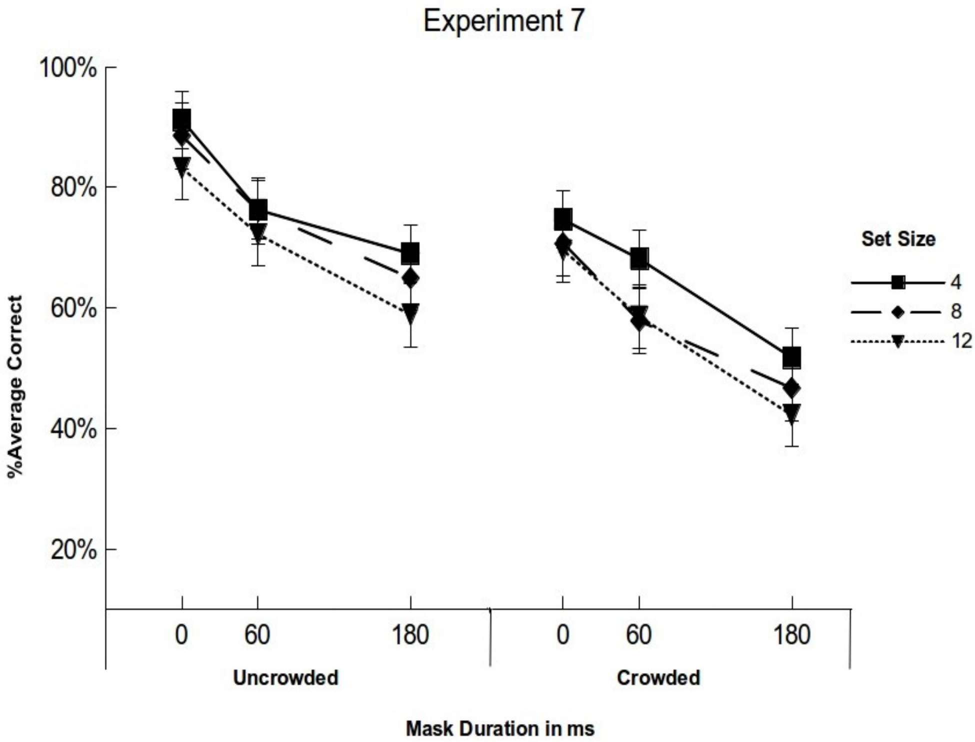

Figure 4.3. *Mean percentage correct identification of the location of the missing side in the target in Experiment 7. The horizontal axis denotes the trailing mask duration and it is divided into scores for trials on which the target square was uncrowded (left part of the graph) and scores for trials on which the target square was crowded (right part of the graph). The lines denote the three set sizes.*

Thus, according to the results of the present experiment, discrimination performance appears to be mediated by two separate factors that act independently on target discriminability, namely crowding and set size the effects of which were not significantly different in affecting performance ($t(22) = -.65$, $p > .05$). What are we to make of this set size effect? At a first glance it appears that it is in contrast to the findings of Experiment 6 and that it goes against our conjecture that the set size effect in tasks that exert OSM is due to crowding. However, an alternative interpretation is that distractors as well as the target might have contributed information to evidence accumulators that eventually determine which response was executed, or in other words, distractors might have competed with the target for control of the response (Colegate, Hoffman, & Eriksen, 1973; Eriksen & Colegate, 1971; Eriksen & Eriksen, 1971). With large gaps (whole sides missing), participants might have had trouble ignoring such information about distractors. So in the next experiment, such competition from distractors will be controlled by using distractors that are physically dissimilar to the target.

Experiment 8

Experiment 8 was designed to avoid any response confusion arising from the detection of the critical feature in distractors by decreasing the level of similarity between target and flankers. The experiment was identical to Experiment 6 except that instead of the distractors (but not the target) having a gap they were complete squares. The choice of the gap size used in Experiment 6 rather than that used in Experiment 7 was made with the intention to avoid possible ceiling effects in the uncrowded trials. Performance was close to ceiling for uncrowded trials in the control condition of Experiment 7 even though distractors were potentially confusable with the target and may possibly have caused some level of response confusion. Removing the possibility of response confusion by making distractors complete squares could have been expected to raise performance in the uncrowded condition even higher if the same gap size (one whole side missing) had been employed again. While this was the rationale for the choice of gap size in Experiment 8, in retrospect it is a flawed rationale. Since it was Experiment 7 that showed a set-size effect, whereas Experiment 6 did not, only a replication of Experiment 7 with complete square distractors could prove whether or not response confusion contributed to the effect. If a set-size effect was absent from Experiment 8, there would be no way of knowing whether this was due to the use of complete square distractors or to the use of the smaller gap size which failed to produce a set-size effect in Experiment 6. As we will see, however, the results of Experiment 8 were such that this design flaw ceased to be of relevance.

Method

For Experiment 8 nineteen participants (16 females) as previously described, but including also author IA as well as Prof. Angus Gellatly and Dr Michael Pilling, performed the experiment (average age = 24.05 years, SD = 10.96). The stimuli were the same as those in Experiment 1 but the disctractors (but not the target) were complete squares.

Results and discussion

Figure 4.4 shows mean percentage correct responses for each combination of set size and mask duration when the target square was uncrowded (left side of the graph) and when it was crowded (right side of the graph). None of the participants had a score for any condition above 90% or below 33%. The data were analysed in a three way repeated measures ANOVA with set size, mask duration and crowding as within subjects factors. Results from the ANOVA showed significant main effects of crowding $F(1, 18) = 85.99$, $p < .0001$, partial $\eta^2 = .83$, of set size $F(2, 36) = 12.62$, $p < .0001$, partial $\eta^2 = .41$ and of mask duration $F(2, 36) = 99.03$, $p < .0001$, partial $\eta^2 = .85$). There were no significant interactions between crowding and set size, crowding and mask duration or set size and mask duration, nor a three way interaction between these factors ($F < 1$, $p > .05$ in all cases).

The most important finding of the experiment was that even when the distractors (complete squares) were physically different from the target (Landolt square) both set size and crowding had independent effects on target discrimination performance. This result was important because it showed that the additive effects of set size and crowding on performance observed in Experiment 7 were unlikely to be due to a response competition between the target and the nearby distractors. Distractors in Experiment 8 did not have the salient feature that was present in the target (i.e. gap) and therefore it was unlikely that information about the distractors competed with the information about the target for control of response. In other words, the main effects of set size and crowding on performance found in Experiment 7 were not due to processing of distractor information feeding into evidence accumulators and influencing responses.

Given the close similarity between Experiments 6 and 8, it would be interesting to know what if any differences in their results would prove statistically significant. Therefore an omnibus ANOVA on the data of the two experiments was carried out with Experiment as a fourth independent variable. Results from the ANOVA showed significant main effects of experiment, $F(1, 31) = 6.61$, $p< .02$, partial $\eta^2 = .18$), crowding $F(1, 31) = 119.46$, $p < .0001$, partial $\eta^2 = .79$, mask duration $F(2, 62) = 136.46$, $p < .0001$, partial $\eta^2 = .82$, and set size $F(2, 62) =10.21$, $p < .0001$, partial $\eta^2 = .25$. Neither the 4-way interaction nor any of the 3-way or 2-way interactions involving the Experiment factor was significant. The experiment x crowding interaction approached significance, $F(1, 31) = 3.17$, $p< .09$, partial $\eta^2 = .09$, but for all other of these interactions F<2, and for most F<1. Of the other interactions, crowding x mask duration was nearest to significance, , $F(2, 62) = 2.24$, $p< .15$, partial $\eta^2 = .07$), with F<2 for crowding x set size and F<1 for the others.

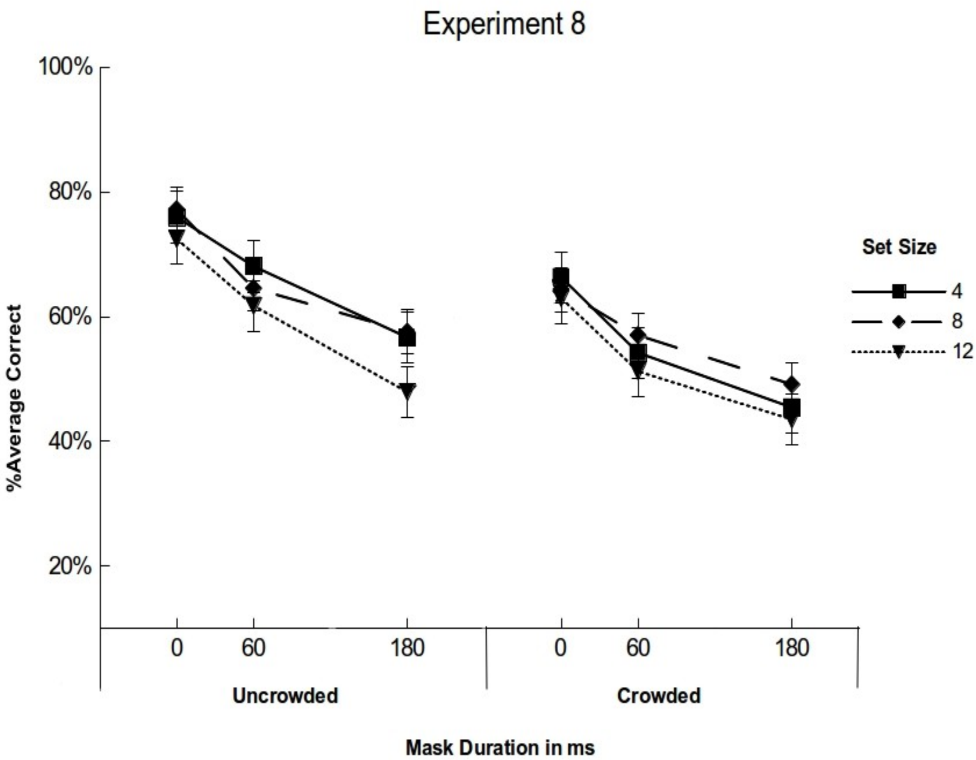

Figure 4.4. *Mean percentage correct identification of the location of the gap in the target in Experiment 8. The horizontal axis denotes the trailing mask duration and it is divided into scores for trials on which the target square was*

uncrowded (left part of the graph) and scores for trials on which the target square was crowded (right part of the graph). The lines denote the three set sizes.

General Discussion

Three experiments were reported in which the role of crowding in OSM was investigated. Experiment 6 supported the prediction that the set size effect in OSM is in fact due to crowding. Controlling the amount of crowding across set sizes resulted in the absence of a set size effect for both the crowded and uncrowded conditions. The low levels of discrimination performance at the longest mask duration, however, might have obscured the observation of further patterns in the data such as a set size effect. In Experiment 7, therefore, the critical feature was made easier to identify, and performance was raised. This led to a significant set size effect that was contrary to the findings from the previous experiment. It was conjectured that the set size effect might be due to high target – flanker similarity with respect to the critical feature to be reported, which might have resulted in response confusion errors. However, the effect was still present in Experiment 8 even when only the target and not the flankers contained the critical feature. Therefore, the additive effects of set size and crowding on performance observed in Experiment 7 were unlikely to be due to a response competition between the target and the nearby distractors. The result for Experiment 8 is unexpected given that in Experiment 6 the same gap size as that used in Experiment 8 was not associated with an effect of set-size, and this even though distractors in Experiment 6, unlike those in Experiment 8, were potentially confusable with the target. However, since we now have two experiments in which a set-size effect was obtained in addition to a crowding effect and only one in which it was not, it seems prudent to consider the lack of a set-size effect in Experiment 6 to have been a Type 2 error. An additional observation regarding the findings from all three experiments is that in none of them set size interacted with mask duration. Thus, they provide further support to the interpretation of the results of the Experiments 1 – 5b (Chapters 2 & 3) that attention (as mediated by set size) does not influence OSM.

Collectively, these findings tend to go against the hypothesis that the set size effect is in fact due to crowding. Both factors affected target perceptibility;

larger set sizes resulted in worse target discrimination performance compared to smaller set sizes, and when the target was uncrowded its discriminability was better compared to when it was crowded. Importantly, the two factors did not interact (although their interaction was close to significant in Experiment 8); increments in the number of distractors did not magnify the effect of crowding. Another important finding is that neither set size nor crowding interacted with OSM. The lack of an interaction between set size and OSM simply replicates the main finding in Experiments 1 – 5a. The lack of interaction between crowding and OSM, on the other hand, perhaps adds further support to the argument that attention is not a relevant factor in OSM; if we assume that crowding stands as a proxy for the speed with which attention contacts the target, then attention (as mediated by crowding) does not affect OSM. This finding, combined with the results of Experiments 1 – 5b suggest that attention does not play a role in OSM; although target perceptibility is influenced either by varying the number of distractors or by whether the target is crowded, OSM is unaffected by these manipulations. This, in turn, has important consequences for Di Lollo et al.s' re-entrant model of OSM in which attention has a central role.

At this point it is important to note that although the results showed that the effects of crowding and set size acted independently on target perceptibility, this lack of interaction may have been an artifact of the experimental set up. Although the design of the experiments was such that it was assumed that an equivalent degree of crowding was expected for all set sizes, as it will be discussed below, this assumption might have been incorrect.

Crowding, super-crowding and set size

Before I continue it is important to consider first the findings from Vickery, Shim, Chakravarthi, Jiang and Luedeman's (2009) study. In their experiments T-shaped items presented at various orientations served both as the target and as the distractors. In some trials the target was the only item on the display; on other trials the target was presented with four distractors which they were positioned at the four cardinal positions around the target. The task was to report the central T's (i.e. the target) orientation. Vickery et al. manipulated two variables; the distance between the target and the flankers, and whether the target was masked. In the masking condition the target was surrounded either by an outline white square (Experiment 1A) or by a white ring (Experiment 1B) whereas in the control condition the target was unmasked. The three types of stimuli (i.e. the target, distractors and the mask, if any) onset and offset simultaneously [5]. The observer' task was to report the orientation of the target. The results showed that in the control condition crowding was observed when flankers fell within 0.5E and performance reached an asymptote when flankers were falling outside of this critical space. The surprising finding however was when the target was masked crowding was observed further beyond the critical 0.5E and performance only started reaching an asymptote when flankers were presented as far as 0.7E. In other words when a target stimulus is masked, crowding is exerted from distractors that are placed beyond the typical crowding range (i.e. 0.5E). The authors reported that a larger critical spacing might have been possible had their screen size allowed them to present stimuli at larger distances. They speculated that the mask might have weakened the target's signal strength resulting in more feature integrators be employed, integrators which probably had a larger receptive field size and thus included features from more distant distractors. As discussed in relation to Experiment 7, however, an alternative interpretation could be that in some trials information about the distractors competed with information about the target for response control resulting in observers responding erroneously about the target's orientation.

What are we to make of this finding? If the four dot mask that was employed in my experiments led to a "supercrowding" effect like the one caused by a square or a circle mask in Vickery et al.'s study (2009), it may also explain the set size effect that was observed in Experiments 7 & 8. Despite my best efforts to control for crowding, it is possible that distractors that were placed further outside of what was considered to be the crowding zone had a deleterious effect on target perceptibility due to super-crowding mechanisms. Therefore, it is possible that in my experiments, in the crowded trials, crowding of the target was caused not only by the distractors that were positioned adjacent to the

5 Although having a mask offsetting simultaneously with the target cannot be considered as a masking condition the authors reported that in a preliminary study reporting the orientation of a "T" was better when it was presented in isolation (no mask and no distractors) compared to when the "T" was surrounded by a square (and no distractors). Therefore, although in this experiment the surrounding ring or square offset concurrently with the target the authors considered it to act as a mask. An alternative possibility is that the surrounding circle or square was crowding rather than masking the target.

target but also by distractors that were outside of the 0.5E distance, an argument that also extends to the uncrowded trials. Thus, when there were 12 items on the display, it was more likely that the target was crowded by more distractors than when 8 items were displayed whereas for set size of four the target was always crowded by only 2 items (it is highly unlikely that the isolated distractor that was positioned at 4 times the 0.5E critical distance from the target could cause any crowding of the target).

If a super-crowding effect was present in the present experiments it is perhaps important to consider whether there was also a set size effect within the, now extended, crowding range. A number of studies show that the crowding effect is insensitive to set size manipulations. For instance in Pelli et al.'s (2004) study target and flanker letters were presented for 200ms either at the centre of the screen or to the right of a fixation point at various eccentricities. In one condition the flankers consisted of either of one, two or four letters such that when they were four they were positioned to the left, right, above and below the target. Pelli et al. reported that when the number of flankers increased from 1 to 2 performance decreased significantly. For further set size increments however (i.e. from 2 to 4), performance was not worse than when the number of flankers was 2. Similar were the results from Wilkinson et al. (1997); they reported in one of their experiments that when the total number of gratings was reduced from 15 to 3, target discriminability performance did not significantly alter for the majority of the subjects. Furthermore, in Toet and Levi's (1992) study the target and the two flankers were the letter “T” and the observers' task was to judge the orientation of the target letter. In their first experiment they reported that in pilot measurements performance was not much better when there was a single item flanking the target compared to when there were two.

For studies such as those described above, however, the lack of an interaction between set size and crowding might be due to methodological issues. For instance, a possible explanation for the lack of set size effect in Pelli et al.'s (2004) study is that the additional flankers (i.e. from 2 to 4) were positioned radially to a target that was presented in the horizontal meridian. It is a well established finding that in crowding there is a radial – tangential anisotropy; when a target is presented in the horizontal meridian, flankers that are positioned horizontally (to the left and to the right of the target) cause stronger crowding effect than those positioned vertically. In addition, results from unreported pilot experiments in Pelli et al.'s paper (as cited in Felisberti, Solomon, & Morgan, 2005) showed that performance was worse for a nine item display compared to 2 item one. In contrast to Pelli et al.'s display set up, Strasburger et al. (Strasburger et al., 1991, Experiment 4) placed two flankers at either side of the target and a substantial set size effect was obtained even for flankers that were positioned outside of the crowded window. Similarly, a strong set size effect was obtained in Poder and Wagemans' (2007) study in which 2,4 or 6 Gabor patch flankers positioned randomly around the target. Finally, in Bouma's study a target letter was flanked either by another letter or by two letters at either side of the target. Correct identification responses suffered when the target was flanked by a single item (compared to when the target was presented in isolation) but performance deteriorated even further with the addition of the second item.

These studies show that varying the number of distractors that could potentially crowd the target has a detrimental effect on target perceptibility. Crowding is not an all-or-none process where target detection/discrimination depends simply on whether it is crowded or not. On the contrary, crowding appears sometimes to be sensitive to the number of items that flank the target. The set size effect in crowding is compatible with pooling models which predict that the target signal becomes weaker when the integration field includes signals from a large number of distractors such that the more items flank the target the more likely is that the target signal will be mingled with that of the distractors (although for letter stimuli the results are inconsistent (Poder & Wagemans, 2007).

A possible explanation for the lack of interaction between set size and crowding in the present experiments can now also be proposed. If masking the target resulted in more distractors being included in the crowding zone then the experimental manipulation of having crowded and uncrowded trials was in fact a manipulation of having crowded and less crowded (but crowded nevertheless) trials. Thus, the lack of an interaction between set size and crowding may simply reflect the absence of a full control (i.e. uncrowded) condition.

Conclusion

The aim of this chapter was to explore whether the set size effect reported in previous studies in OSM and in the previous chapters of this thesis was in fact an effect of crowding. Furthermore, a major point of interest was if crowding mediates the speed with which attention is deployed towards the target in OSM. Although the data of Experiment 6 appeared to suggest that the set size effect is due to crowding, this finding was not replicated in subsequent Experiments 7 & 8. In these experiments both factors independently affected discrimination performance but neither of them interacted with mask duration nor was there an interaction between them (although in Experiment 7 their interaction approached significance). It was suggested the lack of interaction between set size and mask duration might be interpreted as being the result of a super-crowding effect and that crowding might not have been fully controlled in my experiments. The lack of an interaction between crowding and mask duration, on the other hand, suggests that attention (if it is assumed to be mediated by crowding) does not influence OSM.

The finding that neither crowding nor set size influences OSM both within each experiment and when the data from Experiments 6 & 8 were aggregated is a significant one. Furthermore, combined with the findings of Chapters 2 & 3 that set size does not influence OSM strengthens further the conclusion that attention does not modulate OSM. Despite the converging evidence, however, these findings provide only indirect evidence that OSM is not influenced by attention. This is because attention in those Experiments was controlled in an indirect manner. It is possible that when spatial attention is manipulated in a direct manner, OSM may be affected by attention. In the next Chapter this possibility will be investigated.

Chapter 5

Spatial Pre-Cueing in OSM

Introduction

In Chapter 2 it was shown in three 4AFC experiments that attention (as mediated by set size) had no effect on OSM; varying the number of distractors did not modulate the OSM effect. This finding was one which was inconsistent with the predictions of Di Lollo et al.'s re-entrant model (Di Lollo, Enns, & Rensink, 2002) and the empirical data from which that model was derived. The lack of an interaction between mask duration and set size was further demonstrated in a subsequent series of experiments (Chapter 3) in which participants had to report the presence or absence of a critical feature – a bisecting vertical bar – in the target item. Again, manipulating the number of distractors influenced performance but not the masking effect itself. At first glance these results suggest that attention does not play the critical role in OSM that Di Lollo et al. (2000) originally claimed, and which has been widely assumed in the subsequent experimental literature. However, such evidence bears only indirectly on this issue. Experiments 1 to 5b did not involve direct manipulation of attention. Rather, it was assumed, in keeping with all the previous literature on the topic, that manipulation of set size stands as a proxy for manipulation of the speed with which attention can be directed to the target. This assumption itself could be flawed. It may be possible that when attention is controlled in an explicit or direct manner so that spatial uncertainty is reduced then masking is affected. In this chapter this possibility will be tested by using the cueing technique. In particular, I will examine if pre-cueing the target location attenuates OSM. If it does so it will suggest that the speed of attention is important in determining OSM. The converse case will provide direct evidence that attention is not a determining factor in OSM and it will seriously undermine the validity of the re-entrant account of OSM.

Spatial Pre-Cueing.

In order for a visual stimulus to be consciously perceived focused attention must be directed either to the stimulus itself (e.g. Halligan & Marshall, 1993; O'Craven, Downing, & Kanwisher, 1999) or to the spatial location in which the stimulus resides (e.g. Posner, 1980). What is perhaps surprising and counter to intuition is that this shift of attention can be done covertly, in the absence of an eye movement, a function that Posner (1980) termed covert visual orienting. What exactly determines how a stimulus (or a region of interest) can be the locus of covert attention has been the subject of much psychological research for more than a century.

One line of research has shown that prior knowledge about the location of a target stimulus increases its perceptibility. This is demonstrated by having another stimulus, called the pre-cue, directing attention to the target location prior to the target onset (e.g. Eriksen & Colegate, 1971; Eriksen & Hoffman, 1972a, 1972b, 1973; Müller & Rabbitt, 1989). For instance, in Eriksen and Colegate's (1971) experiments a small bar positioned next to the target letter in a eight letter circular array appeared either before the display onset, simultaneously with it or after the display offset. The participants' task was to report the letter that was cued by the bar. In two experiments they found that performance when the cue appeared 250ms before the target onset was better compared to when the cue appeared simultaneously with the target, which in turn yielded better discrimination performance compared to the delayed cue onset condition. Similar results were obtained in a subsequent study by Eriksen and Hoffman (1972b) in which participants were required to report a target letter that was cued by a bar that onset either prior to or simultaneously with the target. Reaction time in reporting correctly the target was shorter in the former compared to the latter condition, presumably because attention was deployed towards the target more rapidly with the pre-cue.

In studies such as those described above the cue is said to be exogenous in that it appeared at the target location or adjacent to it, engaging attention rapidly without requiring voluntary effort from the participant to shift attention to the target. In tasks in which a peripheral cue is employed to highlight the target's position, attention is said to be automatically captured by the cue, activating bottom up processes and resulting in a rapid attentional response to the target. Orienting of attention to the target location, however, need not be an automatic process; top down processes may also be involved such as when a central cue indicates a peripheral target. In Posner, Nissen and Ogden's (1978) study a target could appear either to the left or to the right of a fixation point. The fixation point was either a cross (uninformative cue - neutral trials) or an arrow pointing either to the target location (valid cue trials) or to the opposite location (invalid cue trials). Posner et al. found significant benefits in detecting the target when observers attended the target location prior to the target onset (difference in performance between valid and neutral cue trials). Additionally, they found significant costs (the difference in performance between neutral and invalid cue trials) when attention was directed to a location away from the target or it is widely distributed. Furthermore, because in these tasks the observer needs first to decode the visual marker and subsequently to direct his attention to the indicated location the cue is said to be endogenous in nature and attention to be goal directed (Posner et al., 1980; Posner, 1980).

Cueing studies such as those described above show that cueing the target location, either exogenously or endogenously, results in an improved detection and/or discrimination performance. How cueing the target facilitates perception of it has been the subject of some debate. Two models that have been proposed to account for cueing effects are limited capacity (Henderson & Macquistan, 1993; Henderson, 1996) and noise-reduction models (Lu, Lesmes, & Dosher, 2002; Shiu & Pashler, 1994). The first class of models is based on the assumption that visual processing resources are limited in capacity and thus at any time are distributed only over a limited region of the visual field (Treisman & Gelade, 1980; Treisman & Sato, 1990; Wolfe et al., 1989; Wolfe, 1994). In these models perceptual processing is said to occur faster in this limited attended region; stimuli that fall within this region receive more attentional resources and are, therefore, processed faster than stimuli falling outside of this region. Thus, cueing improves perceptual performance because it directs attentional resources appropriately towards the target location. The alternative model that has been proposed to account for cueing effects is an external noise exclusion model (Lu et al., 2002; Shiu & Pashler, 1994). According to this model, the benefit of cueing the target location arises not from directing attention to the target but from suppression of noise from non-target locations which interfere with the perceptual classification of the target. This model is supported by findings which show that spatial pre-cueing effects are absent when there are no distractors in the display – and therefore there is not noise to be excluded (Shiu & Pashler, 1994). These findings are not predicted by the limited capacity models because these models do not assume that distractors are relevant to the pre-cueing effect.

Although the mechanisms that underlie cueing have yet to be clarified there is, nevertheless, a consensus that pre-cueing a target does improve its perception compared to when it is not cued or is invalidly cued and this effect has been demonstrated through a number of paradigms. For instance, in a change detection paradigm, change blindness (Rensink et al., 1997; Simons & Rensink, 2005) is attenuated when the target location is cued with a peripheral cue (e.g. Scholl, 2000; Wilson et al., 2005). Cueing effects have also been observed in attentional blink tasks. Typically, the attentional blink is realised when two targets are presented in close succession within a rapid sequence of non-target items (typically 10 items per second) presented at fixation; reporting the second target (T2) is impaired when it falls within 200-500ms after the presentation of the first target (T1) (Kawahara, Di Lollo, & Enns, 2001; Kawahara, Kumada, & Di Lollo, 2006; Raymond et al., 1992; Shapiro, Raymond, & Arnell, 1994). If, however, a cue is employed performance in reporting T2 is improved (Nieuwenstein, Chun, van der Lubbe, & Hooge, 2005; Nieuwenstein, 2006; Zhang, Shao, Nieuwenstein, & Zhou, 2008). For instance, Zhang et al. (2008) employed an endogenous cue (an arrow) that was pointing to the location of T2. The two targets (drawn from a set of upper case letters) appeared at different locations on the display; T1 either above or below the fixation point and T2 either to the left or to the right of the fixation point. On half of the trials T2 was cued and on the other half it was not. The cue was an arrow presented at the middle of the display pointing either to the left or to the right and its validity varied across three experiments; the cue was valid either 100% (Experiment 1), or 50% (Experiment 2) or 80% (Experiment 3). The participants' task was to report both T1 and T2. The data showed that in the cue-arrow trials identification performance (of T2) was better compared to uncued trials.

In OSM literature, pre-cueing has been employed primarily to observe the supposed role of attention on masking (Di Lollo et al., 2000; Enns, 2004; Germeys, Pomianowska, De Graef, Zaenen, & Verfaillie, 2010; Luiga & Bachmann, 2007; Neill et al., 2002). The first study that attempted to explore the role of cueing the target in OSM was from Di Lollo et al. (2000). In their Experiment 6 pre-cueing was manipulated by sometimes presenting the four dot mask before the target array appeared. Target and distractors comprised of circles half of which had a vertical segment and the participants were instructed to report whether or not the target circle contained a vertical segment. Each trial started with the four dot mask that preceded the search display by either 0ms (no cue condition) or by up to 180ms and remained visible for 90ms after the target offset. The results of that experiment are shown in Figure 5.1. As can been seen in this graph the longer the pre-cue was visible the better was the discrimination performance and this pattern was obtained across all set sizes. Based on these results Di Lollo et al. reported that "...the strength of masking declined progressively as the duration of the pre-cue increased" (Di Lollo et al. 2000, p.495). The facilitating effect of the pre-cue on performance was argued to add further empirical support to their re-entrant model. In this interpretation, the presence of the four dot cue prior to the target onset was said to allow for spatial attention to focus on the target location so that when the target appeared, attention was deployed towards it. This, in turn, allowed for a better performance compared to when the target was not cued. In Di Lollo et al.'s model this happened because fewer iterations would have been required for a target representation to be established eliminating the possibility that the four dot representation would substitute that of the target. As the cue duration decreased, more time would have been required for attention to focus on the target location. This would have increased the number of iterations needed to form a representation and, thus, increase the vulnerability of the target to substitution by the four dot mask.

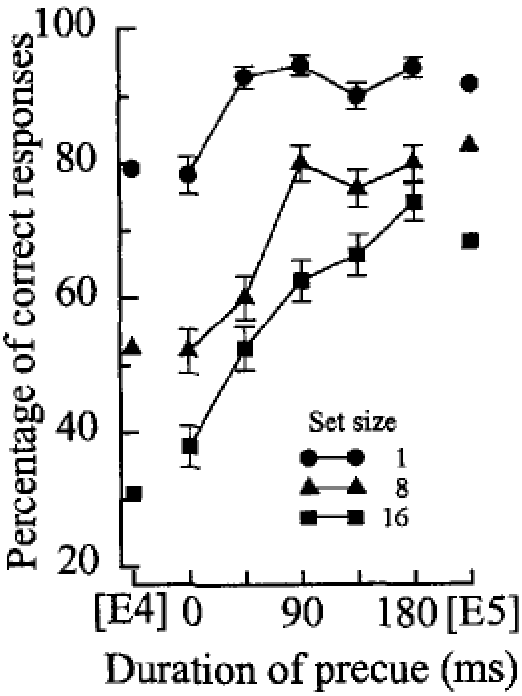

Figure 5.1. *Results from Di Lollo et al.'s (2000) Experiment 6. The abscissa shows the duration of the pre-cue and the ordinate shows correct responses. The graph shows that discrimination performance improved with increments of pre-cue duration and this was observed across all set sizes.*

There are two issues with Di Lollo et al.'s claim in this regard. Firstly, in their experiment the pre-cueing was confounded with mask preview. Research has shown that previewing of the mask stimulus reduces masking even when the cue is uninformative (Gellatly, Pilling, Carter, & Guest, 2010; Lim & Chua, 2008; Neill, Hutchison, & Graves, 2002). Therefore, in Di Lollo et al.'s experiment it is not clear if masking was reduced because of pre-cueing or because of the mask preview. Secondly, in their experiment the mask duration was not manipulated; there was no control condition (i.e. target-mask common offset). Mask duration after target offset was fixed (i.e. 90ms) and, therefore, the extent of OSM could not be measured. Therefore, their results were not informative about the effect of cueing (and thus of attention) on OSM. What Di Lollo et al.'s findings showed was that with increased pre-cue durations the overall performance was improved, not that masking was also attenuated.

In fact, other studies that used the mask as a pre-cue did report an interaction with OSM. For instance, in Luiga and Bachmann's (2007) experiments, in half of the trials the four dot mask appeared either simultaneously with or prior to the target onset and indicated the location of the target (exogenous pre-cue). On the other half of the trials a central arrow was employed indicating the position of the target (endogenous pre-cue). Target and distractors were drawn from the set of four upper case letters. Masks offset either simultaneously with the target or up to 133.6ms after the target offset and set size was fixed to four items. The task was to report the identity of the letter that was surrounded by the four dots. Their results showed that when the four dots served both as a mask and as a pre-cue identification performance was improved and masking was reduced. In other words, there was an interaction between pre-cueing and masking such that the longer the cue was visible before the target onset the shallower the masking functions. However, as it was argued earlier when discussing Di Lollo et al.'s (2000) results, pre-cueing was confounded with mask preview and therefore it is not clear if OSM was reduced because of the pre-cue or because of the mask preview. Indeed, on the other half of the trials in which the pre-cue was a central arrow (and not the four dot mask), the interaction between pre-cue and mask durations was absent. This result suggests that when decoupling the pre-cueing from the mask previewing effects, pre-cueing does not influence OSM. An alternative interpretation is that perhaps exogenous (i.e. mask) and endogenous (i.e. central arrow) attention have different effects on OSM (Luiga and Bachmann, 2007).

Germeys et al. (2010) replicated Luiga and Bachmann's experiment and compared the effects of an endogenous (an arrow) to an exogenous (outline of a square) pre-cue. They found that pre-cueing reduced OSM irrespective of the type of pre-cue. However, for both types of pre-cue performance in the control condition (common target – mask offset) was at ceiling and therefore the results do not show that the masking effect depends on the allocation of focused attention on to the cued location. They rather show that pre-cueing the target moved performance out of the measurable range for FDM.

Other studies have also used pre-cueing to indicate the target location while decoupling the pre-cueing from the mask previewing effect. For instance, in Neill et al.'s (2002) Experiment 4 the cue was a central arrow pointing towards the target location. The onset of the arrow was either simultaneous with the stimulus array (no pre-cue condition) or 133ms beforehand (pre-cue condition). The target and the only distractor were one of the letters “E” and “F” and they were different to each other. The target and the distractor were presented to the left and right of a fixation cross. A four dot mask offset either at the same time as the stimulus array or 133ms later. The participants were asked to report the letter that was cued by the central arrow. The results showed an interaction between pre-cueing and masking; the masking effect was reduced in the pre-cue condition compared to the no pre-cue condition (Figure 5.2). Neill et al. argued that their results are in accordance with the re-entrant model, namely, that directing attention towards the target reduces OSM. However, because in their results performance was close to ceiling in the pre-cue condition for both simultaneous and delayed offset trials, this interaction might have been an artifact of the data being compressed by a ceiling effect.

Figure 5.2. *Part of the results of Experiment 4 reported by Neill et al. (2002). The bars on the left part of the graph show performance in the pre-cue trials and the bar on the right performance in the no pre-cue trials for simultaneous (black bar) and delayed offset conditions. The masking effect was reduced as a result of the pre-cue. Image adapted from Neill et al. (2002, p.689).*

In Jiang and Chun's (2001b) study the aim was to test if OSM is location specific, namely if OSM occurs only when target and mask are at the same location or if it also occurs when the two stimuli are in different locations. Part of their data, however, are relevant to the present discussion. In their Experiment 1 the search array consisted of eight letters presented in a circular array. The mask was a four dot pattern and the pre-cue stimulus was a small box. The authors manipulated three factors: firstly, the mask duration after the target offset which was either zero (control condition) or 160ms (masking condition). Secondly, the four dot mask appeared either at the same location as the target (same condition), or peripherally or centrally to the target with the centre of the display being the reference point (different condition, see Figure 5.3 for an examples of the mask position). Thirdly, the pre-cue was either valid (appearing briefly at the target location prior to the target onset), or neutral (appearing briefly at the centre of the display and therefore it was uninformative as to where the target would appear). The participants were asked to report the identity of the letter that was closest to the four dot mask. Figure 5.4 shows examples of the frames sequence in one trial. The results showed that there was an overall interaction between pre-cue and masking such that a reduced OSM was obtained at the valid pre-cue trials compared to the neutral pre-cue trials. Figure 5.5 shows the identification performance under same and different mask location conditions. As it can be seen from the graph, for both conditions OSM was larger at the neutral compared to the valid pre-cue conditions and this difference was significant. Jiang and Chun argued that these results show that pre-cueing attention to the target location reduces OSM compared to when attention is widely distributed (i.e. under neutral pre-cue conditions). However, as it can be seen in Figure 5.5, performance when the pre-cue was valid in the control condition was at or close to ceiling. Therefore, similar to Neill et al.'s (2002) and Germeys et al.'s (2010) results, the interaction between pre-cueing and OSM could be an artifact due to performance being at ceiling.

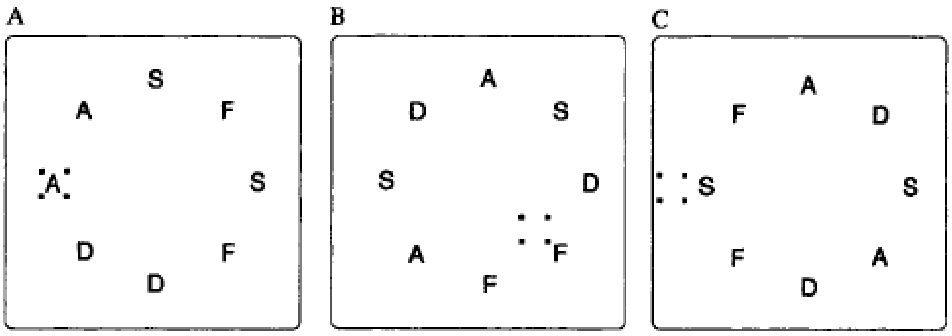

Figure 5.3. *Examples of the position of mask relative to the fixation point. A: The mask is positioned at the same location as the target. B: The mask is positioned centrally to the target. C: The mask is positioned peripherally to the target. Image taken from Jiang and Chun (2001b, p.897).*

To summarise, a number of studies of OSM have used pre-cueing to direct attention towards the target location. Their findings seemingly appear to be consistent between each other and with the re-entrant model; pre-cueing reduces OSM compared to no pre-cueing or neutral trials. However, in all these studies the findings were problematic. This is either because: a) there was not a control condition (Di Lollo et al., 2000), or b) when there was one, in some studies pre-cueing was confounded with mask preview (Di Lollo et al., 2000; Luiga & Bachmann, 2007), or c) when an interaction between pre-cueing and OSM was reported ceiling effects were evident (Germeys et al., 2010; Jiang &

Chun, 2001b; Neill et al., 2002). Thus, the data from these studies are not conclusive about the role of attention in OSM when a pre-cue is employed.

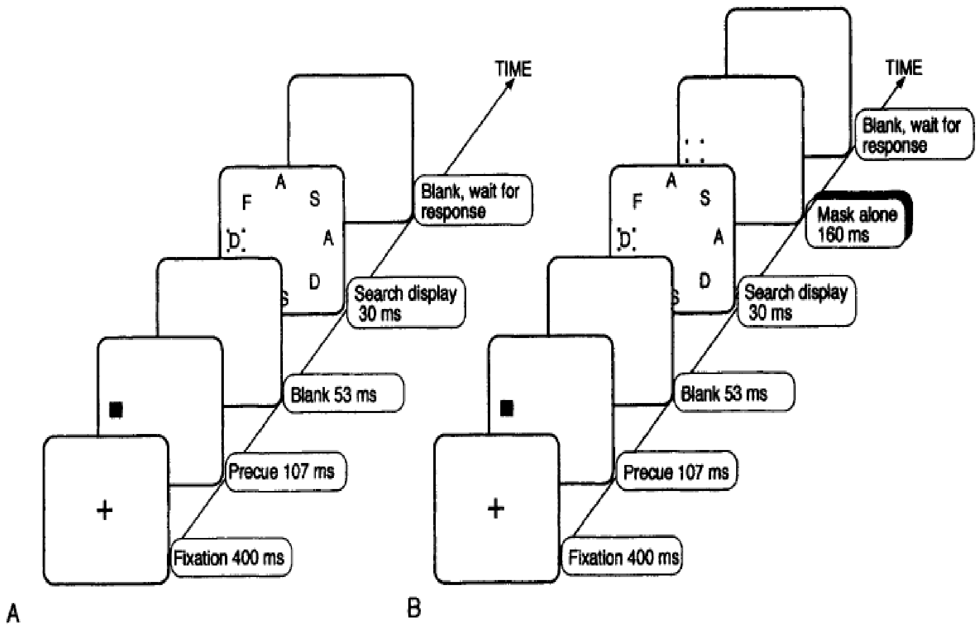

Figure 5.4. *Examples of the frame sequence in Experiment 1. A: control condition, B: masking condition.*

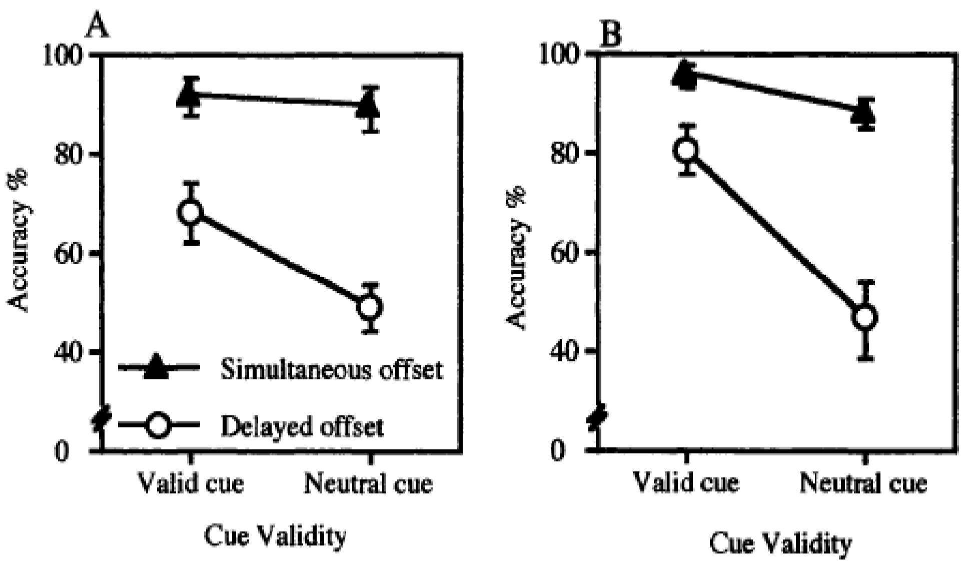

Figure 5.5. *Identification performance when the mask was at the same*

location as the target (A) or at a different location (B), as a function of pre-cue validity and mask offset. Graphs taken from Jiang and Chun (2001, p.899).

In the absence of conclusive evidence on the effect of cueing in OSM, the present chapter investigates the effect of pre-cueing attention to the target location. Given the findings in Chapters 2, 3 & 4, in which it was shown that OSM does not interact with either set size or crowding, the present experiment will contribute further to the investigations on the role of attention in OSM.

Experiment 9

In the present experiment a radial line cue was employed to designate the target location. Because in Experiment 1 in Chapter 2 overall performance was at low levels, the present Experiment used similar stimuli to that one to avoid potential ceiling effects induced by the line cue. The line could be perceived both as an endogenous cue to the target location and, due to illusory line motion away from fixation (Hikosaka, Miyauchi, & Shimojo, 1993), an exogenous cue. The cue onset either simultaneously with the target display (no pre-cue condition) or some tens or hundreds of milliseconds beforehand (pre-cue conditions). If the magnitude of OSM is influenced by spatial attention then masking should be attenuated on pre-cue trials whereas extensive masking should be obtained on no pre-cue trials on which cue and target appear at the same time. This is because, in the latter case, spatial attention will be diffused or not focused on the target location at the time of the search array onset.

Method

Participants were 25 undergraduate students (17 females) with an average age of 21.91 (s.d. = 5.43). All participants reported normal or corrected-to-normal visual acuity. They were recruited from the OBU Psychology Department Participants Panel and received course credits for taking part in the study.

The present experiment was identical to Experiment 1 except for the following changes: a) there were always seven distractors presented with the target (i.e. set size equal to eight), b) rather than using four dots to indicate the target, the target was indicated by a radial line which was 1.6 in length and had the same thickness as the dots and c) four dot masks surrounded each item in the display. This latter manipulation ensured that the target was not cued both by the line and the four dot mask possibly leading to ceiling effects and confusing the effects of cueing and masking. Similarly, the size of the gap in each square, which was identical to that employed in Experiment 1, was chosen to avoid performance reaching ceiling because of the target being cued.

Each trial began with a blank screen for 1000ms followed by a fixation cross for 500ms. The cue line then appeared either 0, 50, 100 or 150ms before the stimulus array (Cue-Target Interval, CTI). Then the cue line, the search array and the four dot masks appeared for 50ms. The four dot masks surrounded each distractor and the target. The cue line was 100% valid. This was followed by a post-target display containing only the four dot masks and the cue line for 0, 60 or 180ms. This was followed by a blank display and the observer responded, which initiated the next trial (see Figure 5.6).

Figure 5.6. *Schematic representation of the frame sequence of Experiment 9. In each trial a line onset either simultaneously with the target (no pre-cue condition) or 50ms, 100ms or150ms prior to the target onset indicating the location of the target square (pre-cue condition). Four-dot configurations surrounded the target and each distractor and they either offset simultaneously with the target and the distractors (common offset) or they lingered for up to 180ms after the target and the ditractors offset (delayed offset or masking condition). The participant's task was to report the location of the gap in the square that was indicated by the line. In this figure only the pre-cue/masking condition is depicted.*

Results and discussion

Figure 5.7 shows the mean percentage of correct responses for each condition. As can be seen from the figure, the data were free from ceiling and floor (chance score equal to 25%). Furthermore, pre-cueing resulted in better discrimination performance compared to non pre-cueing conditions across all mask durations. A 2-way repeated measures ANOVA with mask duration and CTI as the within subjects factors showed significant effects of mask duration ($F(2, 48) = 251.4$, $p < .0001$, partial $\eta^2 = .91$) and of CTI ($F(3, 72) = 17.7$, $p < .0001$, partial $\eta^2 = .43$). The interaction between these two factors did not approach significance ($F(6, 144) = 1.73$, $p > .05$). Because for some participants the scores were at or close to ceiling or floor the data from participants who scored below 90% and above 33% in any condition were subjected to a subsequent analysis. This was done in order to test the possibility that an interaction will be obtained when the data were free from individual ceiling and floor effects. An ANOVA on the data of the 11 participants who met these criteria showed the same pattern of findings (Figure 5.8); there were significant main effects of mask duration ($F(2, 20) = 157.77$, $p < .0001$, partial $\eta^2 = .94$) and CTI ($F(3, 30) = 13.09$, $p < .0001$, partial $\eta^2 = .57$) but not an interaction between these two ($F(6, 60) = 0.61$, $p > .05$).

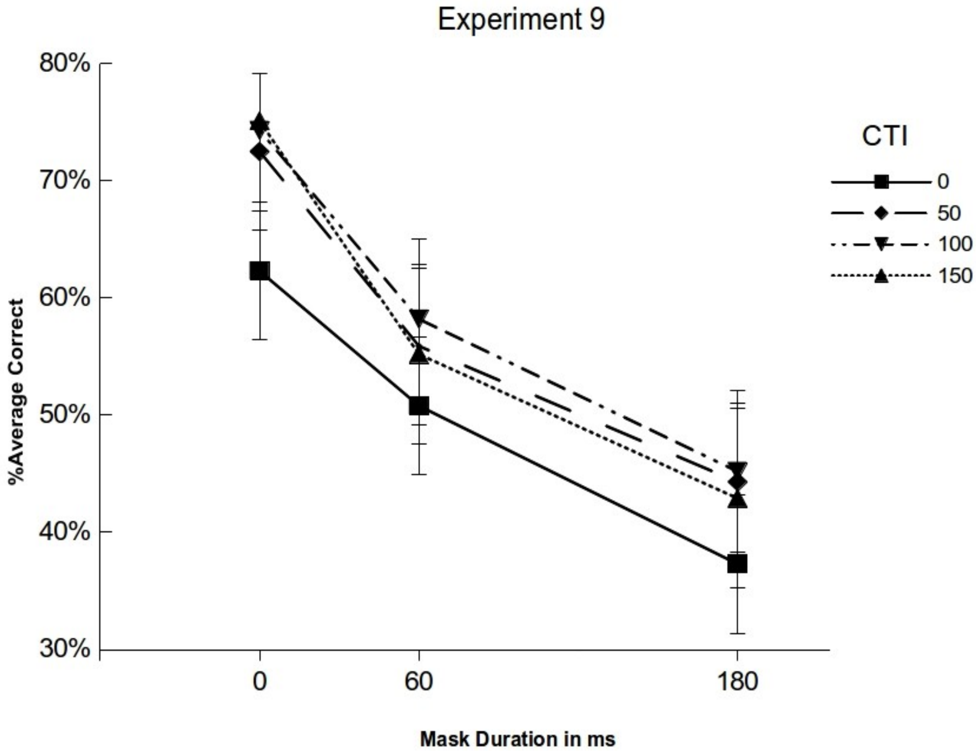

Figure 5.7. *Mean percentage correct identification of the location of the gap in the target. The horizontal axis denotes the mask duration and the lines denote the cue – target interval.*

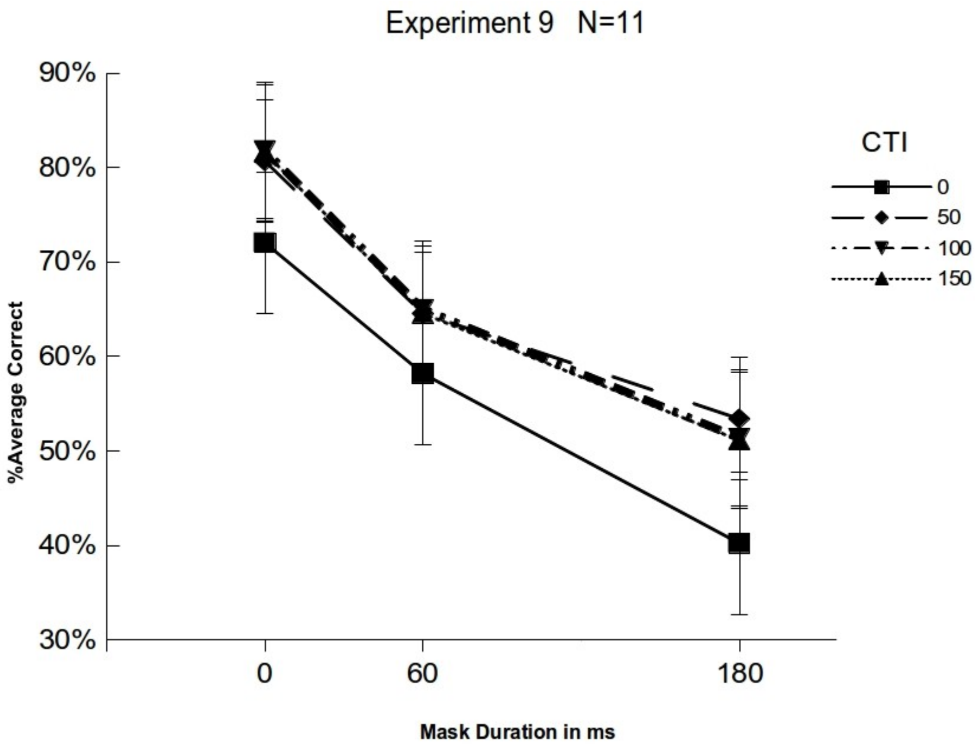

Figure 5.8. *Mean percentage correct identification of the location of the gap*

in the target for the participants whose mean scores were below 90% and above 33%.

The first thing to observe is that in the present experiment when attention is pre-cued to the target location OSM is not reduced; pre-cueing the target had a facilitating effect on target discriminability but this improvement was not accompanied by a corresponding reduction of masking. This is in striking contrast to Di Lollo et al.'s (2000) claim that when attention focuses on the target location prior to the target onset OSM is attenuated. Furthermore, the pre-cueing effect appeared to be an all-or-none process; pre-cueing the target improved performance compared to when CTI was zero but the pre-cue – target interval had a minimal effect on target perceptibility. What this shows is that the pre-cue drew attention to the target location relatively rapidly after its onset and longer CTIs did not have an effect on target perceptibility. This finding is compatible with reports that exogenous cues capture attention rapidly (Jonides, 1981; Müller & Rabbitt, 1989).

Discussion

The present experiment investigated whether a direct manipulation of spatial attention would modulate OSM. Attention was modulated by using a pre-cue to indicate the target location. The key variables were the cue-target interval and the duration of the four dot mask. The data showed that pre-cueing the target improved performance compared to when the target was not pre-cued. The CTI manipulation, however, did not affect OSM itself; although pre-cueing the target improved overall performance it did not result in a reduced OSM as indexed by the effect of mask duration. This result shows that, at least under the conditions tested in the present experiment, attention does not influence OSM although it does affect target processing. This finding is inconsistent with the tenets and predictions of Di Lollo et al.'s re-entrant model.

According to the re-entrant account OSM supposedly occurs only under conditions of diffuse attention, namely, when attention is not focused on the target location prior to target onset. The re-entrant account postulates that OSM will be observed under these conditions because an increased number of recurrent processing iterations will be required before attention contacts the target. As was described in the introduction, a number of studies supported this claim by apparently showing that when the target was pre-cued OSM was reduced or eliminated. However, as was argued above, one of the reasons why these studies were problematic was that ceiling effects were present when an interaction between mask duration and pre-cue was reported. In Experiment 9, however, ceiling (and floor) effects were avoided and the interaction disappeared. Although accuracy of performance in the pre-cue conditions was better than when the target was not pre-cued, OSM was the same across all CTIs. Even when a further analysis was performed on the data of a subset of participants whose scores were definitely not at ceiling or floor the interaction was absent. Furthermore, pre-cueing attention to the target location did not eliminate OSM; a substantial OSM effect was obtained even when the CTI was as long as 150ms. Together these findings are inconsistent with the idea, originally proposed by Di Lollo et al. (2000), that OSM is critically dependent on the speed with which attention is focused on the target location.

As was discussed in Chapter 3, an alternative to the re-entrant account is the object updating account (OUA). This account proposes that masking occurs as a result of the target representation being updated with information from the mask in masking conditions rather than the target representation simply being substituted by a representation of the mask alone. Can the findings from Experiment 9 be accommodated by the OUA account (Lleras & Moore, 2003; Moore, Alej, & Lleras, 2005)? Before I proceed to answering this question it is prudent to first consider how the two accounts view the role of attention in relation to OSM. Whereas a role for attention in OSM is central to the re-entrant account, the UOA is less explicit on this issue. The UOA developed out of the substitution account and its proponents pay occasional lip service to a role for attention. However, the exact way in which attention affects OSM is never clearly described. In developing the OUA, Lleras and Moore (2003) reported that OSM occurs “when attention is later allocated to the trailing mask” (p. 118) and that “the target must be initially unattended and the mask must eventually be attended” (p. 119) (see also Oriet & Enns, 2010, for a supposed role of attention in OUA). The results from Experiment 9, however, are inconsistent with this suggestion. The data showed that even when the target is attended – because of a pre-cue – and attention presumably later shifts to the trailing mask, a masking effect will still be obtained. Indeed, in this experiment, even when the target location was known from as early as 150ms prior to the target onset (and, presumably, the target was later attended) performance was significantly impaired when attention later shifted to the mask on the delayed offset trials. What these findings suggest is that even an attended item is not necessarily protected from OSM if attention later shifts to the trailing mask.

The important finding of Experiment 9 was that even when attention was controlled in a direct manner, it did not influence OSM. Although strong conclusions about the role of attention in OSM cannot be drawn from a single experiment, combined with the data from Experiments 1-8, the present results provide a strong indication that attention and OSM do not interact and therefore they pose a serious challenge to the re-entrant account. At this point it is important to consider another study the results of which also strongly suggest that OSM may be observed even under conditions of full spatial attention. Dux et al.'s (2010) study was concerned with whether OSM stems from delayed feed-forward or re-entrant processing and employed dual versus single task conditions. Participants saw a sequence of four digits presented at fixation for 500 ms each, with an inter-stimulus interval of 500 ms. After a further 100 ms (Lag 100) or 800 ms (Lag 800), a circle with a gap surrounded by four dots also appeared at fixation for 10 ms, and the dots either offset simultaneously with the single circle or trailed it for 200 ms. In blocked trials, participants either did an arithmetic calculation on the digits before reporting the orientation of the target gap or reported only the latter. The finding that is of interest for the purposes of my study is that even though there was only one item (i.e. the target) which was also presented at fixation – and therefore at the focus of attention – reliable OSM was obtained in all conditions (Lag 100 versus Lag 800 and single versus dual task); performance was worse in the delayed mask condition relative to the simultaneous mask condition. The authors, being interested in the comparison between single and dual task conditions, did not comment on this feature of their data. However, taken in conjunction with the data of all the experiments so far reported in this thesis, it serves to underline that attention does not mediate OSM.

Conclusion

In this chapter I sought to investigate if OSM is influenced by attention when the latter is controlled in a direct manner. It was argued that previous studies on the effect of pre-cueing (and thus of attention) on OSM were flawed in various ways. The results of Experiment 9 showed that directing attention to the target improved its perceptibility but did not affect OSM. This result adds to the findings from the previous experiments in which OSM was influenced neither by set size nor by crowding. It was argued that this finding can be accommodated neither by Di Lollo et al.'s (2000) re-entrant hypothesis nor by the OUA account. However, strong conclusions cannot be drawn from a single experiment. Further investigations of pre-cueing and OSM are required. Indeed, several further studies by our group have been conducted using different cuing procedures and have essentially confirmed the present result (Pilling, Gellatly, Argyropoulos, & Skarratt, submitted). In all these studies, pre-cueing improved performance without modulating the OSM effect.

Chapter 6

Phenomenal experience in OSM

Introduction

The aim of Chapters 2-5 was to explore the role of attention in OSM. It was shown that when attention was manipulated, by varying either the number of distractors or the duration of a cue-target interval or the level of crowding, performance was markedly affected. The OSM effect, however, was independent of these manipulations of attention. In the present chapter a different aspect of OSM will be explored. In this chapter it will be investigated what it is that is masked in OSM and in particular if there are occasions in which OSM is complete. Namely, the aim will be to explore whether OSM is a phenomenon wherein masking entails a substitution of the target (plus mask) representation by the mask erasing all traces of the target representation.

This study was motivated by reports which imply that in OSM the substitution process is complete. For instance, in Di Lollo et al.'s (2000) paper the authors wrote that “At longer durations of the trailing mask … the four dots appeared to be clearly visible, but the target location appeared empty” (p. 492). Neill et al. (2002) stated for four-dot masking of a letter that “not only does the space inside the dots appear blank, but there is a strong subjective impression of the contours of a square connecting the masking dots” (p. 683). Similarly, Kahan and Mathis (2002), wrote that “the phenomenological experience of this effect is that a mask surface replaces the target” (p. 1249).

Such anecdotal claims of phenomenology appear to provide support to the view that in OSM masking arises from the mask's representation substituting that of the target. As such, the perceptual system does not have access to the record of any target features because the entire representation of the target has been substituted by that of the mask. However, these statements are not supported by experimental data; there are not studies that have systematically investigated what are the conditions under which such reports may have risen (although see Gellatly et al., 2006, described below). Although a number of aspects of OSM have been explored, such as its spatial extent (Jiang & Chun, 2001a, 2001b) and the effect of attention on its magnitude (Argyropoulos, Gellatly, Pilling, & Carter, 2013; Di Lollo et al., 2000; Lleras & Moore, 2003; Luiga & Bachmann, 2007; Moore & Lleras, 2005; Neill et al., 2002), it is rather surprising that the question of whether OSM can be an all-or-none process or if it occurs on some features of the target but not on others has not often been addressed.

If OSM occurs at the level of object tokens wherein the entire representation of the target is being overwritten by that of the mask it is possible that this process may result in the phenomenological experience of a blank space in the target location. Alternatively, if OSM occurs selectively on particular target features, participants may be able to detect the presence of a target but unable to identify it.

In order to measure the effect of OSM on the perception of a target stimulus observers are typically required to detect, discriminate or identify a target. The data from such studies however do not show whether OSM is complete. For instance, in Enns and Di Lollo's (1997) Experiment 3 a briefly presented target diamond, with a missing point either to the left or the right, appeared in one of three possible locations. The other two locations were either left empty or they were occupied by one or two distractor diamonds. A four-dot configuration, which served both as a mask and as a cue to the target, onset either before, simultaneously or after the target. The observers' task was to report if it was the target's left or right corner that was missing. The data showed accuracy performance was worse when the four dots surrounded the target compared to when they surrounded an empty location. The question that arises, in a study such as this, is what was being masked? Were the participants aware that there was a target but they were unable to identify the to-be-reported feature or did the four dots mask the full representation of the target preventing the perceptual system from having access to any of the target's individual features?

Conversely, trials in which participants correctly report the target raise the question whether participants clearly saw the target or just part of it. For instance in tasks in which participants are required to report the mere presence or absence of a target in the target location (e.g. Chen & Treisman, 2009; Woodman & Luck, 2003) what is this that the participants report? Reporting the presence of a target does not necessarily mean that a complete percept of the target (plus mask) was established. It could well be that the participants detected the presence only of a single target feature but they did not have a clear percept of the target. Or that a bundle of target attributes were detected but, due to masking, processing did not proceed to the level of binding these into an object level representation. In both cases, the observers' phenomenological experience would be that something was in the target location. And because observers were instructed to report the target presence or absence in the target location, the perception of a single feature or a bundle of features (Wolfe & Cave, 1999) was enough to tell the participants that the target was present.

Although Di Lollo et al. (2000) did not explicitly state that OSM is an all-or-none affair, the claim that their re-entrant hypothesis describes a process in which "… the compound image (target + mask) is replaced in consciousness with the percept of the mask alone" (Di Lollo et al., 2000, p. 485) has about it the suggestion that all representation of the target object is erased from perception. Thus, the re-entrant account appears to favour the view that it is the whole target representation that is substituted and when this happens the perceptual system does not have access to the individual features of the target.

This view, however, is challenged by findings that show that OSM may not be an all-or-none process but rather may interfere selectively with particular aspects of the target percept. The original aim of Kahan and Mathis's (2002) study was to investigate if grouping of the elements of the mask influences OSM and, also, if it accounts for claims such as that the four-dot mask gives rise to the perception of Kanizsa type square the contours of which connect the dots (Neill et al., 2002). Their study, however, shed some light to the question of whether OSM is complete. In their Experiment 3 the target was a diamond which was missing either the left or the right corner and appeared in one of the four quadrants on the computer screen. In half of the trials two masking dots appeared at the same location as the target and on the other half at a different location, and they always offset 33ms after the target offset. The critical manipulation was the position of the two masking dots relatively to the target; they were positioned either to the left, right, top or bottom of the target (ungrouped condition), or crossed (left to right or right to left – grouped condition) (see Figure 6.1).

Kahan and Mathis (2002) assumed that if the two dots give the perception of a line, then a line that crosses the target (grouped condition) should yield more masking than a line that is adjacent to it (ungrouped condition). The data showed that although masking was significant there was not a significant difference between grouped and ungrouped conditions nor an interaction between mask duration and grouping condition. However, an important finding that is relevant to the present discussion is the outcome of a post hoc test in which the two-dot masks appearing either on the left or the right side of the target was examined as a function of whether they appeared on the same or the opposite side to the missing corner. The results showed that although masking occurred when the two dots were positioned next to the diamonds edge (e.g. Figure 6.1B bottom left), masking was not significant when they were adjacent to the missing corner (e.g. Figure 6.1B bottom right). Kahan and Mathis (2002) suggested that when the two-dot mask appeared on the same side as the missing corner, the observers' internal representation of the target remained intact (i.e. a target with a missing corner on the same side as the two dots). But, when the two-dot mask appeared at the opposite side of the missing corner, that corner was masked, and the observers' internal representation of the target was that of a target with two missing corners. As such the observers were unable to discriminate which side of the target-diamond was missing a corner. Therefore, the finding of interest in Kahan and Mathis's study was that the two dots could mask a particular target feature and not the whole representation of the target object. Kahan & Enns (2010) also found evidence that two dot masking can result in ‘trimming’ of the observer’s percept of the target rather than complete masking of the target.

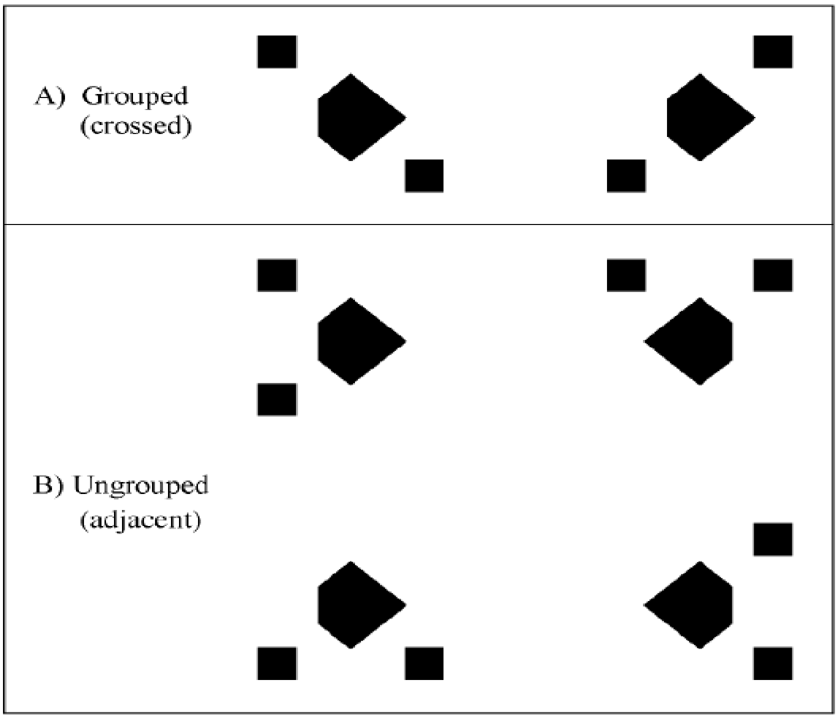

Figure 6.1. *Examples of masking patterns used in their Experiment 3. Figure taken from Kahan and Mathis (2002, p. 1254).*

Perhaps the only study that directly investigated whether OSM occurs selectively on target features or on the target object was from Gellatly et al. (2006). In their Experiment 1, the search display consisted of three diamonds each with either the left or right corner missing. A common onset four dot mask surrounded one of the diamonds designating it as the target stimulus (in half of the detection trials, the four dots surrounded an empty location, there being only two items in the display). The four dot mask offset either simultaneously with the search display items or 500ms after them. In the detection task in half of the trials the target diamond was present and in the other half it was not. The participants were instructed to report if the target was present or not. In the discrimination trials the participants task was to report if it was the left or the right corner of the target diamond that was missing.

The data showed that detection performance was less affected by the mask than discrimination performance. This indicates, there must have been trials in which observers were able to detect the target but they were unable to discriminate its missing corner. Gellalty et al. proceeded further and explored whether masking by substitution occurs on a coherent target representation or on just a bundle of unbound target features. In their Experiments 2 and 3 target, distractors and the mask elements were bars. The target and the mask bars could be either identical (same colour and orientation), match in only one dimension (either colour or orientation) or differ in both dimensions. The reasoning behind this experimental set up was that if masking by substitution occurs after the formation of an integrated target representation then reporting either target feature should be equally affected. If, however, masking occurs before the target features bind together to establish an object level representation then masking should be greater when mask and target bars are similar or identical (match on a single or on both dimensions) compared to when they are different. This is because the signal to noise ratio will be greater in the former conditions than in the latter. The results showed that when target and mask matched on one dimension, reporting of that dimension was more affected by the mask compared to reporting of the dimension that the two stimuli differed on. Moreover, the largest masking effect was observed when target and mask matched on both dimensions. These data were taken as evidence that masking occurs prior to the binding of the individual features into an integrated target representation. Masking occurred selectively on some aspects of the target but not on others.

Collectively, Gellatly et al.'s (2006) experiments show that in OSM there are trials in which there is a partial perception of the target; observers may detect some but not all of the target features. Based on the claims quoted above, however, the question is if in OSM there are also trials in which a phenomenal experience of a blank space in the target location can be obtained. That is, if there are conditions in which observers fail to detect any of the target features and they report perceiving an empty space in the target location. The experiment that follows was designed to address this issue by directly asking the participants to report their visual experience about the target location. These phenomenal reports were also compared with their ability to make a forced choice decision.

Experiment 10

The following experiment will be the first in the OSM literature that will directly investigate the participants' phenomenal experience in a task in which OSM is observed. The principal aim is to explore whether there are trials in which there is a phenomenal experience of a blank space in the target location although the target is present, and what are the conditions under which this experience occurs. To achieve this, participants will be directly asked to report what is their phenomenal experience of the target location. In the same experiment, in addition to reporting their subjective experiences, participants will also be required to perform a discrimination task. The reasoning for employing a discrimination task is to investigate if there are trials in which a target representation can support an implicit but not an explicit perception of the target. In other words, if there are trials in which a target representation is formed that is adequate to support discrimination performance but some or all of the object features are not available for conscious access.

Typically, in OSM studies, participants are required to press a button to report the presence (or absence) of a target or a target's critical feature. In trials in which poor performance is observed as a function of the lingering mask, it is thought to indicate that the target was completely (e.g. Di Lollo et al., 2000) or partially (Gellatly et al., 2006) masked. The novelty of the next experiment is that it will be the first which will investigate the participants phenomenal experience by directly asking them what they saw in the target location.

Method

There were 16 psychology undergraduate participants (15 females) with an average age of 19.5 years (s.d. = 1.3). They were recruited from the OBU Psychology Department Participants Panel for course credits.

The stimulus sequence of the present experiment was similar to Experiment 4 of the present thesis (Figure 6.2). At the beginning of each trial a gray disk (luminance level of 18.95 cd/m2) appeared in the centre of the screen with a radius of 0.1° for 500ms. The disk then grew bigger in size (radius 0.4°) and it immediately shrank to its original size over the course of 800ms and remained on the screen as such until the end of the trial. This method was expected to capture participants’ attention to the centre of the screen (and hence of the circular search array) and control for eye movements at the beginning of each trial. Immediately following the shrinking of the gray fixation disk to its original size twelve circles appeared for 50ms. Each circle contained either a vertical or a horizontal bar (except for the bar absent and target absent trials in which only the distractors contained a bar). A common onset four dot mask that indicated the target circle offset either simultaneously with the target (control condition) or lingered for 180ms after the target offset (masking condition). The offset of the mask was followed by a blank frame. After 500ms a frame appeared which asked the participants to press the “Q” key if they thought that the target contained a horizontal bar or the “W” key if there was a vertical bar in the target circle. The participants were also instructed to press either “Q” or “W” even when they thought that there was only a circle or a blank space in the target location. This forced choice was intended to examine if they had implicit knowledge of the orientation of the line even in trials in which they reported not seeing the line. When the participant pressed the “Q” or the “W” key their response triggered the onset of another frame in which they were required to choose among four statements that best described their subjective experience of what they saw in the target location. These statements were:

1. It was completely blank inside the four dots [Blank – BL]
2. I clearly saw a circle without a line [Circle No Line – CNL]
3. I saw something but I am not sure what (e.g. if it was a circle with or without a line) [Uncertain – UC]
4. I clearly saw the target circle with a line [Circle With Line – CWL]

The participants responded by pressing the corresponding numeric key (1, 2, 3, or 4) on the numeric keypad. The choice of these statements was based on results from a pilot study in which six undergraduate students from the Psychology Department of Oxford Brookes University took part. In that study, in addition to the statements described above, the participants had also the choice between the following statements:

- I did not “see” the line and I thought it was not there.
- I did not “see” the line but I thought it was there.
- I am not sure if the line belonged to the target or if it was adjacent to it.

The results from the pilot study showed that these statements were chosen from the participants only on 6% of the trials and therefore they were not retained for the full Experiment.

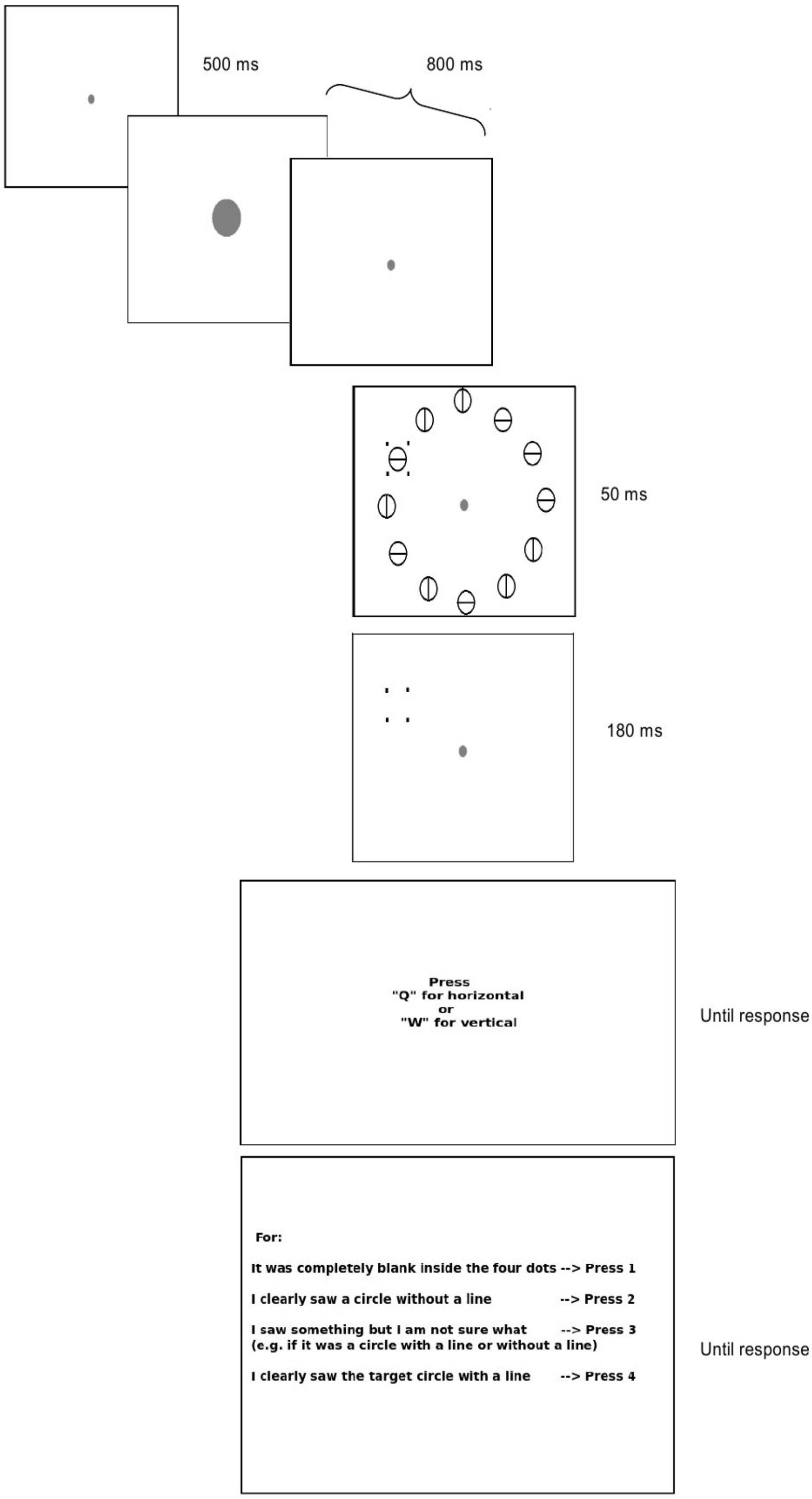

Figure 6.2. *Stimulus sequence and timing parameters used in Experiment 4. In this example the target is present and the mask remains visible for 180ms after the target offset.*

Each participant contributed 400 trials. In 320 trials the target circle contained a bar (bar present); in half of them the bar was positioned horizontally and on the other half vertically. In 40 trials the target circle contained no bar (bar absent) and in the remaining 40 trials the target location was blank (target absent). The participants were informed that, although in the majority of the trials the target location will be occupied by a circle with a bar, there would also be trials in which the target location would be occupied by just a circle without a bar or it would be empty. Every 80 trials the programme prompted the participants to have a brief break. The total duration of the experiment was approximately 45 minutes. Similarly to the previous experiments, a session of 12 demonstration trials with extended frame durations and 36 practice trials preceded the main experiment. Stimuli dimensions, luminance levels and radius of annular array were the same as in Experiment 4.

Before proceeding further, it is important to emphasize the logic of this experimental set up. If masking is complete then, for target present trials in the masking condition, the participants should at least sometimes choose a BL statement. A complete masking effect, however, should also be reflected by chance performance in the discrimination responses. Otherwise, it would show that a target representation was formed that was adequate to support discrimination performance but some or all of the object features were not available for conscious access. Conversely, if masking occurs at the level of target features, then under the same conditions observers should report seeing at least something by responding with CNL or UC; masking would be affecting some but not all aspects of the target. Again, discrimination performance should not be significantly different from chance unless they have implicit perception of the line.

The principal aim of the experiment is to discover if there are conditions in which participants do experience a blank space in the target location and, if they do, how often this occurs. A secondary aim is to analyse their scores from the discrimination task and see if there is a pattern or relationship between their subjective reports and the “objective” measurement of discrimination performance. This comparison will allow us to infer if putative “blank” experiences are due to substitution of the representation of the target object by that of the mask or because the target representation did not gain access to awareness (but it was adequate to support discrimination performance).

Results and discussion

Figure 6.3 shows the type of responses the participants chose in the target present trials. In general, in the control condition (common offset – blue bars) participants reported seeing the target (i.e. CWL) in the majority of trials and there were only few trials that they responded UC or CNL and even fewer in which they responded BL. In the masking condition (red bars), however, BL responses were obtained on almost one fourth of the trials, showing that there are trials in which the OSM is complete.

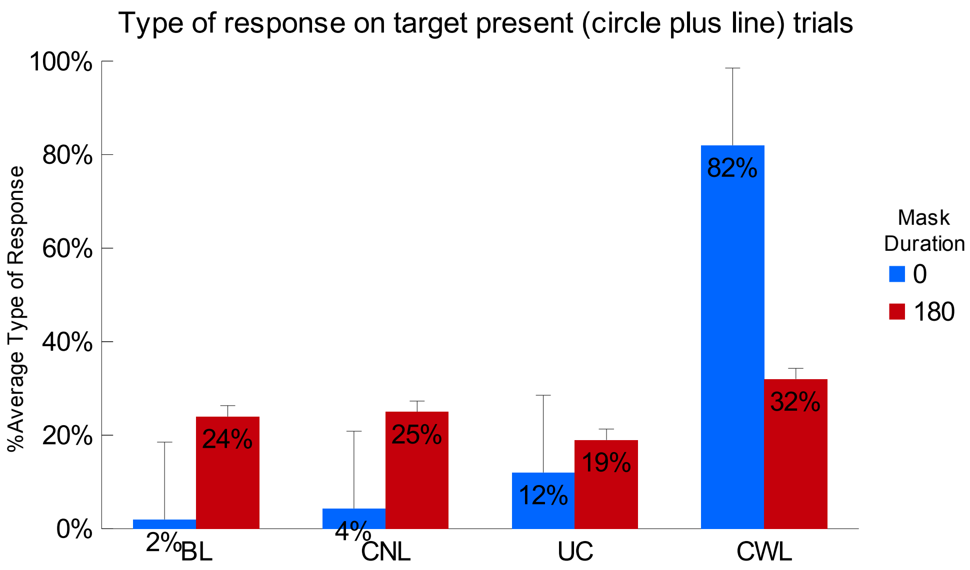

Figure 6.3: *Percentages of types of report in the target present trials in the control and masking condition. BL = Blank, CNL = Circle No Line, UC = Uncertain, CWL = Circle With Line.*

In the common offset condition (blue bars) participants reported seeing both the circle and the line in 82% percent of the trials which shows that in the majority of the trials the target was clearly visible. In the delayed offset condition (red bars) this percentage dropped to 32% which is significantly differed from their score in the common offset trials ($t(15) = 7.35$, $p < .001$) and shows the detrimental effect of the mask on target visibility (to account for multiple testing I used the Bonferroni correction and considered significant only those differences between responses, or scores for which $P < .001$). This raises the question as to what the participants perceived on the remaining 68% of the trials in the masking condition. The data showed that 19% of the time they were uncertain about what they saw in the target location and on 25% of the trials they reported that they saw only a circle but without a line. Strikingly, on 24% of the trials the participants reported that they saw a blank space inside the four dots although the target was present, indicating they experienced a complete masking effect. There were not significant differences between the types of responses in the masked condition ($x^2 = 3.44$, $p > .05$) which indicates that observers were distributing their responses randomly across the four response categories.

Figure 6.4 shows the type of responses in trials in which there was only a circle in the target location. In the control condition (i.e. blue bars) there were more reports of seeing the circle without a line (37%) than reports of seeing a blank space in the target location (6%) ($t(15) = 5.41$, $p < .001$). However, reporting CNL was not significantly different from reporting UC or CWL ($t(15) < 2.6$, $p > 001$). This shows that in the majority of the control trials the participants were unable to report accurately what was in the target location. With the delayed mask offset (red bars) none of the report conditions was significantly different from the others ($x^2 = 5.36$, $p > .05$). This shows that when the mask had a delayed offset participants were generally unclear as to what they had seen although they reported seeing *something* on 71% of trials and a blank on only 29%. Finally, although in the control condition on only 6% of the trials they reported seeing a blank space in the target location, this percentage significantly increased to 29% in the masking condition ($t(15) = 4.86$, $p < .001$). This means that, similarly to the data from the target present trials (Figure 6.3), a relatively large proportion of “blank” responses was obtained under masking conditions when there was something present in the target location.

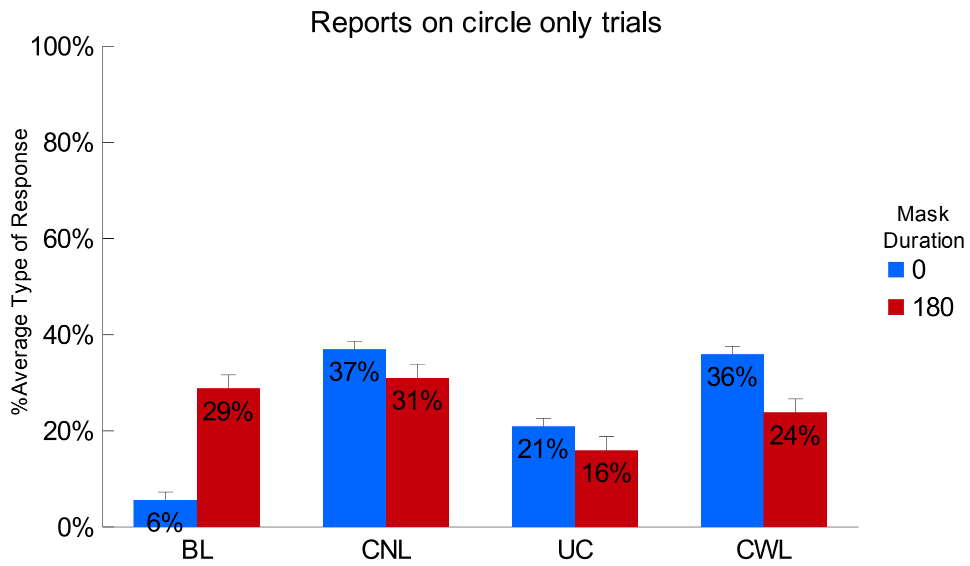

Figure 6.4. *Percentages of type of reports in the circle only trials in the control and masking condition.*

Interestingly, reporting BL (29%) in the masking condition in the circle only trials was not significantly difference from reporting BL in the masking condition in the target present trials (24%). This finding suggests that the four dots did not mask just the to-be-reported feature (i.e. line) but rather the entire contents in the target location.

Furthermore, and rather surprisingly, the difference in reporting CNL between control (37%) and masking condition (31%) was not significant ($t(15) = 1.2$, $p > .001$). This is a rather surprising finding as one would expect observers to report seeing only a circle more often in the control condition compared to the masking condition.

Finally, in trials in which both the circle and the line were absent, so the target location really was blank, participants reported seeing a blank space on 76% of the trials in the control condition and 71% in the masking condition a difference that was not statistically significant ($t(15) = 1.32$, $p > .001$) (Figure 6.5). This finding is important because it shows that observers were not just more inclined to report "BL" in the masking condition. If we now compare this finding with the finding that for "target present" and "circle no line" trials observers reported "BL" more often for mask trials than for control trials it allow us to be confident that in the "blank trials" they really experienced "BL" on some mask trials and they were not simply exhibiting a response bias responding BL when the four dot mask stayed on after the target offset.

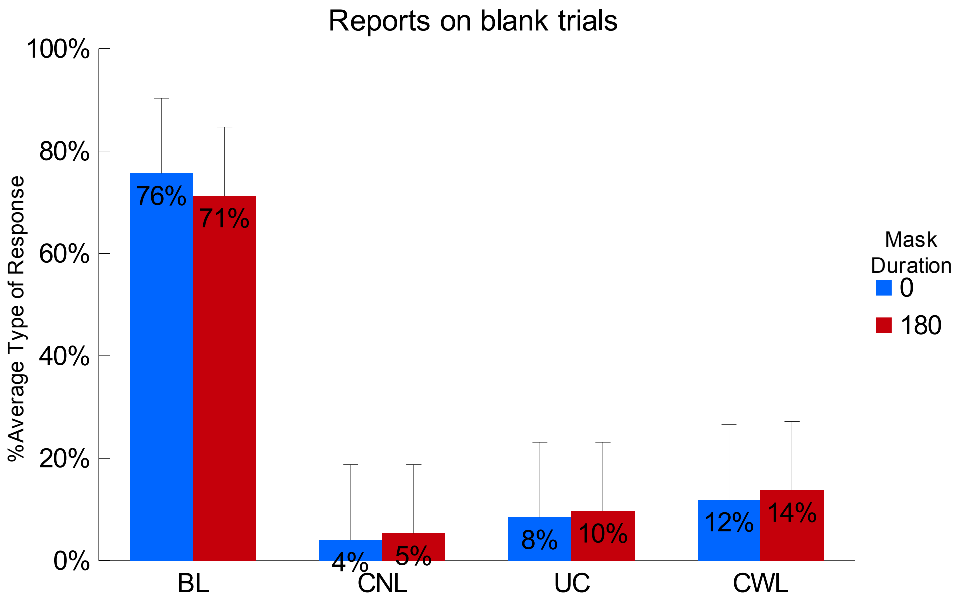

Figure 6.5. *Percentages of type of reports in the blank trials in the control (i.e. blue bars) and masking condition (red bars).*

Interestingly, on 12% of the control trials and 14% of the masking trials they reported seeing both the circle and the line although the target location was empty. This means that some of the CWL responses in the target present trials (the last two bars in Figure 6.3) were due to guessing. A simple treatment is to perform a guessing correction by subtracting the CWL responses in the blank trials from the CWL responses in the target present trials. As Figure 6.6 shows there are now fewer CWL responses but the difference between control and masking conditions for CWL responses remained significant ($t(15) = 8.67$, $p < .001$). The differences between the types of responses in the masking condition remained non significant ($x^2 = 1.72$, $p > .05$).

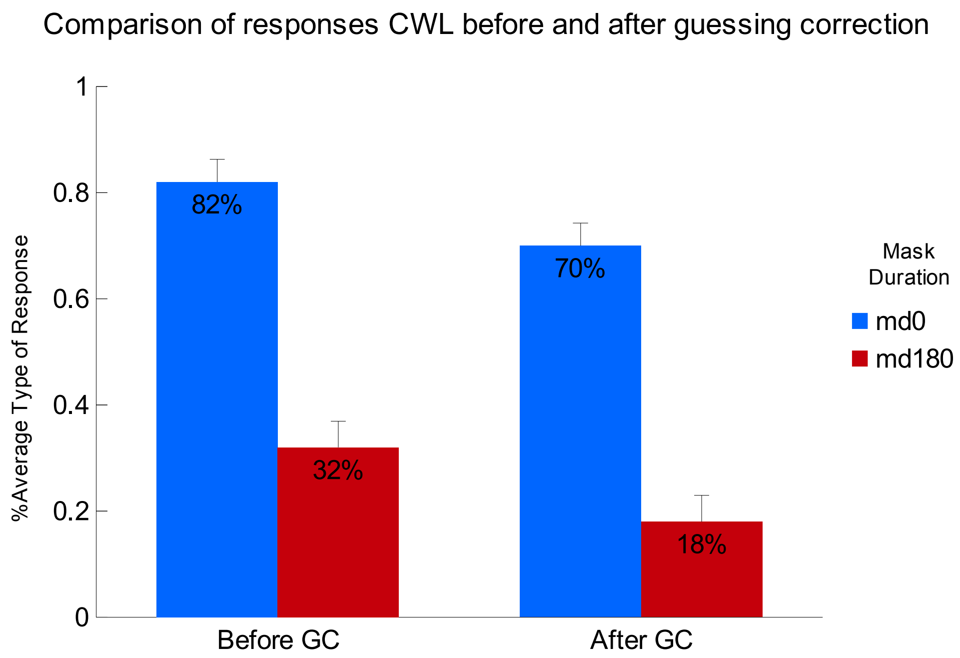

Figure 6.6. *Comparison of the responses CWL before guessing correction (GC)(i.e. the two bars to the left of the graph) and after GC (i.e. the two bars to the right of the graph).*

I now turn to the scores for the discrimination task in the present experiment. Figure 6.7 shows the participants' scores in the masking condition when they were choosing a particular response. The first thing to observe is their high discrimination performance when they were responding CWL (84%); it shows that in target present trials in which participants reported seeing the target circle and the line (18%, Figure 6.6) they were able to say correctly 84% of the times that the line was horizontal or vertical. Another important aspect of the data is the participants' scores when they were responding with a BL, CNL or UC statement. From the sixteen participants, there were fifteen (N=15) who chose BL response, fourteen (N=14) who chose CNL response and fifteen (N=15) who chose UC response at least once. None of the scores when choosing any of these statements was significantly different from chance ($t < 1.98$, $p > .001$). Thus, when observers reported seeing either only a circle but not the line or they were uncertain as to the contents of the target location or they just saw a blank space although the target was present, their scores suggest that, indeed, they were unable to discriminate the target.

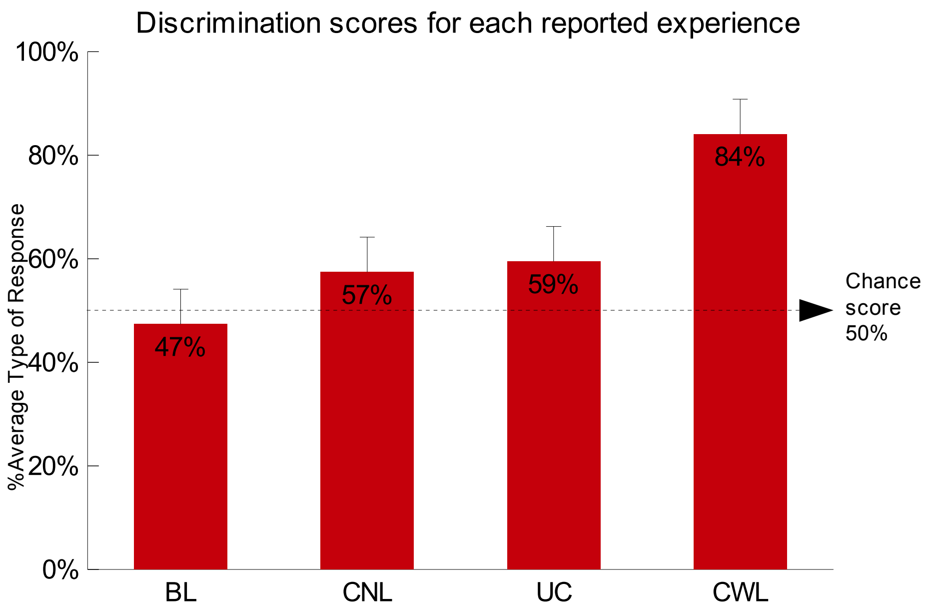

Figure 6.7. *Discrimination performance when participants were choosing a statement for target present trials in the masking condition (i.e. red bars in previous graphs).*

Discussion

In the present study I investigated if there are conditions in which participants experience a blank space in the target location and, if they do, how often this occurs. A task was employed in which the participants had both to report their phenomenal experience and to discriminate the target. The principal finding was that at the delayed offset trials a substantial number of “blank” reports was obtained; there were trials in which participants reported seeing an empty space in the target location even though the target (i.e. circle plus line) was present. This finding adds to the growing number of reports in studies in OSM that there are trials in which the masking effect is complete resulting in observers perceiving a blank space in the target location (Di Lollo et al., 2000; Kahan & Mathis, 2002; Neill et al., 2002). That there were trials in which reports of a “blank” experience at the target location were obtained is also in accordance with the Di Lollo et al.'s (2000) re-entrant account which states that substitution occurs of the whole representation of the target (plus mask) when the mask remains visible for some time after the target offset (although only on some trials). The consequence of this substitution process was the phenomenal experience, for at least some trials, of an empty space in the location that was previously occupied by the target; the observers did not have access to the record of any of the target's features.

Looking at their scores in the discrimination task when they were reporting blank on target present trials we observe that these were not significantly different from chance; when observers reported seeing a blank space in the target location they were also unable to correctly report the target. This finding may be subject to two interpretations. The first one is that if there was an implicit perception of the target in the present experiment, this was not sufficient to influence forced choice responses about the orientation of the line. The second interpretation is that the observers' chance scores when they were reporting blank in the target present trials may have been an artefact of eye movements. That is, in the beginning of each trial the observers may have been fixating not at the centre of the circular array but rather to a location that was further away from the target. Or that upon target onset their eye movements followed a pattern that increased the possibility that the target offset before their eyes moved to the target location. I will discuss each interpretation separately.

An aim of the present study was to investigate if when observers reported of seeing a blank space in target present trials an implicit perception of the target (if any) could support discrimination performance in the same trials. The data showed that if there was an implicit perception this was not strong enough to influence discrimination performance; when observers reported BL in the target present trials their score was not different from chance. This finding, however, seems to be at odds with a number of studies in OSM which suggest that even when observers are unable to report the target, the target may still be processed at a featural or even semantic level and guide their behaviour. For instance, in Chen and Treisman's (2009) Experiment 1, the target (present on 50% of the trials) was a double arrow pointing either to the left or to the right and appeared in one of the four quadrants on the screen. The mask consisted of four sets of single arrows which, like the target, were pointing to the left or right. On half of the target present trials the target double arrows and the mask single arrows were pointing in the same direction (congruent trials) and on the other half in different directions (incongruent trials). The observers had first to report the direction of the mask arrows (i.e. left or right) and then to report if the target was present. The reasoning behind this experimental set up was to examine if target - mask congruency will affect reaction time to the mask as a function of whether the target was detected or not. The results showed that when in the target present trials observers failed to detect the target they were still faster at reporting correctly the direction of the mask arrows in the congruent than in the incongruent trials. Chen and Treisman's (2009) interpretation of this finding was that although the observers reported not seeing the target, the target was nevertheless processed to a featural level. As a result, in the congruent trials, the match between the target and the mask was detected. This in turn resulted in a better performance in the congruent compared to the incongruent trials. In a subsequent experiment (Experiment 2) they showed that a masked target is not processed at a categorical level.

There is one study that claimed that an undetected target can be processed beyond the featural level. In Goodhew, Visser, Lipp and Dux's (2011b) study (Experiment 1) the target was either one of four words (‘BLUE’, ‘PINK’, ‘MAIL’, or ‘HOUR’) or a non word. The mask consisted of four dots which were either pink or blue in colour. Trials were either compatible (target word matched the mask colour), incompatible (target word mismatched the mask colour) or neutral (the target was a non word). The participants had first to report as quickly as possible the colour of the mask and subsequently they had to perform a lexical decision on the target, namely if the target was a word or a non word. The results showed that both when the target was correctly recognised as a word or a non word, reaction times at reporting the colour of the mask were significantly better in the compatible than in the incompatible trials. Goodhew et al. (2011) explained this finding by suggesting that even in trials in which the target went undetected its semantic properties were still processed influencing subsequent behaviour by priming responses about the colour of the mask.

Goodhew et al.'s findings, however, are in contrast to Chen and Treisman's (2009) Experiment 2 which, as noted earlier, showed that a masked target was not subjected to a categorical analysis. They are also in contrast to Reiss and Hoffman's (2006) findings who also investigated if a masked target could be processed semantically using an EEG measure. They examined the N400 component in a task in which a word (a prime) that preceded the target was semantically either correlated or uncorrelated with the target. The N400 component is a negative-going potential, which peaks typically at about 400ms after the stimulus onset and reflects the degree of semantic incongruity between the target and the context it appears. Reiss and Hoffman found that although a substantial N400 component was observed in the common offset trials, this was abolished in the delayed offset trials. This was taken to show that in the masked condition the target was not implicitly perceived and it was not processed semantically, a finding that is in contrast to the results provided by Goodhew et al.'s (2011).

Be that as it may, the present study shows that to the extent that there might have been any implicit perception of the target in the target present trials, this was not sufficient to support discrimination performance when participants reported seeing a blank space in the target location.

The second interpretation of the finding that scores in the discrimination task were at chance when observers reported seeing a blank space in the target location in the target present trials is that observers really did not represent any information about the target but that their experience of a blank location may reflect an artefact of eye movements which influenced the distribution of attention over the stimulus display. There have been many studies that show that there are strong links between eye movements and attention (see Hoffman, 1998 for a review on the relationship between eye movements and attention). In my study, prior to the task, observers were instructed to fixate at the centre of the screen at the beginning of every trial. A fixation circle that was presented in the beginning of every trial and it was having its size changed over time it was also expected to capture the observers' attention. Eye movements, however, were not recorded and therefore it is difficult to say whether observers were fixating at the centre of the screen (and hence of the circular array) at the beginning of each trial.

To investigate whether “blank” phenomenal experiences are due to masking mechanisms or are an artefact of eye movements it is necessary to record eye movements. In such task, if in target present trials when observers report blank the pattern of their eye movements is different from that when reporting seeing the target, this would suggest that the “blank” experiences is likely to be an artefact of the eye movements. Conversely, if the pattern of their eye movements is the same both when they report seeing the target and when they perceive a blank space in the target location it will indicate that blank responses are due to masking. Such a study will shed light on the nature of the blank responses and the conditions under which these occur.

Finally, and relevant to present study are the findings from Sekar, Findley, Poeppel and Llinas (2013). These authors investigated whether conscious experience emerges as a result of an all-or-none process. In their experiment the participants had to report the identity of a briefly presented digit (0-9). After they reported the identity of the digit the participants were asked to choose between four awareness reports. These were: “Did not see”, “Could not identify”, “Unsure” and “Sure”. At the same time brain activity was recorded by measuring the event related fields (ERF). These are components that are produced when brain activity is recorded using magnetoencephalografy (MEG). The results showed that although an ERF was present 240ms post stimulus regardless of which awareness report was chosen when the participants reported seeing the digit (i.e. they were reporting “Sure”) MEG activity was significantly larger compared to other reports (i.e. when they were reporting “Did not see”, “Could not identify” and “Unsure”). The authors claimed that this finding showed that conscious visual experience follows an all-or-none rule rather than a gradient from unconscious to conscious experience (although see Bachmann, 2013, for why Sekar et al.’s findings should be treated cautiously). These results can be seen as supporting a similar conclusion arrived at by Sergent & Dehaene (2004) regarding missed T2s in the attentional blink. However the present results suggests that while perception in OSM may sometimes be ‘none’ (blank responses on target present trials) it may often be partial (guessing corrected CNL and UC responses on target present trials). My conclusion therefore is similar to that of Nieuwenhuis and de Kleijn (2011) who argue that whether or not conscious experience appears to be a continuum or all-or-none depends on both task difficulty and the type of response required.

Conclusion

The present study was the first in the literature to investigate the observers' phenomenological experience of the target for a task that produces OSM. The principal finding was that there were target present trials in which “blank” responses were obtained. This occurred when the mask had a delayed offset and accounted for nearly one fourth of responses to target trials. Whether this finding reflects masking or is an eye movement artefact needs to be further investigated.

Chapter 7

General Discussion

In the first Chapter of this thesis, I started by considering a fundamental issue in visual perception, namely the fact that we consciously perceive only a tiny proportion of the visual information available to our eyes. The mere presence of something on the retinal image is not sufficient for visual awareness. Attention plays a critical role in awareness, the importance of which is demonstrated in a number of phenomena, such as change blindness and inattentional blindness, in which otherwise highly salient changes or appearances of visual items are frequently missed when not the focus of an observer’s attention. Though attention seems to be a necessary condition for awareness it was noted that there is evidence that it is not, by itself, sufficient (e.g. Hsieh, Colas and Kanwisher, 2011). The exact nature of the relationship between attention and visual awareness is a matter of ongoing debate. One paradigm which has claimed to yield some insights into the relationship between attention and visual awareness is object substitution masking (OSM). According to Di Lollo and colleagues (Di Lollo et al. 2000; Enns and Di Lollo, 2000; Di Lollo, Enns & Rensink, 2002) OSM occurs because of conflicts between iterative information exchanges at higher and lower levels of visual processing via reentrant pathways in the brain which occur as a part of the normal processes of visual perception. Spatial attention was said to play a central role in this conceptualization of the OSM phenomenon. Evidence suggested that the occurrence of OSM depended on the distribution of attention over the target display. Under diffused attention conditions large masking effects were observed but when, by a variety of means, spatial attention was either pre-focused on the target location prior to the target onset, or rapidly focused upon it immediately thereafter, little or no OSM occurred (e.g. Di Lollo et al., 2000; Kotsoni, Mareschal, Csibra, & Johnson, 2006). The reentrant model, together with its computational implementation CMOS, was both based on, and neatly accounted for, these experimental observations. Attention was viewed as being the principal factor in determining the number of reentrant iterations required in order for a conscious percept to form. Where attention was unable to rapidly focus on a briefly presented target and when a trailing mask was present at that location, the result was that a stable percept of the mask alone rather than of target plus mask was most likely to emerge as a consequence of the process of reentrant exchanges, the probability of the former increasing the longer the mask remained on screen after the target offset.

Because re-entrant processing is in the core of OSM, OSM was thought to be a test of the general model of re-entrant processing of visual awareness. According to Di Lollo et al. OSM occurs because, in the mask delayed offset trials, the perceptual hypothesis of the target plus mask does not match with the current visual input (i.e. mask alone). As a result a new iterative loop commences based on what is currently presented on the display and persisting activity in low level cells. This new activity leads to the perception of the mask alone and OSM occurs. Therefore, the importance of OSM and its re-entrant account is that it meshes well with much current thinking about the manner in which the visual system functions, namely that visual awareness is the result of the intercommunication between hierarchically different levels of visual processing.

Because OSM has been thought to reflect such processes it has been often used as a tool to examine visual awareness deficits to atypical population. For instance, Wynn et al. (2013), using the FDM paradigm and manipulating the SOA between the target and the mask, found that patients who suffer from schizophrenia performed significantly worse in a discrimination task compared to healthy participants. The authors suggested that his finding perhaps shows that the patients' poor performance may be because of dysfunctional re-entrant processing which impedes the perception of the target. Similar results were obtained by Green et al. (2011) who showed that patients with schizophrenia exhibit worse performance than healthy participants in a OSM task.

The results of my experiments are in accordance with the general re-entrant model of visual awareness and Di Lollo et al.'s re-entrant account of OSM. They showed that as mask duration increased it was more difficult for the observers to report the target. This was because in the mask delayed offset trials there was a mismatch between the perceptual hypothesis of the target plus mask and the current input of the mask alone. As a result the representation of the target was substituted in awareness by that of the mask alone. However, as it will be discussed below, my results showed that attention, at least in the context of OSM, does not play a role in a re-entrant model.

In the next section I will summarise the findings of the experiments in which the question of the role of attention in OSM is revisited. I will start by briefly describing the findings from those experiments in which attention was controlled either implicitly by manipulating either set size or the level of crowding (Chapters 2-4) or explicitly by employing a spatial pre-cue (Chapter 5). I will then go on to discuss how these findings fit to the current accounts of OSM and a discussion will follow about the role of target resolution in OSM. The discussion will then turn to the phenomenology of OSM (Chapter 6) and the implications that the present findings on this have for accounts of OSM. Finally, some proposals will be made about the direction of future research on OSM and its place in understanding of visual awareness.

OSM and attention.

In Chapter 2 the claim that attention modulates OSM was tested in a indirect manner by varying set size. This method reflected some of the experiments originally conducted by Di Lollo et al. (2000) but with the constraint that performance remained within a measurable range. Four alternative forced choice discrimination tasks were employed in which observers had to report the location either of a gap in one of the sides in a target square (Experiments 1 & 3) or of a missing side in the target square (Experiment 2) while the number of distractors (also with missing segments or missing sides) was manipulated across trials. The principal finding was that, contrary to previous reports (e.g. Di Lollo et al., 2000), set size and mask duration did not interact, although their individual effects on performance were large and highly significant. Mask duration had a similar reductive effect on performance irrespective of the number of distractors. Even when the data for set sizes of 4 and 16 from all three experiments were combined to increase the statistical power of the study there was still no evidence of an interaction between the two factors that would be consistent with any involvement of attention in OSM. In a subsequent series of experiments a detection task was employed. The observers were asked to report the presence or absence of a critical target feature (a bisecting vertical bar in a target circle). The results of Experiment 4 showed a seeming interaction between set size and mask duration when the bar was present in the target circle. However, when the data from the bar absent trials were taken into account the interaction between the two factors no longer occurred. Even when the stimuli were presented at reduced eccentricity no interaction was evident in the data when the bar absent trials were included in the analysis (Experiment 5a). The two factors interacted only when ceiling performance in the bar absent trials was observed (Experiment 5b). This level of performance was elicited by changing the experimental instructions in such a way that participants were induced to set a high criterion for making target present responses and which, thereby, reduced or eliminated false alarms. The findings of the last three Experiments suggest that an interaction between set size and mask duration is only present when ceiling or floor effects are present in the data. In other words, the "interaction" between these factors, where it occurs, is wholly a spurious consequence of the restrictions in the measurable range of performance. Where such restrictions are absent set size and mask duration are clearly shown to have independent effects on performance.

At this junction it is worth considering if the different stimuli used in the experiments of Chapter 2 and Chapter 3 may have played a role on the different set size effect observed in those experiments. For instance, when comparing the pattern of results of Experiment 3 (Figure 2.5) to Experiments 4 and 5a,b, (Figures 3.3, 3.5 and 3.7) one thing to observe is the differences of the set size effects on performance. Whereas in Experiment 3 set size influenced performance only when it increased to 16 items, for Experiments 4 and 5a,b, any increment of the number of distractors had a differential effect on performance. One could argue that such differences of the set size effects on performance between experiments could be attributed to the different type of stimuli employed in these experiments (i.e. Landolt squares versus circles with or without a bisecting vertical bar). In other words, the different stimuli might have induced different demands on visual selection. However, there are not theoretical reasons to believe that the differential effects of set size between experiments can be attributed to the different types of stimuli used in those experiments. In fact, Alpern et al. (1972) and, Johnson, Ketner and Balestrery (1978) showed that when squares and circles are used in a visual search task detection thresholds are the same for both types of stimuli (although they did not compare set size effects for the two types of stimuli). In the FDM paradigm, and in other paradigms in visual search literature, many different types of stimuli have been used and to the best of the author's knowledge there are no systematic attempts to compare them in terms of their demands on visual selection.

A relevant study is from Palmer (1994) who considered how different types of stimuli may influence set size in a visual search paradigm. He examined if set size effects depend on the type of stimuli both in a simple and in a complex search task. Palmer (1994) considered a task to be simple when there is homogeneity between distractors, in other words that distractors are identical to each other but different from the target (Palmer, 1994). Conversely, a task was considered complex when the distractors are different to each other and to the target. Palmer found that in simple tasks in which different stimuli were employed the magnitude of the set size effects was not different between experiments. Palmer concluded that this finding shows that in simple tasks set size effects are independent from type of stimuli. For complex tasks, although he found that the set size effects were larger for complex tasks compared to the simple ones he did not compare this effects between complex tasks in which various stimuli were used. Because the tasks employed in my experiments are better described as complex (because the distractors were heterogeneous) it is difficult to discern if and how the different types of stimuli played a role in the observed set size effects between experiments. Therefore, although there is no evidence that the differential effects of set size observed between experiments in the present thesis can be attributed to the different types of stimuli used in those experiments it is possible that under the present experimental conditions Landolt squares and circles with a bisecting vertical bar resulted in different set size effects between experiments.

In Chapter 4 the question was investigated of whether the set size effect, that was observed in the performance data in the previous experiments and in other studies on OSM (e.g. Di Lollo et al., 2000), might actually be due to crowding. It was conjectured that if the set size effect was in fact a result of crowding then it should not be observed in a task in which crowding is kept equivalent for different set sizes. The results from Experiment 6 were that when crowding was controlled the set size effect was no longer evident. This finding provided initial support to the conjecture that the set size effect in OSM studies might have been in fact due to crowding alone and not to the number of distracter items themselves. Subsequent experiments, however, did not support this finding. In Experiment 7, which was essentially a replication of Experiment 6 but with the critical feature increased in saliency (i.e. larger gap size), both a main effect of set size and a main effect of crowding were obtained. This finding was further replicated in Experiment 8 in which only the target contained the critical feature. These latter two results are in contrast to the hypothesis that the effect of set size in OSM was due to crowding. They demonstrate that the two factors influence discrimination performance independently; increasing the number of distractors and/or crowding the target reduces the accuracy with which the critical feature of the target is reported. Two further important findings were present in all these three experiments. First, as in Experiments 1 – 3 (in which identical stimuli to the crowding experiments were employed), set size did not interact with mask duration, supporting the finding that attention does not influence OSM. Secondly, crowding also did not interact with mask duration. Trials in which the target was crowded did not result in a larger masking effect compared to trials in which the target was free from crowding. If we accept that crowding is a consequence of a failure of spatial attention (He, Cavanagh, & Intriligator, 1996, 1997; Wolford & Chambers, 1983) then the absence of an interaction between crowding and mask duration in Experiments 6 – 8, together with the findings from Experiments 1-5, can be taken as evidence that the distribution of spatial attention does not influence OSM.

To summarise, the results from all these experiments are consistent in suggesting that attention does not modulate OSM. Variations of the number of distractors did not affect OSM (Experiments 1-5). Similarly, having a crowded target did not result in a larger masking effect compared to when the target was not crowded (Experiments 6-8). However, for reasons that will be discussed below, caution would be required in drawing any firm conclusions regarding the role of attention in OSM.

The design of the experiments in Chapters 2 and 3 was similar, in all major respects, to that of Di Lollo et al.'s studies which were predicated on the assumption that set size is a proxy for the speed with which attention becomes focused on the target (Duncan & Humphreys, 1989; Treisman & Kanwisher, 1998; Wolfe et al., 1989). This assumption itself, however, is not impervious to challenge. Experiments by Carrasco and her colleagues (Carrasco, Evert, Chang, & Katz, 1995; Carrasco & Frieder, 1997) and Verghese and Nakayama (1994) showed that the set size effect could be attributed, at least partially, to sensory factors rather than to shifts of covert attention. For instance, Carrasco et al. (1995) manipulated orthogonally set size, which ranged from 2 to 36 items, and target eccentricity from fixation, which ranged from 0.7° to 3.5°. They found that set size effects were larger in magnitude at larger target eccentricities. In a later study (Carrasco & Frieder, 1997) they enlarged the size of the more peripheral stimuli in line with the cortical magnification factor. This manipulation allowed more peripheral stimuli to be matched to less peripheral stimuli in terms of visual resolution. The authors found that when the stimuli were matched in terms of visual resolution the effect of eccentricity on set size was eliminated. This finding led Carrasco and her colleagues to attribute the set size effect to factors related to the spatial resolution of the items located in the peripheral vision rather than to factors related to attentional processes[6]. If Carrasco et al.'s conclusions are correct then the lack of an interaction between set size and mask duration in Chapters 2 and 3 may not be informative about the role of attention in OSM. This is because set size is a variable which is potentially unrelated, or partially related, to how spatial attention is allocated over the visual field.

Carrasco et al.'s findings have also implications on the interpretation of the finding in the crowding experiments (Chapter 4) in which crowding and mask duration did not interact. This finding was interpreted as evidence that attention (as mediated by crowding) did not affect OSM. This interpretation was based on the assumption that crowding is a proxy for the speed with which attention contacts the target. For instance, a number of studies have shown that when a crowded target was cued the effect of crowding on the target was reduced (Chakravarthi & Cavanagh, 2009; Freeman & Pelli, 2007; Strasburger, 2005; Yeshurun & Rashal, 2010). In these studies, deployment of attention to the cued target was said to decrease the critical target-flankers distance at which crowding was observed. Other studies, however, which also employed a cue to

[6] Wolfe, O'Neil and Bennet (Wolfe, O'Neill, & Bennett, 1998) proposed that the eccentricity effects found in Carrasco et al.'s studies may in fact reflect an attentional bias towards the centrally positioned items rather than a decline to spatial resolution of the more peripheral items. It is important to note however, that in Wolfe, O'Neil and Bennet's experiments the display configuration was that of a matrix array. It is unclear how their suggestion could apply to Experiments 6 – 8 where the target was embedded in a circular array where the distance between the target and fixation was kept constant.

direct attention to a crowded target found little effect of attention on crowding (e.g. Nazir, 1992; Scolari, Kohnen, Barton, & Awh, 2007; Wilkinson et al., 1997). After all, as Levi (2008) noted, it is typical in crowding studies that the observer knows in advance where and when the target will appear and therefore it may be unlikely that crowding can be explained on the basis of attentional deployment. Thus, the finding in Chapter 4 that crowding and mask duration do not interact should be interpreted cautiously because crowding may not actually be a proxy for the speed with which spatial attention contacts the target.

However, a further experiment in this series gave a more unambiguous picture about the status of spatial attention in OSM. In Experiment 9 a 100% valid spatial pre-cue onset simultaneously with or some milliseconds before the target. As previously, the observers were required to report the location of a gap in one of the sides in the target square. The data showed that pre-cueing the target improved discrimination performance significantly; observers reported the target feature more accurately when the cue onset before the target compared to when it onset simultaneously with the target. This improved discrimination performance in the precue conditions was not, however, accompanied by decreased OSM as the re-entrant account would have predicted; the facilitative effect of the pre-cue was the same across all mask durations.

Chapter 6 had a different aim to the earlier chapters. The aim was to explore the phenomenal consequences of OSM on target perceptibility. Namely, it was investigated whether, in OSM, there were conditions in which participants experienced a blank space in the target location although the target was present, and what were the conditions under which this experience occurred. This was done using a novel method by collecting subjective reports about the observers' phenomenal experience of the target location together with objective reports about target target perceptibility in the form of a discrimination task in the same experiment. The principal finding was that a relatively large proportion of “blank” reports (i.e. reporting seeing a blank space in the target location) were obtained in the delayed mask offset trials (about 24%). This finding appears to be in accordance with the re-entrant theory which states that complete substitution of the target representation occurs in the delayed mask conditions (although “complete” masking occurred only on some trials in this experiment). This finding is also consistent with the informal phenomenal observations reported by Di Lollo and his colleagues (2000). Importantly, the objective measures that were taken from the discrimination task showed that in conditions where observers reported seeing a blank space at the masked location their performance was at chance. This finding was interpreted as showing that even if there was some implicit perception of the target it was certainly not sufficient to support accurate forced choice responses.

Collectively, although some of the findings presented in this thesis are in accordance to the re-entrant account (i.e. Experiment 10) the majority of the results pose serious problems for Di Lollo et al.'s re-entrant account. As it was described in the previous chapters, the re-entrant account of OSM views factors such as set size and (pre)cueing as proxies for the speed with which attention is deployed towards the target. According to this account, factors that induce conditions of diffused attention (e.g. large set sizes) may result in longer times for the target to be located. This in turn means that, under delayed offset trials, the display may change from target plus mask to mask only before the target has been fully processed (or identified) thus rendering it susceptible to masking. On the other hand, if attention locates the target rapidly either because there are not many items to delay the deployment of attention to the target or if the target location is known in advance, the target is said to be protected from masking. In this case, the target is said to be processed rapidly and identified before the mask alone interferes. The experiments described above challenge this interpretation in two ways. First, neither variations of set size nor variations of cue-target onset asynchrony had an effect on OSM. Secondly, even when the only item in the display was the target (i.e. set size of one) or when the target location was known several milliseconds in advance (i.e. cue-target onset asynchrony of 150ms) substantial OSM was obtained. Collectively, these findings pose serious problems to the re-entrant account. In the next section two other accounts will be considered; the object updating account as proposed by Lleras and Moore (2003), and Moore and Lleras (2005) and the attentional gating model (Põder, 2012) . The relevance of the current findings to these models will be assessed.

Sources of the set size effect

As it was described in the introduction of Chapter 4 a number of studies claimed that the set size effect in visual search tasks may reflect the operation of sensory factors on the effect. Such factors include multiple eye fixations in displays with many items (Irwin, 1991; Rayner & Fisher, 1987), eccentricity effects (Yager & Davis, 1987) and crowding (Verghese & Nakayama, 1994). For instance with larger set sizes stimuli are typically presented at larger eccentricities. However, processing efficiency typically declines as stimuli move further from the centre of gaze, which in turn, results in larger set size effects (Andersen & Kramer, 1993; Andersen, 1990; Downing, 1988). Crowding, on the other hand, has been said to operate when target and distractors appear in close distance. Under this condition the distractors' features integrate with those of the target making the target less visible. The more are the distractors that flank the target (i.e. set size) the less discriminable the target becomes.

In my experiments only in Experiment 3 sensory factors seemed to contribute to the observed set size effect. In that experiment, the effect of set size was small when the number of items increased from 1 to 4 and from 4 to 8 but it became much larger when it increased to 16 items. It was argued that such difference perhaps could be attributed to the target becoming more crowded with set size of 16 items. However, in a subsequent series of experiments (Experiments 6-8) it was shown that set size did not vary with crowding; whether the target was crowded did not influence the effect of set size. Other potential sensory effects (i.e. eye fixations and target eccentricity) can also be excluded. Firstly, when Experiment 4 was compared to Experiment 5a in which target eccentricity was reduced it was shown that eccentricity did not influenced the set size effect. Secondly, the display duration was too brief to allow any voluntary eye movements. Therefore, the set size effect obtained in my experiments cannot be explained by an account that attributes set size to bottom-up sensory factors or to volitional eye movements.

On the other hand, set size effects have also been viewed as reflecting the distribution of attention over the search display. For instance, when a target is pre-cued or it pops out from its background the set size effect vanishes (Duncan & Humphreys, 1989; Treisman & Kanwisher, 1998; Wolfe, Cave, & Franzel, 1989). Two post-selection attentional processes have been thought to contribute to the set size effect (Broadbent, 1958; Palmer, 1994, 1995). The first process refers to the limited information that the perceptual system can process at a time. According to this view the perceptual system has limited capacity. When many stimuli are attended at a time fewer resources can be devoted to each stimulus. Therefore, when the target is presented with many distractors fewer perceptual resources will be allocated to the target compared to when it is presented with few distractors or in isolation. The other post-selection process refers to the problem of determining which of the stimuli is the target, a process that is known as the decision integration hypothesis. According to this hypothesis, the perception of the target is affected by the integration of information from non-target items; every time an additional distractor appears with the target, extra noise is added to the representation of the target. This may then result in a distractor to be mistaken for a target which in detection tasks, will lead to a high rates of false alarms (i.e. reporting that a target is present when it is not).

The set size effects observed in my experiments reflect better such attentional processes than sensory ones. For Experiments 1-3 and 6-8 in which the observers had to report the location of the gap of the target square, it is not clear if the set size effects reflect the perceptual system's limited capacity to process information as set size increased or to the decision of whether the gap was located to the left, right, or bottom of the square. It is possible that either or both processes contributed to the effect. As set size increased fewer perceptual resources were devoted to the target which influenced target perceptibility. On the other hand, the presentation of additional distractors added more noise to the target's representation which affected the decision about the location of the target's critical feature. For Experiments 4 and 5a&b it appears that the set size effects were caused by the decision of whether the target's critical feature was present. This was especially so in Experiments 5a. In that experiment, as set size increased so did the false alarm rates; observers were reporting more often that the target was present although it was not as more distractors were added in the display. This increment of the false alarm rates as set size increased shows that the distractors were adding more noise to the target's representation resulting in reporting erroneously that the target's critical feature was present. Only when the response criterion for reporting the target was raised (in Experiment 5b) the false alarm rates were reduced or even eliminated in some conditions. This shows that for those experiments the set size effect reflected more attentional processes that concerned the decision of whether target's critical feature was present than processes that are related with the perceptual system's limited capacity.

Implications for alternative models of OSM: Object updating account and feed-forward only accounts.

In Chapter 3 the object updating account (OUA) was described and discussed in relation to the finding that set size and mask duration did not interact in OSM. In this section the main tenets of OUA are revisited. The discussion will be about the predictions of OUA and whether the OUA can account better is better placed to account for the findings in the present thesis than the re-entrant model.

An alternative to Di Lollo et al.'s re-entrant account is the object updating account (OUA) (Enns, Lleras, & Moore, 2009; Lleras & Moore, 2003; Moore & Lleras, 2005). The OUA posits that OSM occurs at the object token level of visual representation. According to this account, when the target and mask onset simultaneously and in more or less the same location, the visual system treats them as a single integrated object. OSM arises from this failure of the visual system to create separate tokens for the target and the mask. Initially, the type representation attached to the single token contains feature information about both the target and the mask. When the mask remains present after target offset, this is interpreted as a transformation of the original object. The type representation attached to the token representation is updated to include only the features of the mask. Target-plus-mask transforms into mask-alone, and feature information about the target is lost. If, however, the visual system initially represents the target and the mask as two different objects, each represented by an individual token, then the contents of the target's object token are protected from the updating process when the mask's offset is delayed. Perhaps the strongest evidence in favor of the OUA was the finding in Lleras and Moore's (2003) Experiment 4. In that experiment a target search array was presented briefly around a fixation point. The offset of the target search array was followed by a blank frame (ISI) which was then followed by masks comprising of a single dot. These were presented at further eccentricities than the items in the search array. A critical manipulation was the duration of the ISI between the target and these dot masks. Short ISIs created the perception of apparent motion between the target and the mask. Long ISIs did not lead to such visual experience. Lleras and Moore found that for short ISIs significant masking was observed whereas for long ISIs masking was weaker. They argued that because of the apparent motion the visual system interpreted the object token that was created by the trailing mask as being a continuation of the target object token. This resulted in the contents of the target's object token being updated or overwritten by the contents of the trailing mask's object token. This updating process, however, did not occur for long ISIs because the visual system perceived the target and the mask as two separate and discriminable object tokens. This resulted in the target being protected from masking.

The finding in Experiment 9 that directing attention to the target location did not influence OSM may be better explained by the OUA. In Experiment 9 the target and the mask not only had a common onset but they also occupied the same spatial location. Thus, the pre-cue indicated not only the location of the target but also of the mask. This in turn, suggests that attention might have been directed to both stimuli. If this was the case then, according to OUA, the visual system might have been unable to individuate the two stimuli (target and mask) into two separate object tokens at the onset of the target search display. Therefore, the failure of cueing to reduce OSM may be because cueing was unhelpful in directing attention exclusively to the target. If we assume this possibility, the lack on an interaction between CTOA (cue-target onset asynchrony) and mask duration can be viewed as consistent with the OUA. Perhaps, were the target and mask presented at different spatial locations (for instance, as in the paradigm used by Lleras and Moore (2003)), the spatial pre-cue might have been more effective in terms of directing attention to the target alone rather that to both the target and to the mask. In such a case, perhaps more masking would have occurred when the pre-cue – target asynchrony was zero compared to non-zero trials resulting in an interaction between CTOA and mask duration. This is because, compared to zero CTOAs, for non-zero CTOAs it would have been more likely for the visual system to represent the two stimuli as two separate object tokens because attention would have been deployed to the target location prior to the target onset. Further work is required to explore the effects of pre-cueing on the updating process when the target and the mask location is manipulated.

Whereas in both the re-entrant account and the OUA the notion of reentrant neural connections constitutes an integral and critical part of their theoretical frameworks, other models promote a view in which only feed-forward processes are considered to account for OSM. Francis and Hermens (2002) suggested that a feedforward theory based on existing models of backward masking could also explain OSM, without the need for re-entrant processes. They presented computer simulations in which models of the processes involved in metacontrast masking were applied to Di Lollo et al.'s data which resulted in masking functions similar to those obtained by Di Lollo et al. (2000). Di Lollo, Enns and Rensink (2002), however, argued that only some their results were addressed by Francis and Hermens's computer simulations and that other important aspects of the data were ignored. Furthermore, the main assumption in Francis and Hermens simulations was that spatial attention has sufficient spatial resolution to focus only on the mask. However, in Di Lollo et al.s' (2000) experiments the spatial difference between the target and the mask was only 20 mins of arc and a number of studies have shown that spatial attention' s resolution cannot discriminate two items that are less than a degree of visual angle apart (He, Cavanagh, & Intriligator, 1997; Laberge, 1990)[7].

More recently Poder (2012) developed a feedforward-only model which was argued to provide a better account of the masking effects shown in FDM. According to Poder's attentional gating model OSM occurs as a result of changes in the target's signal-to-noise ratio (SNR) brought about by the presence of the lingering mask after target offset. Specifically he claims that because of the common onset of the target and the mask there is a temporal integration of their signals. If the two stimuli offset simultaneously then both signals will be preserved up to the object identification level; the mask's signal adds some noise to the target's signal (and vice versa) but the target is still identifiable. On the other hand, when the mask remains visible after the target offset the signal of the mask alone is available for a longer time. As a result the

[7] Although this objection may apply to situations in which the target and the mask occupy the same depth plane it is not known if it also applies to situations in which the two objects are presented in different depth planes or they are perceived as being so. For instance, Nakayama and Silverman (1986) showed that when two items appear at different depth planes observers may attend each plane selectively. In FDM, because the mask has greater energy than the target perhaps it appears as being closer to the observers than the target. Indeed, Kahan and Lightman (2006) showed that OSM was evident when in their tasks the target and the mask appeared at the same depth plane or when the mask appeared in front of the target but not when the mask appeared behind the target.

mask's signal adds more noise to that of the target and as a result the target is masked. Poder's attentional gating model makes a different prediction from the re-entrant account about the effect of set size and the role of attention in OSM. Specifically, he argues that the time it takes for attention to locate the target is independent of set size. This follows because the four dot mask, being the most salient object, pops out in the display and attention is rapidly directed towards it. This is different from the re-entrant account of OSM in which set size is thought to delay the deployment of attention towards the target.

At a first glance, the data from Chapters 2&3 (in which set size and mask duration were manipulated) appear to fit better to Poder's attentional gating model than Di Lollo's re-entrant account. This is because it does not make any stipulations about an interaction between set size and mask duration. However, as it will be discussed below, in its current form, the attentional gating model cannot account for some aspects of the data from Chapters 2,3 &5. First, in Poder's model it is not the speed with which attention contacts the target that is important. Instead, Poder viewed attention as a factor that enhances the target signal after the initial parallel processing of the display. In this view, in the pre-cue task in Chapter 5 (Experiment 9) little or no masking should have been obtained at CTOA greater than zero because attention was deployed to the target location prior to the target onset and thus enhancing the target (plus mask) signal right from the beginning. Indeed, that discrimination performance for non-zero CTOAs was better than for zero CTOA shows that the pre-cue increased the target signal in trials in which the cue onset prior to the target. However, in Experiment 9 substantial masking occurred even when the target location was known up to 150ms prior to target onset. This shows that although the target's signal-to-noise ratio, which is a central concept to Poder's attentional gating model, influences performance it does not affect OSM. In other words, although Poder's model would predict an interaction between CTOA and mask duration (i.e. better performance for CTOA greater than zero compared to performance for CTOA equal to zero) the results of Experiment 9 showed that such an interaction did not occur. A possible counterargument could be that the pre-cue increased not only the target's signal but also, and perhaps of equal amount, the mask's signal (i.e. noise). Under these circumstances the target's signal-to-noise ratio would have been constant during target display only to be decreased during the mask delayed offset trials (because of the added noise from the mask in the delayed mask offset trials).

Even in such case, however, greater masking should have been obtained in the delayed mask offset trials compared to the common offset trials which would resulted in an interaction between CTOA and mask duration. Second, Poder's model predicts a non-linearity in the masking functions; performance drops monotonically as the mask duration increases but it reaches a plateau at relatively long mask durations. According to Poder this is because some information about the target was acquired during the initial divided attention stage and thus performance does not drop to chance. Indeed, in Experiments 5a and 5b in Chapter 3 performance at detecting the target reached a plateau when mask duration was 180ms for target present trials a feature that was also present in a subsequent guessing correction analysis. However, for Experiments 1-4 in Chapters 2&3 performance dropped monotonically as mask duration increased. Furthermore, Poder's prediction of a non-linerity in the masking functions is in contrast to some studies in FDM which show that performance improves as mask duration increases resulting in a U-shape curve (Goodhew et al., 2011a, 2012).

Spatial resolution and OSM

The Experiments described in Chapters 2 & 3 were very similar, in all major aspects, to those of Di Lollo et al. (2000). A difference between the two sets of studies, however, that could have influenced the results in these chapters (and may have accounted for the lack of an interaction) was that the size of the stimuli employed in my tasks was smaller than that used by Di Lollo et al. In other words, the target resolution in the present studies was rather smaller which in turns means that it might have been more difficult to detect or discriminate the critical feature compared to Di Lollo et al.'s work. However, it will be argued in the following sections that the size of the critical feature (and hence target resolution) did not influence the effects obtained in the present studies.

When the data of the Experiments 1-3 (in which the gap size of the Landolt squares varied from one experiment to another) for the set sizes of 4 and 16 were combined there was not an interaction between gap size (i.e. Experiment) and mask duration. In Experiments 4 & 5a the size of the critical feature (i.e. a bisecting vertical bar) was the same in both Experiments but display eccentricity was decreased in Experiment 5a compared to Experiment 4. A smaller eccentricity entails better spatial resolution for the displayed items and thus for the target. However, when the data of the two Experiments were combined the results showed that the difference in eccentricity did not interact with mask duration. Similarly, in Chapter 4 (Experiments 6 – 8) in which crowding was controlled, the combined results of the three Experiments showed that reducing target resolution through crowding did not enhance masking.

Perhaps the strongest evidence in favor of the view that the strength of OSM is independent of target resolution comes from Experiment 9 in which attention was directed to the target explicitly. Studies have shown that when attention is deployed toward a stimulus which includes a gap then gap localization performance is better than when the target stimulus is unattended (Gobell & Carrasco, 2005; Shalev & Tsal, 2002; Tsal & Shalev, 1996). For instance, Shalev and Tsal (2002) explored the role of attentional receptive fields (ARF) in perception of the continuity of centrally and peripherally presented line segments. An AFR is "...a hypothetical construct that operates as a functional receptive field" (p.23) the size of which is attention dependent. In their Experiment 1, a vertical line was presented either at the centre or to the right or to the left of fixation (see Figure 7.1). In half of the trials the line was solid and on the other half of trials the line had a small or large gap. An uninformative pre-cue (75% valid) cued the target location. The observers were asked to report whether the line was solid or had a gap (i.e. broken line). Their results showed that the observers were better at detecting the gap in peripheral broken lines when these were pre-cued (i.e. attended) than when they were not attended especially so when the gap was a small one. They attributed the poor performance for an unattended peripheral gap to the two parts of the broken line stimulating an ARF in the same way as would an unbroken line with the resulting percept being of an unbroken line.

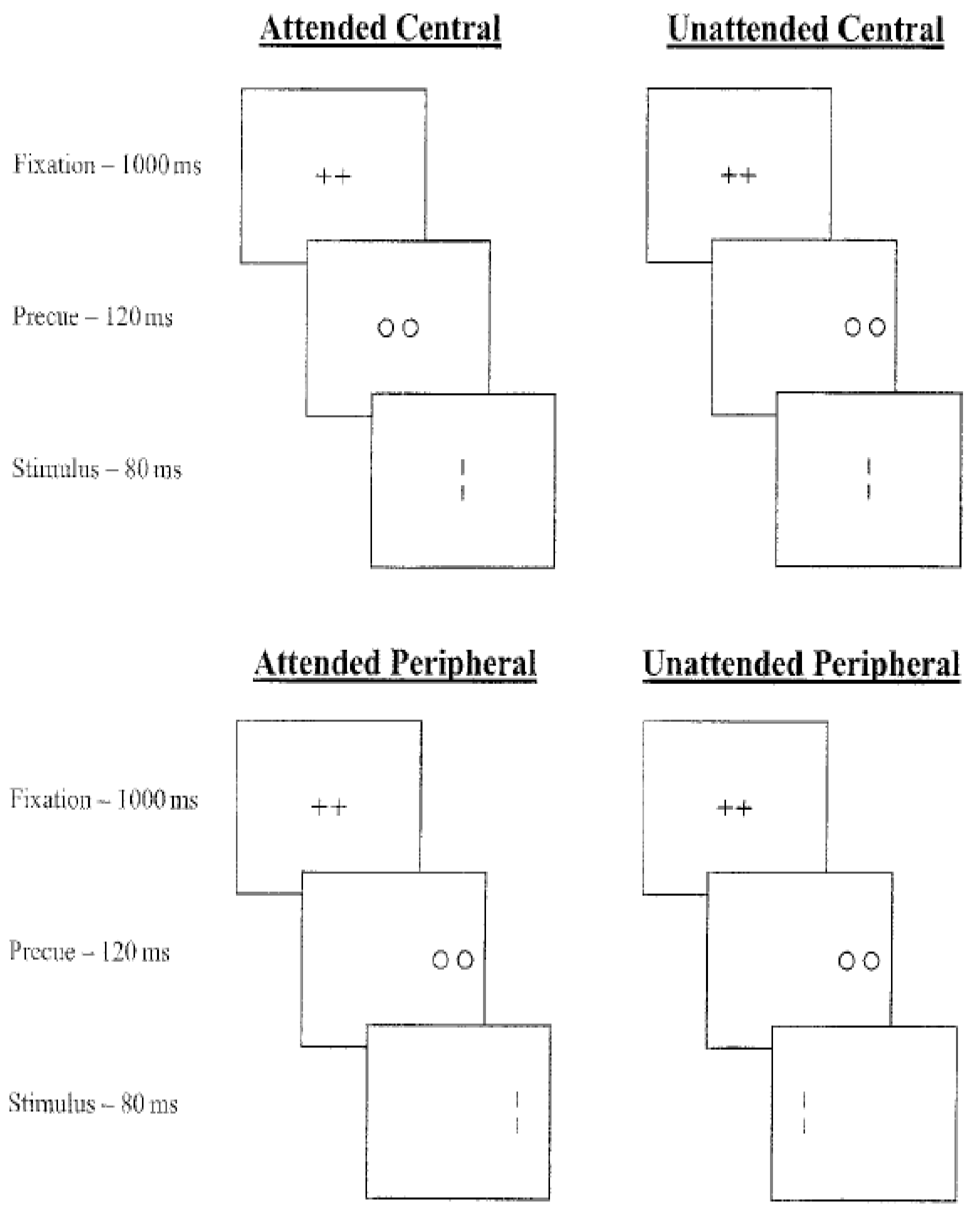

Figure 7.1. *Illustration of the frames sequences in Shavel and Tsal's (2002) Experiment 1. Illustration copied from Shavel and Tsal (2002, p.7)*

Similarly, Gobell and Carrasco (2005) sought to investigate if the enhanced gap localisation performance of attended peripheral stimulus observed in Shavel and Tsal's (2002) study could be replicated with Landolt squares. In their Experiment 2, two Landolt squares appeared one to the left and one to the right of a fixation square. In each trial the size of the gap of one square had a standard value of 0.2° (standard square, SS) and the gap size of the other square had values that varied from less to more than the gap size of the standard square (test square, TS). Prior to the onset of the squares an uninformative pre-cue appeared either at fixation or to the left or to the right of fixation. The observer's task was to report the location of the gap (top or bottom) for the square with the larger gap. They found that in trials in which the TS's gap size was smaller than the gap size of the SS, and the TS was attended, the two gaps were considered to be equal. When the SS was attended and it had a smaller gap than the TS observers judged the two gaps to be of equal size. These results showed that directly attending to a Landolt square causes its gap to be perceived as larger than it actually is relative to the gap in an unattended square. Gobell and Carrasco suggested that this is because attention enhances both spatial resolution and acuity for the square that is being attended and the consequence of this enhancement is an increase of the subjective perception of the gap size. In other words, attending to a Landolt square leads to the perception of its gap as larger than the gap of an unattended Landolt square although their gap sizes are equal and hence to its better localization.

If attending to a gap leads to a better gap localisation because of an increased spatial resolution of the attended item then, perhaps, attention might be expected also to decrease OSM. However, as was shown in Experiment 9, precueing the target did not have an effect on OSM. In other words, increasing target resolution by directing attention to the target did not influence OSM. It can, therefore, be argued that the quality of the target's sensory image (or – as in Experiments 6 and 7 - the size of the target's critical feature) is not a relevant factor in OSM. Thus the superficial difference of the stimulus (or critical feature's) size with Di Lollo et al.'s original work does not explain the lack of interaction between set and mask duration.

Suggestions for future research

The findings of all the experiments of the present thesis are summarized as follows; first, contrary to earlier reports, set size and mask duration do not interact. Increments of the number of distractors that surround the target do not influence OSM. Secondly, set size cannot be attributed to crowding; the two factors have additive effects on performance. Thirdly, crowding also does not influence OSM. Fourthly, OSM is not influenced by whether or not attention is directed to the target location prior to the target onset. Finally, a phenomenal consequence of OSM is that the target representation is entirely erased from awareness on at least in some trials (approximately 25% in Experiment 10). Although these findings contribute considerably to our understanding about the factors that affect OSM there are still many unresolved issues that require further investigation. Some of these issues are discussed below.

1. As it was described earlier, the data of some of the experiments showed that target resolution did not affect masking. In particular it was found that OSM remained the same when target resolution was decreased through crowding. The inverse was also true; increasing target resolution either by decreasing target eccentricity or by directing attention to the target (which has been shown to increase the apparent gap size) did not reduce less masking. Collectively, these data suggest that masking occurs regardless of target resolution. It is therefore possible that in a common onset task OSM will not be affected if the target's critical feature is degraded. This can be done, for example, with a random noise or a pattern mask. Enns and Di Lollo (1997) argued that OSM is a combination of object formation (camouflage) masking that occurs at the “lower” levels of visual processing and so-called substitution masking caused by information conflict between “lower” and “higher” levels of visual processing. What differentiates “lower” from “higher” level component of OSM is that, in the former component, the representation is said to be specific to a location whereas the latter component it is not (Lleras and Moore, 2003). Enns and Di Lollo (1997) argued however that camouflage masking played little role in the obtained substitution masking effects. Based on the results of the experiments of the present thesis a prediction can be made that in FDM there should be no interaction between substitution masking and object formation masking. If this prediction is confirmed it will be in accordance to the view that OSM occurs at the higher levels of visual processing and it is not influenced by the spatial interactions between the target and the mask.

2. In Chapter 6 in which the observers' phenomenal visual experience was explored it was found that for the delayed offset trials a substantial number of “blank” reports was obtained; there were trials in which participants reported seeing an empty space in the target location although the target was present. This finding suggested that in some of the delayed offset trials OSM was complete; the mask's representation substituted that of the target plus mask erasing all phenomenal traces of the target representation. It was argued that

an alternative possibility was that the "blank" reports in target present trials might reflect an artefact of eye movements which influenced the distribution of attention over the target location. A number of studies have shown that there are strong links between eye movements and overt attention (see Hoffman, 1998 for a review on the relationship between eye movements and attention). To investigate whether "blank" phenomenal experiences, such as those reported in Chapter 6, are due to masking mechanisms or are an artefact of eye movements, then eye movements should be recorded. If in target present trials when observers report seeing a blank the pattern of their eye movements is different from when they report wholly or partially perceiving the target it will suggest that the "blank" experiences is an artefact of the eye movements. Conversely, if the pattern of their eye movements is the same both when they report seeing the target and when they perceive a blank space in the target location it will suggest that blank experiences are due to masking mechanisms. Such study will shed light on the nature of the blank responses and the conditions in which these occur.

3. In Chapter 6 (Experiment 10) when the target was present (target circle plus bar) in 24% of the masking trials participants reported seeing a blank space in the target location although the target was present. Furthermore, at the same conditions observers did not perform significantly different from chance when they were asked to report the orientation of the bar in the target circle. Together, these findings led to the conclusion that if there was an implicit perception of the target in the present experiment, it was not sufficient to influence forced choice responses about the orientation of the line. However, this interpretation needs to be treated with some caution. This is because discrimination performance for when they were choosing one of the other two responses was also at chance (i.e. CNL and UC). What this shows is that when the target was present, in the masking trials, participants were unable to discriminate what was in the target location and, consequently they may have been choosing BL, CNL and UC response options randomly on such trials.

One way to resolve this ambiguity is by doing a further experiment in which participants are additionally asked to rate their confidence of their responding. Participants first respond to a stimulus and they subsequently report how confident they are about the correctness of their response. Confident ratings have been a popular subjective measure of stimulus awareness in studies of visual search (e.g. Baldassi, Megna, & Burr, 2006; Boyer, Harrison, & Ro, 2005; Maniscalco & Lau, 2012; Varakin, Levin, & Collins, 2007) and in OSM studies in particular (e.g. Koivisto, 2012; Zehetleitner & Rausch, 2013). In Experiment 10, confident ratings could take the form of three-points scale. For instance, after participants had performed the discrimination task, they would be required to rate their confidence by choosing a number from 1 to 3 (3 = high, 2 = intermediate, 1 = low). As an example, in Experiment 10, for those trials in which participants reported correctly the orientation of the bar but they nevertheless chose “low” or even “intermediate” confidence about their response, the scores for those trials could be removed as they would be considered guesses.

Concluding remarks

Object substitution masking has been said to provide new insights about the temporal and spatial dynamics of visual attention and about the mechanisms underlying conscious perception. It appears to tap properties of higher visual areas such as hypothesis formation and hypothesis testing, properties that constitute an integral part of our everyday visual experience. The assumption, however, that OSM depends on the speed with which attention is deployed towards the target is false.

The re-entrant theory put forward by Di Lollo et al. (2000) might have appeared intriguing at first because it supposedly provided an explanatory framework for the set size and (pre)cueing effects found in common onset tasks. The present experiments showed that FDM was not influenced by such modulations of spatial attention nor by target discriminability.

Finally, it is important to note that these findings are equivocal with regards to the question of the contribution of re-entrant connections between lower and higher levels of vision in visual experience. What these findings show is that Di Lollo et al.'s specific implementation of re-entrant account is invalid. Therefore, the re-entrant model, or at least the form of the model proposed in DiLollo’s original account (Di Lollo et al, 2000) has not stood up well to empirical scrutiny. It therefore does not seem to constitute a useful organising framework upon which to understand OSM nor the relationship between attention and awareness. Finally, the present results also highlight the need to be cautious when we build models and develop theories based on results that are less than conclusive. Many studies in OSM literature have based their hypotheses – and subsequently the interpretation of their findings – on the basis of a central assumption that this thesis has shown to be false, namely the dependence of OSM on the distribution of attention. The main reason for this misinterpretation of the nature of the OSM phenomenon was due to over-interpretation of the statistical interactions which were evidently a consequence of ceiling and floor effects in performance, or in other cases the failure to correct for clear response biases, or manipulation which influenced aspects of the task in addition to the distribution of spatial attention. Caution must always be exercised in making any interpretation about the seeming interactivity of experimental manipulations where such issues may be at play.

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