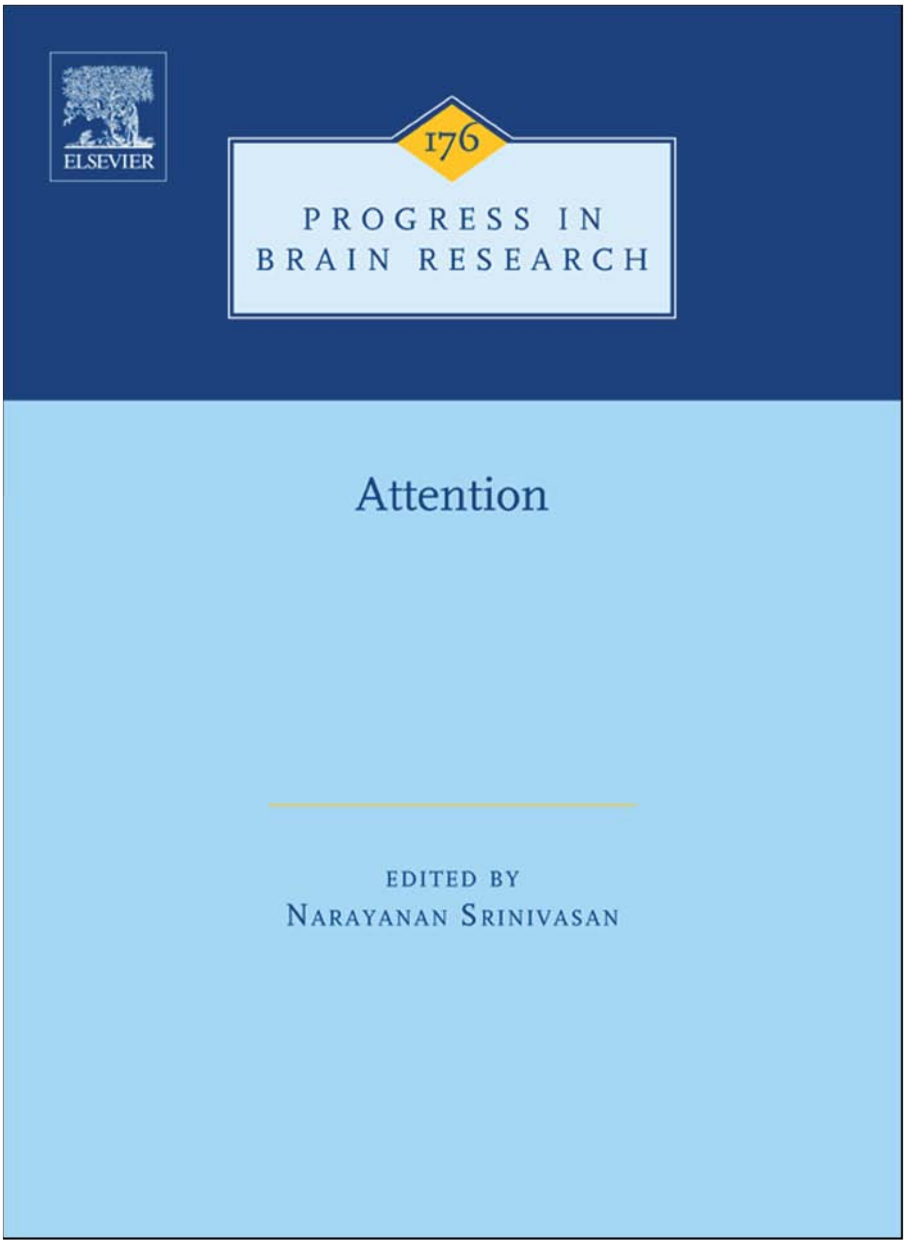

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CHAPTER 6

Focused and distributed attention

Narayanan Srinivasan*, Priyanka Srivastava, Monika Lohani and Shruti Baijal

Centre of Behavioural and Cognitive Sciences, University of Allahabad, Allahabad, India

Abstract: Recent studies on attention have emphasized distinctions between focused and distributed attention. Distributed attention has been shown to play a key role in obtaining statistical information or processing global aspects of a scene. In addition to differences in information processing, focused and distributed attention differ in terms of the way they interact with emotions. We review findings that indicate close relationship between focused attention and sad emotions as well as distributed attention and happy emotions. Given the potentially close relationship between attention and consciousness, these two types of attention may differ in terms of processes leading to awareness. We review different positions on the relationship between attention and consciousness and arguments for the existence of opposition between attention and awareness that have been made based on findings with color afterimages. We discuss our studies on attention and afterimages indicating the close linkage between different types of attention and awareness as indicated by differences in the strength of afterimages based on the type of attention deployed.

Keywords: focused attention; distributed attention; emotions; awareness; afterimages

Focused attention

The process of selecting information from the visual field for identification and awareness has been visualized in terms of a spotlight (Posner, 1980) or zoom lens (Eriksen and Yeh, 1985). Selective attention is theorized in terms of the stage at which the selection occurs. Early selection theories (Broadbent, 1958) argue that selection occurs at an early stage in perceptual processing and directing attention to a particular location or object typically enhances information processing at that location or for that object. Late selection theories argue that selection occurs after identification of stimuli to choose appropriate actions or responses (Deutsch and Deutsch, 1963). Intermediate views on the stage at which selection occurs have also been proposed (Treisman, 1960). In general, selective attention focused toward a location or object or an action results in better performance.

Studies based on visual search (Treisman and Gelade, 1980) have led to a two-stage model consisting of a preattentive stage and an attentive stage. Preattentive processing can be defined as quick and basic feature analysis of the visual field, on which attention can subsequently operate. These basic featural computations are combined or bound together through focused attention enabling object identification (Treisman and Gelade, 1980). An alternate way to think of attention would be in terms of the load theory of attention. Focusing on a task at hand can prevent

*Corresponding author.
Tel./Fax: +915322460738;
E-mail: nsrini@cbcs.ac.in, ammuns@yahoo.com

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task-irrelevant stimuli from reaching awareness (early selection) when the processing of task-relevant stimuli involves a high level of perceptual load that consumes all available capacity. In contrast, when processing of the task-relevant stimuli places lower demands (low load) on the perceptual system, spare capacity or processing resources leads to the perception of irrelevant stimuli as proposed by late selection theories (Lavie, 1995; Lavie et al., 2004). In contrast to focused attention, attention could be distributed over visual space to enable processing of multiple stimuli. We discuss the concept of distributed attention in the next section. We also discuss the role of focused and distributed attention in terms of emotional information processing as well as awareness.

Distributed attention

The concept of distributed attention has been proposed to explain aspects of information processing that cannot be accounted by focused attention. Treisman (2006) has discussed the significance of two types of distinct attentional allocations that lead to differences in processing, with focused attention enabling detailed analysis of specific features and objects and distributed attention facilitating global registration of scene properties. Ariely (2001) showed that visual system represents statistical properties when sets of similar objects are presented. He showed that mean size of discs of various sizes could be perceived more accurately compared to their individual sizes. Moreover, it was later shown that mean judgment was more compatible with tasks that require distributing attention globally compared to a task that requires focusing attention to individual items in the display (Chong and Treisman, 2005b). Even the variation of inherent properties of the distribution of sizes also did not affect mean judgments (Chong and Treisman, 2003). These findings points to separate mechanisms underlying distributed attention system.

It is possible that the distributed attention mechanisms are recruited when focused attention fails to benefit perception. For example, it was shown that even with the poor identification of individual items such as orientation signals in crowded displays, the visual system accurately estimates the average tilt (Parkes et al., 2001). The extraction of the statistical properties appears to be a robust process and it applies to many stimulus dimensions, including orientation (Dakin and Watt, 1997; Parkes et al., 2001), motion speed (Atchley and Andersen, 1995; Watamaniuk and Duchon, 1992), and motion direction (Williams and Sekuler, 1984). Moreover, the mean size can be computed almost as efficiently as the size of a single item (Chong and Treisman, 2003). Mean judgment accuracy also remains good under difficult perceptual conditions, such as brief set exposure duration, or the insertion of a delay between two sets that need to be compared based on mean judgments. In addition, increasing the numerosity and density of the elements of the multiple item display did not impair the performance on the mean judgment task (Ariely, 2001; Chong and Treisman, 2005a). There is also evidence that extraction of statistical properties is not an automatic process and can be modulated by features of the previously attended item (de Fockert and Marchant, 2008).

An alternative account for the lack of set size effects on computing statistical information is the subsampling strategy which has been used as an alternate explanation for the findings of mean judgment of size (Myczek and Simons, 2008). A number of simulations were performed where subsets were selected at random and on average those subsets had a mean size similar to that of the entire set. As a result, simulations based on subset-averaging of one or two items were very similar to the performance of participants who were instructed to average the entire set. However, the strategy of subset-averaging may not explain all the findings on distributed attention based tasks of mean computation. For example, in dual task conditions, the task of mean judgment benefited from tasks requiring distributed or global attention (pop-out search) compared to focused attention task (conjunction search) (Chong and Treisman, 2005b). This emphasizes parallel processing mechanisms for distributed attention contrary to serial processing mechanisms for focused attention. The parallel accounts for distributed attention were also confirmed when an advantage in mean judgment was observed with successive presentation compared to simultaneous presentation of sets (Chong and Treisman, 2005b). In addition to statistical information, distributed attention might be linked to happy emotions and the link between differences in focused and distributed attention in the context of emotions is discussed in the next section.

Scope of attention and emotions

Given the profound social significance, emotions play a significant role in modulating cognitive processes including attention and perception. Studies investigating the emotion–attention interaction, with dot probe (Mogg et al., 1997), visual search (Vuilleumier et al., 2001), and stroop task (MacKay et al., 2004) show emotional stimuli capture and direct attention more readily than neutral stimuli. Imaging studies have also shown amplified response for emotional stimuli compared to neutral stimuli (Stormark et al., 1995). The effects of emotions on cognitive processes like attention and memory are emotion specific (Bradley et al., 2000; Eastwood et al., 2001, 2003; Frischen et al., 2008; Gupta and Srinivasan, 2009; Ohman et al., 2001; Srinivasan and Gupta, submitted; Srinivasan and Hanif, in press; Vuilleumier, 2001).

Several studies have shown that emotional expressions capture attention and interfere with the ongoing task even though they are not relevant to the current task (Vuilleumier et al., 2001; White, 1996). Negative emotional expressions have shown more interference than positive emotional expression indicating more effective attention capture by negative emotional expressions (Yantis, 1996). Studies using visual search task (Eastwood et al., 2001; also see Williams et al., 2005) have shown that sad faces were detected faster than happy faces among neutral faces. In another study using visual search, participants required to count features embedded in negative, positive, and neutral schematic faces, took longer time with negative faces compared to positive or neutral faces (Eastwood et al., 2003). These findings indicate that faces with sad expression may capture attention faster and also holds attention for a longer period of time.

In addition to attention capture, emotions also interact with the scope of attention. Control of attention has been shown to be influenced by the current affective state of the observer (Hasher et al., 2007; Oaksford et al., 1996). It has been long hypothesized that arousal during negative states is associated with a constriction of attentional focus (Derryberry and Reed, 1998). The narrowing of attention is sometimes referred as "weapon focus" where attention is focused at the expense of encoding peripheral details (Christianson and Loftus, 1990). However, studies on positive emotion show that positive emotional stimuli broaden the scope of attentional processes according to the broaden-and-build theory (Fredrickson, 2004; Fredrickson and Branigan, 2005; Wadlinger and Issacowitz, 2006). Broaden-and-build theory proposes that a primary function of positive emotion is to broaden people's thought-action repertoires (Fredrickson, 2001, 2003), increasing their flexibility and enhancing their global scope. Effect of positive affect on creative and more generative mindset shows greater cognitive flexibility across diverse situations (Estrada et al., 1994, 1997), intuitive judgments (Bolte et al., 2003), decision making (Isen, 2001), and creative problem solving (Isen et al., 1987, 1985).

Evidence of broadening of attention comes from a study by Fredrickson (2003) in which a particular emotion was induced by showing participants small evocative film clips. For example, emotion of joy was elicited by showing a herd of playful penguins waddling and sliding on the ice, sadness was elicited with scenes of death and funerals, serenity was elicited with clips of peaceful nature scene, and neutral scenes were used to elicit no emotion. Using global–local visual processing tasks, they measured whether participants saw the big picture or focused on the smaller details. The participants' task was to judge which of the two comparison figures is more similar to a standard figure. One comparison figure resembled the standard in global configuration and the other in local, detailed elements. They found that people who experienced positive emotions (as assessed by self-report or electromyographic signals from the face) tend to choose the global configuration, suggesting a broadened pattern of thinking.

Similarly, another study (Fredrickson and Branigan, 2005) measured the scope of attention and thought-action repertoires as a function of positive emotion and showed that relative to neutral and negative emotions, positive emotion broadens the scope of attention and thought-action repertoires by showing global bias. In their study, temporary states of emotion (amusement, contentment, neutrality, anger, and anxiety) were induced by showing movies followed by the identification of the hierarchical visual stimuli. Participants showed biased selection to global shape when it was followed by a positive emotional state compared to negative and neutral state. Thought-action repertoires were evaluated by the open-ended twenty statements test, which showed that people experiencing positive emotions have more numerous thought-action urges than people experiencing negative emotions.

Rowe et al. (2007) investigated the role of positive emotion in broadening the scope of visual attentional filter and reducing the selectivity. They found that positive emotion results in a fundamental change in the breadth of attentional allocation to both external and internal conceptual space. In their study, they measured the effect of positive emotion on two different cognitive domains: semantic search (remote associate task) and visual selective attention (Erickson flanker task). In remote associate task, participants were asked to override typically semantic associations to find semantically distant or remote associations, whereas in Erickson flanker task, participants were presented a target with flanking distractors and task was to selectively attend the central target while ignoring the distractors. In the conceptual domain, relative to the neutral and sad mood, positive affect was associated with increased capacity to generate remote associates for the familiar words (Isen, 2001). In the visuospatial domain, positive affect impaired the visual selective attention by increasing processing of spatially adjacent flanking distractors, suggesting an increase in the scope of visuospatial attention.

Similarly using a flanker task, Fenske and Eastwood (2003) found flanker effect for happy faces but not sad faces indicating that sad faces lead to narrowing of attention and potentially happy faces might lead to broadening of attention. Srinivasan and Gupta (submitted) have investigated the scope of attention on emotional information by manipulating perceptual load. The participants were shown emotional stimuli (happy, sad, and neutral faces) in the background (distractor) with a letter string consisting of six letters at the center. Participants were required to report the color of the string in the low-load condition and a specific target letter in the high-load condition. The experiment with different load conditions was immediately followed by a surprise recognition test for the distractor faces. The results showed better recognition memory for sad faces compared to happy faces during more focused attention in the high-load condition. In addition, happy faces were recognized better compared to sad faces in the case of distributed attention in the low-load as well as high-load conditions. These results indicate that sad and happy faces interact differently with attention. Sad faces are associated with focused attention while happy faces are associated with distributed attention.

Another study by Srivastava and Srinivasan (2008) has investigated the role of emotional stimuli in shifts of visual attention between objects. In their study, participants were presented with happy and sad stimuli using attentional dwell time paradigm. Attentional dwell time paradigm is method of displaying two targets in sequence at different location with variable temporal separations between two targets. Two experiments were conducted by manipulating emotional faces as T1 or T2 in separate experiments. In the first experiment, emotional stimuli (T1) were followed by the neutral target (T2). The result showed less impairment for neutral T2 performance when it was preceded by the happy faces compared to sad faces. This could be due to lesser attentional resources or broadening of attention associated with happy faces. To investigate whether happy stimuli demand less attentional resources, second experiment was conducted using emotional stimuli as T2 preceded by neutral T1. Result showed better identification of the happy faces than sad faces, indicating less attentional demand for happy stimuli compared to sad face.

In agreement with the differences in the scope of attention, emotion identification has been shown to be associated with differences in processing of hierarchical information (Srinivasan and Hanif, in press). In this study, participants were shown hierarchical letters followed by emotional faces. The task was to identify the emotion present in a face as soon as possible followed by the reporting of the preceding target that occurred either at the global or local level. Happy faces preceded by global target identification were faster than local target identification. Once again these results indicate close relationship between perceptual processing strategies associated with differences in the scope of attention and emotions. In addition to emotion identification, differences in scope of attention have been linked to approach and avoidance behavior (Förster et al., 2006). Approach behavior has been associated with global processing due to the broadening of the scope of attention and avoidance behavior is associated with local processing due to the narrowing of the scope of attention (Förster et al., 2006). Differences in processing global–local processing have also been reciprocally linked differences in regulatory focus with promotion focus linked to global processing and prevention focus linked to local processing (Förster and Higgins, 2005).

These finding support the theories that argue for emotion–attention interactions and more specifically show that reciprocal links between emotions and the scope of attention. Better performance for positive information in presence of global stimuli compared to local stimuli or vice versa supports the theory of positive emotion (Fredrickson, 2003). It also indicates that broadening of attention requires less attention (Srivastava and Srinivasan, 2008) therefore interfere less with the subsequent target processing. In addition to differences related to the nature of information processing as well as emotions, focused and distributed attention might be linked differences in awareness. In the next section, we discuss the relationship between attention and awareness in the context of different types of attention.

Types of attention and awareness

The role of attention in awareness is a central question in the cognitive sciences (James, 1890). One of the earliest discoveries reflecting this idea comes from observations that when people were asked to attend to two events at the same time, they typically became conscious of only one event at any given moment in time (Broadbent, 1958; Cherry, 1953). Findings from many different paradigms have led to views arguing for a strong relationship between attention and consciousness (Mack and Rock, 1998; Rensink et al., 1997). It has been suggested that attention may be necessary for consciousness. It is now widely accepted that the understanding of consciousness rests upon appreciation of the brain networks that subserve attention (Posner, 1994). Given the close relationship between attention and consciousness, a model of cortical-thalamic network implicated in the studies of visual attention was proposed for the study of consciousness (Crick, 1994).

Studies that have provided compelling evidence for the close link between attention and awareness have used the paradigm of inattentional blindness (Mack and Rock, 1998). In their experiments, observers were briefly presented with a cross and were asked to judge, out of the vertical or horizontal components (that differed slightly in length), which of the two was longer. In a critical trial, an irrelevant stimulus was flashed in one of the quadrants formed by the cross. After the trial, observers were asked to perform a recognition task to test whether they could identify the unexpected target. With their attention focused on the discrimination task, a large number of observers failed to notice the target stimulus. Around 25% of participants said that they did not notice the unexpected stimulus that appeared parafoveally while the cross was presented at fixation. Interestingly around 75% of the participants reported not perceiving the target stimulus that appeared at fixation with the cross presented parafoveally. Observers failed to report the irrelevant stimulus when they were not aware that such a stimulus might appear, although the unidentified stimulus would have been visible under normal conditions. Mack and Rock (1998) argued that in the absence of attention, the irrelevant stimuli never rose to the level of conscious perception. We may not consciously perceive objects that we have not attended.

The lack of attention leading to inattentional blindness is also used to explain the failure of change detection in several change blindness (CB) experiments (Grimes, 1996; Rensink, 2002; Rensink et al., 1997). Grimes (1996) tracked observers' eye movements while they viewed scenes for 10 s, in a change detection experiment. Scenes were altered during eye movements, and a single object was changed either in size, color, or location or they could disappear. Observers failed to detect these changes because the changed object was not attended and thus not consciously perceived. CB is the phenomena where we fail to perceive large changes, in our surroundings as well as in experimental conditions. Change could be in existence, properties, semantic identity, and spatial layout. Attention is required to perceive change and in the absence of localized transient motion signals (that may attract or grab attention) attention is directed by high level of interest (Rensink et al., 1997). Only when attention is focused on an object, a change in the object is usually perceived. The contents of visual short-term memory are simply over written with succeeding stimuli without focused attention (Rensink, 2002).

However, inattentional blindness fails to explain convincingly the results of Simons and Levin (1997) or Rensink et al. (1997) experiments in which stimuli is presented for a very long time. In their CB experiments, observers may have attended to the object and yet not detected changes to them. CB studies do show that more information is available than what is reported. For example, it has been shown that performance on a localization task was above chance level even in undetected trials (Fernandez-Duque and Thornton, 2000). In addition, response times are longer in failed change detection trials in which change actually occurred (Williams and Simons, 2000). Change detection has been shown for changes in the background (Driver et al., 2001). More interesting are claims of mindsight in which observers claimed to sense the change before they were aware of the change suggesting that sensing could be a different form of awareness (Rensink, 2004).

A slightly different perspective on the close relationship between attention and consciousness is provided by the studies in which load was manipulated and awareness of stimuli were evaluated (Cartwright-Finch and Lavie, 2006; Lavie, 2006). One was an inattentional blindness task in which the primary task was easy (low load) or difficult (high load). They found that inattentional blindness was more in the high-load condition compared to the low-load condition (Lavie, 2006). They also performed a change detection study in which the primary task (low load or high load) was presented at fixation and change between two scenes had to be detected at peripheral locations. Once again, change detection was better in the low-load condition compared to the high-load condition indicating that focused attention is necessary and plays a critical role in awareness (Lavie, 2006). In addition to better performance, a recent study has shown that attention can alter phenomenal appearance (Carrasco et al., 2004). They showed that the contrast of an attended (using an exogenous cue) grating was higher than the contrast of the unattended grating indicating once again the critical role of focused attention in awareness.

While acknowledging the close relationship between attention and consciousness, a large number of recent studies have convincingly argued that attention is different from consciousness (LaBerge, 1995; Baars, 1997; Hardcastle, 1997; Naccache et al., 2002; Crick and Koch, 2003; Lamme, 2003; Woodman and Luck, 2003; Kentridge et al., 2004). According to Lamme (2003), consciousness operates prior to attention. Attentional selection operates on conscious stimuli leading to verbal report or store for later conscious, typically verbal access. Unconscious stimuli are outside the control of attention.

According to Dehaene et al. (2006), consciousness and top-down attention can be thought of in terms of a 2×2 matrix in which one of the dimensions is bottom-up stimulus strength (weak or sufficiently strong) and the other is top-down attention (absent or present). They identified four classes of processing: subliminal-unattended, subliminal-attended, preconscious, and conscious. These different types of processes are subserved by different neural networks. Conscious processing refers to the case in which stimulus strength is high and top-down attention is present. This class is characterized by reportability, intense activation, and long-range interaction across cortical areas. They also argue that the subliminal (unattended) is characterized by absence of priming, is typically not affected by top-down attention, and can be characterized as essentially feed-forward processes in the brain. Unlike the subliminal (unattended) processes, the processes in the other subliminal class are supposed to show stronger activation and short-term priming. Both the subliminal types of processes are not associated with reportability. The preconscious, mainly sensorimotor in nature, display priming effects and are also not reportable in the absence of top-down attention. They also argue that global synchronization is characteristic of conscious processes and local synchronization is characteristic of preconscious processes (Dehaene et al., 2006).

In a similar vein, Koch and Tsuchiya (2007) have proposed a fourfold classification scheme in which attention and consciousness are different. Certain processes are analyzed in terms of whether top-down attention is necessary or not and whether they give rise to consciousness, resulting in a 2×2 matrix of possibilities. Some processes like early rapid vision do not need attention and may not give rise to consciousness. This will also cover a significant amount of unconscious information processing. Some processes may need attention and will give rise to consciousness. Some processes like priming and thoughts may require attention and may not give rise to consciousness. It is quite possible that some processes benefit from attentional processing without the involvement of consciousness. The most interesting possibility is the case of processes for which attention is not required but gives rise to consciousness.

Argument for the potentially opposite effects of attention and awareness have been made based on findings from studies in which the lack of attention resulted in better performance (Kanai and Verstraten, 2006; Li et al., 2002). In an experiment using stimuli in which the direction of motion was ambiguous, priming effect was reduced when attention was distracted using a task in between the presentation of the prime and the ambiguous motion stimulus (Kanai and Verstraten, 2006). The role of attention on the ability to identify meaningful categories has been investigated with a dual task paradigm involving a difficult visual search task in which observers had to search for an odd element in an array of five randomly rotated Ls or Ts as well as a scene/object categorization task (Li et al., 2002). Participants performed better with categorization of objects present in natural scenes like animal versus non-animals and vehicle versus non-vehicles and such quick categorizations involving meaningful stimuli has been argued to occur with almost no attention (Li et al., 2002).

Although several accounts have described the relationship between attention and consciousness in terms of attended versus unattended as well as conscious versus unconscious, it is important to consider the effects of different types of attention and consciousness. One way in which consciousness has been characterized is in terms of primary consciousness and access consciousness (Block, 2005). Primary consciousness refers to the phenomenal aspects of experience, i.e., qualia. Access consciousness refers to the functional aspects of consciousness, which is related to cognitive processes like executive attention, planning, and voluntary control that facilitates its subjective nature and reportability.

Wyart and Tallon-Baudry (2008) recorded magnetoencephalographic signals while human subjects performed a task in which faint gratings were presented at an attended or unattended location (on some trials no stimulus was presented). After each trial, participants indicated which of two orientations they thought matched the previously presented grating and whether they had seen the grating. Trials were classified as aware (grating was detected and orientation was identified correctly) or as unaware (grating was not detected and orientation was identified at chance level). Spatial attention increased the likelihood of conscious report: more gratings were consciously seen at the attended location (~50%) than at the unattended location (~40%). Attention also shortened reaction times on the orientation discrimination task for consciously seen gratings, but not for unseen gratings. Additionally, the gamma band power changes reflected in separate frequency and time ranges represented attention and awareness-related activity, which was found to be independent of each other although both correlated with conscious report. The awareness-related gamma power changes represented phenomenal awareness that represents raw neural representation of perceptual information (van Gaal and Fahrenfort, 2008).

Melloni et al. (2007) investigated the neural correlates of access awareness, which relates to the ability to report about the phenomenal representations and found that conscious report is selectively correlated with increased phase coupling in gamma band activity across occipital, parietal, and frontal areas rather than power changes. These results indicate that different forms of consciousness may be associated with different types of attention and different neural mechanisms (van Gaal and Fahrenfort, 2008).

Typically, the notion of "attention" used in many of the studies exploring the relationship between attention and awareness is focused attention. Given that different types of attention provide different kinds of information (Ariely, 2001; Chong and Treisman, 2003, 2005a; Treisman, 2006), they may also result in differences in awareness. The phenomenal awareness associated with the reports of participants who have claimed to see more than they could verbally report in iconic memory experiments might be linked with distributed attention and access consciousness might be more closely linked to focused attention. While change detection in an object might depend on focused attention, the feeling associated with sensing the change (without accompanying the detection of change itself) in change detection might depend on processes associated with distributed attention (Rensink, 2004).

Color afterimages and attention

One important methodology that has been used to study awareness is through adaptation and afterimages (Kirschfeld, 1999). An afterimage is complementary to the original pattern in both brightness and color and such afterimages are thus called negative afterimages (Suzuki and Grabowecky, 2003). For example, an afterimage occurs after the adaptation to a particular stimulus (color) for a prolonged period of time, e.g., prolonged looking at a red square produces a green afterimage. Awareness of afterimage as measured by the strength of the afterimage gets affected by manipulation of focused attention during adaptation (Suzuki and Grabowecky, 2003). Focused attention to the adapting stimulus reduces the strength of the afterimage. More specifically, strength of afterimages has been shown to be modulated by spatial spread of attention and level at which the stimulus structure is being processed (Baijal and Srinivasan, submitted).

Suzuki and Grabowecky (2003) showed two overlapped triangles to the participants for 7–10 s during adaptation period. Both the triangles were afterimage inducers. The task was to selectively attend to one of the superimposed triangles (on the basis of color or motion). The results indicated that the attended triangle produced weaker afterimage. The effect was further confirmed by the demonstration of delayed onset of afterimage when the afterimage inducer was attended (when participants reported change in color of the inducer) compared to unattended (when participants performed a digit counting task away from adaptor). Even when attention was manipulated during the formation of afterimages rather than during adaptation, focused attention produced deleterious effects on the strength of afterimage (Lou, 2001). In their study, participants were asked to attend to either of the afterimages and attended afterimage was found to disappear from the awareness faster than unattended afterimage. These findings have been used to argue that attention may have opposing effects on awareness (Koch and Tsuchiya, 2007). However, it is yet not clear how different manipulations of attention affect awareness.

One way to view attention is in terms of processing load (Cartwright-Finch and Lavie, 2006). Theeuwes et al. (2004) argued that low processing load ensues broadening of the attentional window. If low load leads to increase in the scope of attention, then manipulation of processing load also provides a way to investigate the effect of attention on awareness. To observe the effect of processing load on the inducing stimulus and afterimage formation, attention was manipulated in a study with color afterimages using a central task with differing attentional demands/resources during the adaptation period. In the afterimage formation period, attention was manipulated by instructing the participants to attend a particular afterimage to see the effect of voluntary attention on the strength of afterimages.

The stimuli consisted of two triangles of opposite orientations superimposed on each other, forming a star against the black background (Fig. 1). One of the component triangles was green and the other was orange. The triangles were presented along with a constant stream of letters in the centre for 30 s. Load was manipulated using a 0-back task (low load) and 2-back task (high load). The participant had to count the number of occurrences of a given target letter in 0-back task. In the 2-back task, participants had to count the number of times a current letter was the same as the one before the previous letter. This was followed by afterimage formation period where a gray screen with fixation mark was displayed. Blue and pink colored afterimages were formed for orange and green triangles respectively. Participants were instructed to attend to the blue afterimage on half of the trials and pink on the other half trials. Since the onset was immediate after the removal of the adapting stimulus (given the long adaptation periods used), it was not measured. Participants were instructed to press the assigned key as soon as one of the afterimages (attended or unattended) disappeared and press the corresponding key on the reappearance of any of the disappeared triangles. The sequence of frames in a particular trial is shown in Fig. 2.

Fig. 1. Afterimage inducer display.

In all the trials, the attended afterimage disappeared first consistent with the findings from Lou (1999). The durations of the afterimage was measured and the results are shown in Fig. 3. There was a significant effect of processing load, during the adaptation stage, on afterimage durations with longer durations for the 2-back condition compared to the 0-back condition (see Fig. 3). The result adds to the previous findings (Suzuki and Grabowecky, 2003) that attention weakens the afterimage and delayed the appearance of the afterimage. It is not simply the lack or presence of attention that affects afterimage formation but processing load also determines the duration of afterimages. Low processing load associated with broadening of attention (Theeuwes et al., 2004) may have resulted in better distractor (the inducers) processing leading to the lesser afterimage durations compared with the high processing load condition. The results indicate that attention and working memory play a critical role in the formation and duration of afterimages.

An explicit distinction was made between different types of attention based on their effects on perceptual awareness (Baijal and Srinivasan, submitted). The participants performed a central task with small, large, local, or global letters and a blue square as adapting stimulus for 20 s. Once the

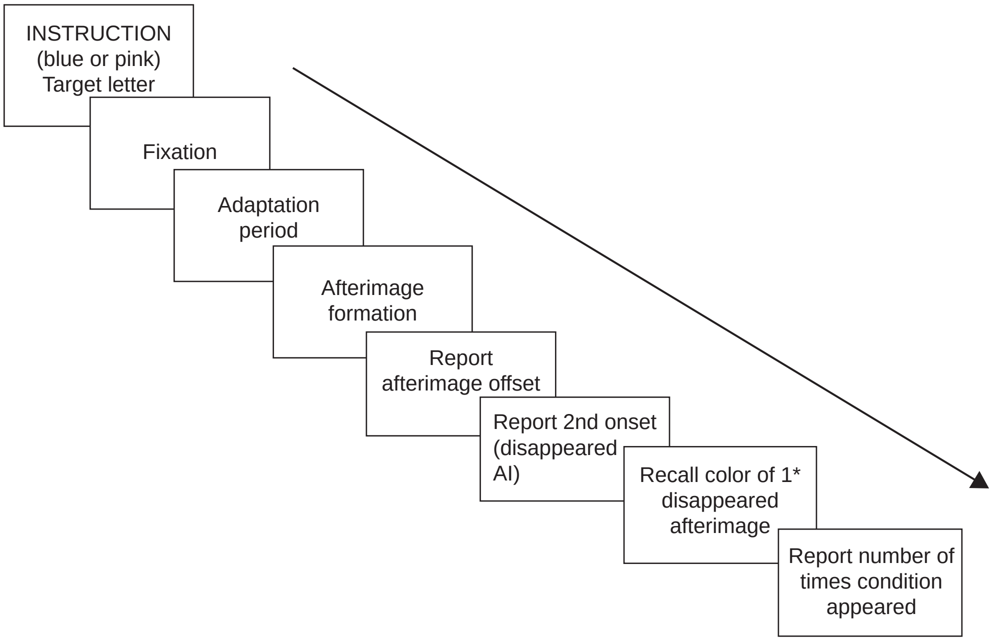

Fig. 2. Sequence of events in a given trial.

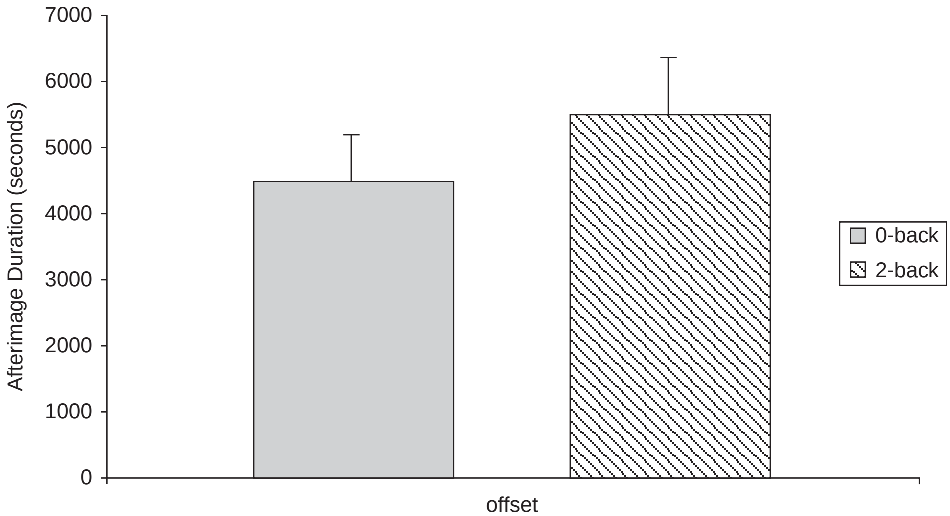

Fig. 3. Afterimage duration as a function of the load.

inducing stimuli was removed resulting in the color afterimage, the participants indicated the onset and offset of the afterimage. It was observed that the increase in spatial spread of attention (modulated by the central task) results in decrease of afterimage duration. However, in terms of levels of processing, global processing produced larger afterimage durations with stimuli controlled for spatial extent. The results suggest that focused or distributed attention produce different effects on awareness, possibly through their differential interactions with polarity-dependent and independent processes involved in the formation of color afterimages.

Attention has been shown to have contrasting effects on color afterimages (Lou, 1999, 2001; Suzuki and Grabowecky, 2003; Tsuchiya and Koch, 2005) and the aftereffects of motion, tilt, and depth (Chaudhuri, 1990; Rose et al., 2003; Spivey and Spirn, 2000). With color afterimages, attention reduces the strength of the afterimages. However, with motion aftereffects, focused attention increases the strength of the aftereffects. A possible explanation of these contrasting effects has been proposed by Suzuki and Grabowecky (2003), according to which attention may affect polarity-dependent and polarity-independent processes differently, thereby leading to different effects on adaptation. Polarity-independent processes in the visual system that play a critical role in contrast adaptation have been postulated to underlie the effect of attention on negative color afterimages (Suzuki and Grabowecky, 2003). The effect of attention on the motion, tilt, and depth aftereffects in this view may depend on polarity-dependent processes.

Yet another possible explanation of the effect of attention on color afterimages is provided with a model based on two different systems, a boundary contour system (BCS) and a feature contour system (FCS) (Wede and Francis, 2007a, b). According to this model, more attention on adapting stimuli generates stronger aftereffects in the orientation-dependent and polarity-independent BCS, resulting in the delayed and weaker color afterimages produced in the polarity-dependent FCS that underlies the formation of color afterimages. In the context of this model, distributed attention may weaken boundaries thereby resulting in weaker aftereffects in BCS. This would enable stronger color afterimages in the FCS. There is some evidence that global processing is more dependent on low spatial frequency processing (Badcock et al., 1990; Shulman and Wilson, 1987). This would further result in stronger afterimages based on aftereffects in the FCS (Georgeson and Turner, 1985; Wede and Francis, 2007a). While the mechanisms proposed above to explain the effects of differences in attention on color afterimages are tentative, the results of the study with afterimages and other paradigms do clearly show that differences in attention do matter for awareness.

Conclusions

Focused and distributed attention mechanisms differ in terms of the nature of information processing. In addition, they also differ in terms of emotional processing with close links between sad and focused attention as well as happy and distributed attention. Given the natural links between attention and awareness, it is important to consider different types of attention for understanding the relationship between attention and awareness. The results show that not only focused and distributed attention differ in terms of differences in information processing but also may result in differences in awareness. Further investigations, particularly those in which brain activity is simultaneously monitored while different forms of attentional mechanisms are recruited to generate attention-dependent awareness, are needed to understand the relationship between attention and awareness.

References

Ariely, D. (2001). Seeing sets: Representation by statistical properties. *Psychological Science*, *12*, 157–162.

Atchley, P., & Andersen, G. (1995). Discrimination of speed distributions: Sensitivity to statistical properties. *Vision Research*, *35*, 3131–3144.

Baars, B. J. (1997). *In the theater of consciousness: The workspace of the mind*. Oxford, England: Oxford University Press.

Badcock, J. C., Whitworth, F. A., Badcock, D. R., & Lovegrove, W. J. (1990). Low frequency filtering and the processing of local-global stimuli. *Perception*, *19*, 617–629.

Baijal, S. & Srinivasan, N. (submitted). Types of attention matter for awareness: A study with color afterimages.

Block, N. (2005). Two neural correlates of consciousness. *Trends in Cognitive Sciences*, *9*, 46–52.

Bolte, A., Goschke, T., & Kuhl, J. (2003). Emotion and intuition: effects of positive and negative mood on implicit judgments of semantic coherence. *Psychological Science*, *14*, 416–421.

Bradley, B. P., Mogg, K., & Miller, N. H. (2000). Covert and overt orienting of attention to emotional faces in anxiety. *Cognition and Emotion*, *14*, 789–808.

Broadbent, D. E. (1958). *Perception and Communication*. London: Pergamon Press.

Carrasco, M., Ling, S., & Read, S. (2004). Attention alters appearance. *Nature Neuroscience*, *7*, 308–313.

Cartwright-Finch, U., & Lavie, N. (2006). The role of perceptual load in inattentional blindness. *Cognition*, *102*, 321–340.

Chaudhuri, A. (1990). Modulation of the motion aftereffect by selective attention. *Nature*, *344*, 60–62.

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *Journal of the Acoustic Society of America*, *25*, 975–979.

Chong, S. C., & Treisman, A. (2003). Representation of statistical properties. *Vision Research*, *43*, 393–404.

Chong, S. C., & Treisman, A. (2005a). Statistical processing: Computing the average size in perceptual groups. *Vision Research*, *45*, 891–900.

Chong, S. C., & Treisman, A. (2005b). Attentional spread in the statistical processing of visual displays. *Perception & Psychophysics*, *67*, 1–13.

Christianson, S. A., & Loftus, E. (1990). Some characteristics of people's traumatic memories. *Bulletin of the Psychonomic Society*, *28*, 195–198.

Crick, F. (1994). *The astonishing hypothesis*. New York: Scribner's.

Crick, F., & Koch, C. (2003). A framework for consciousness. *Nature Neuroscience*, *6*, 119–126.

Dakin, S., & Watt, R. J. (1997). The computation of orientation statistics from visual texture. *Vision Research*, *37*, 3181–3192.

de Fockert, J. W., & Marchant, A. P. (2008). Attention modulates set representation by statistical properties. *Perception & Psychophysics*, *70*(5), 789–794.

Dehaene, S., Changeux, J., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: A testable taxonomy. *Trends in Cognitive Sciences*, *10*, 204–211.

Derryberry, D., & Reed, M. A. (1998). Anxiety and attentional focusing: Trait, state and hemispheric influences. *Personality and Individual Differences*, *25*, 745–761.

Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review*, *70*, 80–90.

Driver, J., Davis, G., Russell, C., Turatto, M., & Freeman, E. D. (2001). Segmentation, attention and phenomenal visual objects. *Cognition*, *80*, 61–95.

Eastwood, J. D., Smilek, D., & Merikle, P. M. (2001). Differential attention guidance by unattended faces expressing positive and negative emotion. *Perception & Psychophysics*, *63*, 1000–1013.

Eastwood, J. D., Smilek, D., & Merikle, P. M. (2003). Negative facial expression captures attention and disrupts performance. *Perception & Psychophysics*, *65*, 352–358.

Eriksen, C. W., & Yeh, Y. (1985). Allocation of attention in visual field. *Journal of Experimental Psychology: Human Perception and Performance*, *11*, 583–597.

Estrada, C. A., Isen, A. M., & Young, M. J. (1994). Positive affect influences creative problem solving and reported source of practice satisfaction in physicians. *Motivation and Emotion*, *18*, 285–299.

Estrada, C. A., Isen, A. M., & Young, M. J. (1997). Positive affect facilitates integration of information and decreases anchoring in reasoning among physicians. *Organizational Behavior and Human Decision Processes*, *72*, 117–135.

Fenske, M. J., & Eastwood, J. D. (2003). Modulation of focused attention by faces expressing emotion: Evidence from flanker tasks. *Emotion*, *3*, 327–343.

Fernandez-Duque, D., & Thornton, I. M. (2000). Change detection without awareness: Do explicit reports underestimate the representation of change in visual system? *Visual Cognition*, *7*, 323–344.

Förster, J., Friedman, R. S., Özelsel, A., & Denzler, M. (2006). Enactment of approach and avoidance behavior influences the scope of perceptual and conceptual attention. *Journal of Experimental Social Psychology*, *42*, 133–146.

Förster, J., & Higgins, E. T. (2005). How global versus local perception fits regulatory focus. *Psychological Science*, *16*, 631–636.

Fredrickson, B. L. (2001). The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. *American Psychology*, *56*(3), 218–226.

Fredrickson, B. L. (2003). The value of positive emotions. *American Scientist*, *91*, 330–335.

Fredrickson, B. L. (2004). The broaden and build theory of positive emotion. *Philosophical Transactions: Biological Sciences (The Royal Society of London)*, *359*, 1367–1377.

Fredrickson, B. L., & Branigan, C. (2005). Positive emotions broaden the scope of attention and thought-action repertoires. *Cognition and Emotion*, *19*, 313–332.

Frischen, A., Eastwood, J. D., & Smilek, D. (2008). Visual search for faces with emotional expressions. *Psychological Bulletin*, *134*(5), 662–676.

Georgeson, M. A., & Turner, R. S. (1985). Afterimages of sinusoidal, square-wave and compound gratings. *Vision Research*, *25*, 1709–1720.

Grimes, J. (1996). On the failure to detect changes in scenes across saccades. In K. Akins (Ed.), *Vancouver studies in cognitive science. Vol. 5. Perception* (pp. 89–110). New York: Oxford University Press.

Gupta, R., & Srinivasan, N. (2009). Emotions help memory for faces: Role of whole and parts. *Cognition and Emotion*, *23*, 807–816.

Hardcastle, V. G. (1997). Attention versus consciousness: A distinction with a difference. *Cognitive Studies: Bulletin of the Japanese Cognitive Science Society*, *4*, 56–66.

Hasher, L., Lustig, C., & Zacks, R. T. (2007). Inhibitory mechanisms and the control of attention. In A. Conway, C. Jarrold, M. Kane, A. Miyake, & J. Towse (Eds.), *Variation in working memory* (pp. 227–249). New York: Oxford University Press.

Isen, A. M. (2001). An influence of positive affect on decision making in complex situations: Theoretical issues with practical implications. *Journal of Consumer Psychology*, *11*(2), 75–85.

Isen, A. M., Daubman, K. A., & Nowicki, G. P. (1987). Positive affect facilitates creative problem solving. *Journal of Personality and Social Psychology*, *52*, 1122–1131.

Isen, A. M., Johnson, M. M. S., Mertz, E., & Robinson, G. F. (1985). The influence of positive affect on the unusualness of word associations. *Journal of Personality and Social Psychology*, *48*, 1413–1426.

James, W. (1890). *The principles of psychology* (Vol. 1). New York: Holt. (Reprinted in 1950 by Dover Press, New York).

Kanai, R., & Verstraten, F. A. (2006). Attentional modulation of perceptual stabilization. *Proceedings of the Royal Society of London. B: Biological sciences*, *273*, 1217–1222.

Kentridge, R. W., Heywood, C. A., & Weiskrantz, L. (2004). Spatial attention speeds discrimination without awareness in blindsight. *Neuropsychologia*, *42*, 831–835.

Kirschfeld, K. (1999). Afterimages: A tool for defining the neural correlate of visual consciousness. *Consciousness and Cognition*, *8*, 462–483.

Koch, C., & Tsuchiya, N. (2007). Attention and consciousness: Two distinct brain processes. *Trends in Cognitive Sciences*, *11*, 16–22.

LaBerge, D. (1995). *Attentional processing*. Cambridge, MA: Harvard University Press.

Lamme, V. A. F. (2003). Why visual awareness and attention are different? *Trends in Cognitive Sciences*, *7*, 12–18.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 451–468.

Lavie, N. (2006). The role of perceptual load in visual awareness. *Brain Research*, *1080*, 91–100.

Lavie, N., Hirst, A., De Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General*, *133*, 339–354.

Li, F. F., van Rullen, R., Koch, C., & Perona, P. (2002). Rapid natural scene categorization in the near absence of attention. *Proceedings of the National Academy of Sciences*, *99*, 9596–9601.

Lou, L. (1999). Selective peripheral fading: Evidence for inhibitory sensory effect of attention. *Perception*, *28*, 519–526.

Lou, L. (2001). Effects of voluntary attention on structured afterimages. *Perception*, *30*, 1439–1448.

Mack, A., & Rock, I. (1998). *Inattentional blindness*. Cambridge, MA: MIT Press.

Mackay, D. G., Shafto, M., Taylor, J. K., Marian, D. E., Abrams, l., & Dyer, J. R. (2004). Relations between emotion, memory, and attention: Evidence from taboo Stroop, lexical decision, and immediate memory tasks. *Memory & Cognition*, *32*, 474–488.

Melloni, L., Molina, C., Pena, M., Torres, D., Singer, W., & Rodriguez, E. (2007). Synchronization of neural activity across cortical areas correlates with conscious perception. *Journal of Neuroscience*, *27*, 2858–2865.

Mogg, K., Bradley, B. P., de Bono, J., & Painter, M. (1997). Time course of attentional bias for threat information in nonclinical anxiety. *Behaviour Research and Therapy*, *35*, 297–303.

Myczek, K., & Simons, D. J. (2008). Better than average: Alternatives to statistical summary representations for rapid judgments of average size. *Perception & Psychophysics*, *70*, 772–788.

Naccache, L., Blandin, E., & Dehaene, S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science*, *13*, 416–424.

Oaksford, M., Morris, F., Grainger, B., & Williams, J. M. G. (1996). Mood, reasoning, and central executive processes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 477–493.

Ohman, A., Lundqvist, D., & Esteves, F. (2001). The face in the crowd revisited: a threat advantage with schematic stimuli. *Journal of Perception of Social Psychology*, *80*, 381–396.

Parkes, L., Lund, J., Angelucci, A., Solomon, J., & Morgan, M. (2001). Compulsory averaging of crowded orientation signals in human vision. *Nature Neuroscience*, *4*, 739–744.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3–25.

Posner, M. I. (1994). Attention: The mechanisms of consciousness. *Proceedings of the National Academy of Sciences*, *91*, 7398–7403.

Rensink, R. A. (2002). Change detection. *Annual Review of Psychology*, *53*, 245–277.

Rensink, R. A. (2004). Visual sensing without seeing. *Psychological Science*, *15*, 27–32.

Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science*, *8*, 368–373.

Rose, D., Bradshaw, M. F., & Hibbard, P. B. (2003). Attention affects the stereoscopic depth aftereffect. *Perception*, *32*, 635–640.

Rowe, G., Hirsh, J. B., & Anderson, A. K. (2007). Positive affect increases the breadth of attentional selection. *Proceedings of the National Academy of Sciences*, *104*, 383–388.

Shulman, G. L., & Wilson, J. (1987). Spatial frequency and selective attention to local and global information. *Perception*, *16*, 89–101.

Simons, D. J., & Levin, D. T. (1997). Change blindness. *Trends in Cognitive Sciences*, *1*, 261–267.

Spivey, M. J., & Spirn, M. J. (2000). Selective visual attention modulates the direct tilt aftereffect. *Perception & Psychophysics*, *62*, 1525–1533.

Srinivasan, N., & Gupta, R. (submitted). Time course of visual attention for emotional faces.

Srinivasan, N., & Hanif, A. (in press). Global-happy and local-sad: Perceptual processing affects emotion identification. *Cognition and Emotion*.

Srivastava, P., & Srinivasan, N. (2008). Emotional information modulates the temporal dynamics of visual attention. *Perception*, *37*, . ECVP Abstract, S11

Stormark, K. M., Nordby, H., & Hugdahl, K. (1995). Attentional shifts to emotionally charged cues: Behavioural and ERP data. *Cognition and Emotion*, *9*, 507–523.

Suzuki, S., & Grabowecky, M. (2003). Attention during adaptation weakens negative afterimages. *Journal of*

Experimental Psychology: Human Perception and Performance, *29*(4), 793–807.

Theeuwes, J., Kramer, A. F., & Belopolsky, A. V. (2004). Attentional set interacts with perceptual load in visual search. *Psychonomic Bulletin and Review*, *11*, 697–702.

Treisman, A. (1960). Contextual cues in selective listening. *Quarterly Journal of Experiment Psychology*, *12*, 242–248.

Treisman, A. (2006). How deployment of attention determines what we see. *Visual Cognition*, *14*, 411–443.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, *12*, 97–136.

Tsuchiya, N., & Koch, C. (2005). Continuous flash suppression reduces negative afterimages. *Nature Neuroscience*, *8*, 1096–1101.

van Gaal, S., & Fahrenfort, J. J. (2008). The relationship between visual awareness, attention and report. *Journal of Neuroscience*, *28*(21), 5401–5402.

Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2001). Effects of attention and emotion on face processing in the human brain: An event-related fMRI study. *Neuron*, *30*, 829–841.

Wadlinger, H. A., & Issacowitz, D. M. (2006). Positive mood broadens visual attention to positive stimuli. *Motivation and Emotion*, *30*, 89–101.

Watamaniuk, S. N. J., & Duchon, A. (1992). The human visual system averages speed information. *Vision Research*, *32*, 931–942.

Wede, J., & Francis, G. (2007a). Attentional effects on afterimages: Theory and data. *Vision Research*, *47*, 2249–2258.

Wede, J., & Francis, G. (2007b). Cortical dynamics of negative afterimages: Spatial properties of the inducer [Abstract]. *Journal of Vision*, *7*(9), 277.

White, M. (1996). Anger recognition is independent of spatial attention. *New Zealand Journal of Psychology*, *25*, 30–35.

Williams, D. W., & Sekuler, R. (1984). Coherent global motion percepts from stochastic local motions. *Vision Research*, *24*, 55–62.

Williams, M. A., Moss, S. A., Bradshaw, J. L., & Mattingley, J. B. (2005). Look at me, I'm smiling: Visual search for threatening and non threatening facial expressions. *Visual Cognition*, *12*, 29–50.

Williams, P., & Simons, D. J. (2000). Detecting changes in novel 3D objects: Effects of change magnitude, spatiotemporal continuity, and stimulus familiarity. *Visual Cognition*, *7*, 297–322.

Woodman, G. F., & Luck, S. J. (2003). Dissociations among attention, perception, and awareness during object-substitution masking. *Psychological Science*, *14*, 605–611.

Wyart, V., & Tallon-Baudry, C. (2008). Neural dissociation between visual awareness and spatial attention. *Journal of Neuroscience*, *28*, 2667–2679.

Yantis, S. (1996). Attentional capture in vision. In A. F. Kramer, M. G. H. Coles, & G. D. Logan (Eds.), *Converging operations in the study of visual selective attention*. Washington, DC: American Psychological Association.