

Types of attention matter for awareness: A study with color afterimages

Shruti Baijal & Narayanan Srinivasan

Centre of Behavioural and Cognitive Sciences

University of Allahabad

India

Corresponding Author:

Dr. Narayanan Srinivasan

Centre of Behavioural and Cognitive Sciences

University of Allahabad

Allahabad 211002

India

Email: nsrini@cbcs.ac.in

Phone/Fax: +915322460738

Abstract

It has been argued that attention and awareness might oppose each other given that attending to an adapting stimulus weakens its afterimage. We argue instead that the type of attention guided by spatial extent and perceptual levels is critical and might result in differences in awareness using afterimages. Participants performed a central task with small, large, local, or global letters and a blue square as an adapting stimulus in three experiments and indicated the onset and offset of the afterimage. We found that increases in the spatial spread of attention resulted in the decrease of afterimage duration. 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.

Keywords: Attention; Awareness; Focused attention; Distributed attention; Afterimages; Global-local processing

Introduction

Attention is closely related to awareness and some have argued that it is necessary for awareness (Dehaene et al., 2006; Mack & Rock, 2001; Posner, 1994). Studies using various paradigms such as inattention blindness and change blindness have shown that attention not only affects conscious identification of stimuli (Mack & Rock, 2001; Lavie, 2006; Rensink, 2002) but also their phenomenal appearance (Carrasco, Ling, & Read, 2004). On the contrary, other studies have questioned the necessity of attention for awareness (Koch & Tsuchiya, 2007; Lamme, 2003; Tsuchiya & Koch, 2005).

According to Lamme (2003), attention operates on conscious stimuli leading to verbal report rather than consciousness resulting from attended stimuli. Koch & Tsuchiya (2007) proposed a four-fold classification scheme of aware and unaware percepts and behavior into four psychophysically defined categories depending on whether top-down attention is necessary and whether it gives rise to awareness. The organization of these categories include situations and tasks in which (i) attention gives rise to awareness (e.g. detection, discrimination and reportability), (ii) inattention does not give rise to awareness (e.g. rapid vision), (iii) attention does not give rise to awareness (e.g. priming, visual search) and (iv) attention is absent while awareness is present. The fourth case of processes that do not need top-down attention but gives rise to consciousness is based on findings of better performance under conditions of inattention (Kanai & Verstraten, 2006; Leopold et al., 2002; Li et al., 2002; Lou, 2001; Suzuki & Grabowecky, 2003).

Kanai & Verstraten (2006) asked the observers to indicate the direction of motion of a bistable stimulus using ambiguous motion. They showed that the priming effect of an unambiguous motion stimulus reduced when attention was drawn by a

secondary task of letter identification performed during the interval between adaptation with the prime stimulus and the ambiguous motion stimulus (Kanai & Verstraten, 2006). Li et al., (2002) used a dual task paradigm to evaluate the role of focused attention when observers performed a categorization task with objects present in natural scenes at the periphery like animal vs. non-animals and vehicle vs. non-vehicles. The observers showed good performance on the peripheral scene-categorization task with a relatively difficult central visual search task in which observers had to search for an odd element in an array of five randomly rotated Ls or Ts. However, when a letter discrimination task was performed with the same central task, the observers performed at chance level. The study indicated that certain properties of natural scene such as their gist could be accessed with no or very little focused attention (Li et al., 2002).

More pertinent to the current study is the set of findings from studies involving attention and color afterimages (Lou, 1999; Lou, 2001; Suzuki & Grabowecky, 2003; Tsuchiya, & Koch, 2005; Wede & Francis, 2007a) that have been used to argue for the opposing effects of attention on awareness (Koch & Tsuchiya, 2007). Suzuki & Grabowecky (2003) measured afterimage durations and their time of onset/offset in a series of experiments in which participants were asked to focus their attention to one of two overlapping triangle inducers. The afterimage for the unattended triangle appeared earlier and disappeared later compared to the afterimage of the attended triangle. In another experiment by them, the participants either attended to the afterimage inducer or to a stream of letters. They found that afterimage onset was delayed when the afterimage inducer is attended compared to when the letter stream was attended or inducer is not attended (Suzuki & Grabowecky, 2003).

In yet another study (Lou, 1999), the participants were presented with two overlapping inducer triangles that produced color afterimages of the two triangles. When attention was directed to one of the two afterimages, the attended afterimage disappeared faster than the unattended afterimage (Lou, 1999). These results have been used to support the argument that attention and awareness can have opposing effects on each other (Koch & Tsuchiya, 2007).

Attention is not a unitary process and different types of attention might have different relationships to awareness. One way to characterize attention would be in terms of focused attention and distributed attention (Chong & Treisman, 2005; Demeyere & Humphreys, 2007; Treisman, 2006). Distributed attention involves processing at larger spatial scales whereas focused attention is typically associated with processing at smaller spatial scales (Treisman, 2006). The distributed attention mechanisms involve parallel processing that contrasts with the focused attention mode that individuates objects (Treisman, 2006). Chong & Treisman (2005) showed that that computation of statistical properties of a visual scene such as mean size is compatible with conditions when attention is distributed globally compared to when attention is focused on individual items. Although automaticity accounts have been proposed for explaining distributed attention (Treisman, 2006), others have shown that extraction of statistical properties may be rapid but not automatic (de Fockert & Marchant, 2008).

It is possible that the distributed attention mechanisms are recruited when focused attention is not an optimal strategy for perception. For example, even when poor identification of individual items such as orientation signals is difficult (in crowded displays), the visual system accurately estimates the average tilt (Parkes et al., 2001). Evidence for relative independence of focused and distributed attention

mechanisms comes from studies with simultanagnosic patients who were shown to be sensitive to different forms of information (e.g. color, size) when in distributed attention mode rather than focused attention mode (Demeyere & Humphreys, 2007; Demeyere et. al., 2008). Despite impairment in simultaneously encoding information from a visual display, which manifests as an inability to count more than one or two items, the simultanagnosics were able to estimate the number of stimuli with accuracy better than chance level (Demeyere & Humphreys, 2007).

Given differences in the mechanisms associated with focused vs. distributed attention, they might be linked to different types of awareness. For example, Block (2005) proposed a framework that distinguishes phenomenal and access awareness. Phenomenal awareness refers to experiential aspects of perception while access consciousness refers to conscious content that is broadcast to many systems in the brain and is closely linked to cognitive processes like executive attention, planning, and voluntary control. Whereas phenomenal awareness can be instantiated by brief parallel processing of objects, access awareness necessitates zooming in to individual objects so that they can be eventually acted upon (Block, 2005). There is a potential possibility of phenomenal awareness and access awareness being facilitated by mechanisms of distributed attention and focused attention respectively. In a related vein, object consciousness could be associated with focused attention and background consciousness with distributed attention (Iwasaki, 1993).

The goal of the present study was to investigate differences in awareness due to focused and distributed attention rather than attention vs. inattention. We focus on the findings from afterimages to understand better the relationship between different types of attention and awareness. We manipulated the spatial spread of attention (attentional spotlight) and level (global or local) of attention using a central task

during the adaptation period and measured its effect on the adapting stimulus. Focused or distributed attention was manipulated by using letter stimuli of different sizes and hierarchical (global and local) stimuli. For example, attending the small sized single letters (Fig. 1a) would involve focused attention to a small spatial scale. Whereas, attending to large sized letters would involve either focused (Fig. 1b) or distributed (Fig. 1d) attention to large spatial scales.

Hierarchically structured stimuli provide a unique way to study such distributed attention mechanisms given its focus on the “forest” or “whole” rather than the “trees” or “parts”. Hierarchical stimuli typically consist of a large shape (global) made up of smaller shapes (local). Both global and local levels are processed in parallel at early stages of cortical processing (Heinze & Münte, 1993) and their processing diverges at higher stages of perceptual processing (Heinze et al., 1998). The differences in global and local levels of processing especially with hierarchical stimuli are partly based on spatial frequency processing (Fink et al., 1999; Sasaki et al., 2001; Shulman & Wilson, 1987) and spatial tuning, with global attention to the large shape being associated with enhancement over a larger spatial scale compared to local attention (Sasaki et al., 2001). Yet, local attention to small shapes that make up a large shape may be associated with a larger spatial extent compared to focused attention to an individual element. This may be possible due to grouping of local elements contributing to greater spatial spread during local processing (Han et al., 2002). Apparently, a stimulus with a smaller size would involve attending to a smaller region compared to the same stimulus with larger size. Even with a spatial region selected for further processing, attention could be manipulated in terms of different levels of object-based processing.

The role of object-based representations for awareness has been emphasized in a binocular rivalry study where the cued surface dominated subsequent perceptual rivalry even when the dominant and the suppressed surfaces occupied the same region of space (Mitchell, Stoner & Reynolds, 2004). This indicates that processes involved in awareness are affected by the way attention operates on object-based representations. The differences in the level of processing on which attention operates might be important in determining the nature of adaptation aftereffects. Therefore, we were particularly interested in examining the role of focused/distributed attention in terms of spatial spread and levels of object-based processing on awareness through afterimages.

Given the links between attention and awareness, we hypothesized that the type of attention will differentially affect the duration of afterimages. In terms of spatial attention, as attention is more focused with the central task, afterimage durations should be longer with the small compared to the large letter and local compared to global letter. This is based on the findings of stronger afterimages observed when attentional focus was maintained at the center of the display compared to when attentional scope was broad by performing a task with the peripheral inducer (Suzuki & Grabowecky, 2003).

There is some indication that attentional selection at the global or local level is linked to differences in neural activity associated with awareness (Koivisto, Revonsuo & Lehtonen, 2005). Koivisto, Revonsuo & Lehtonen (2005) found interactions between awareness and the type of attention in the later portions of the early anterior negativity (P2-N2 window), with larger differences between recognized and unrecognized stimuli for local attention compared to global attention in the right hemisphere. This interaction indicates that awareness could be influenced by attention

to local and global levels. Given potential differences in awareness for the global attention and its link to distributed attention that operates on large spatial scales (Chong & Treisman, 2005; Treisman, 2006), we hypothesized that global target identification would produce stronger afterimages compared to identification of the same-sized single large letter that relies more on focused attention.

Experiment 1

We systematically varied the different levels of object-based processing and the attentional spread by manipulating stimulus attributes that determined identification in the central task. Most importantly, to determine the effect of attentional manipulation on awareness of an afterimage, the observers reported onset and offset of an afterimage induced under different task conditions defined by tasks in which global, local, large and small letter stimuli were identified. The tasks with local and small stimuli differed in terms of levels of processing along with spatial spread of attention. Similarly, the tasks with local and global stimuli differed in both the level of processing and the spatial spread of attention. The tasks with small and large stimuli on the other hand, only differed in terms of the spatial region involved when attention is directed to them.

Method

Participants

Twenty one adult volunteers (age range - 19 to 25) from University of Allahabad provided informed consent and participated in the Experiment. All had normal or corrected-to-normal vision. Data from one participant (very large afterimage durations

greater than three standard deviations above the mean) was not included in the analysis.

Stimuli & Apparatus

The stimulus was a block letter “U” presented as either upright, inverted, or rotated towards the right or left (by 90°). The letter “U” could be presented as a single (small or large) (Fig. 1a, b) or hierarchical letter stimulus. The hierarchical letter was composed of many single small letters (Fig. 1c). The single small letter subtended $0.64^\circ \times 0.57^\circ$. The single large and hierarchical letter subtended $5.72^\circ \times 4.65^\circ$. The letter stimuli were presented in the centre of a blue square frame inducer (14.4 cd/m^2) whose inner boundary subtended $7.19^\circ \times 7.19^\circ$ with thickness 0.8° . The background color was grey (58 cd/m^2). All stimuli were presented on a 17” monitor with 70 Hz refresh rate using DirectRT (Empirisoft Corp, USA) and data was collected using the keyboard.

Procedure

There were four practice trials followed by twenty randomized experimental trials (five trials per condition). At the centre, forty black letter stimuli were presented in each trial (two stimuli per second) for a total duration of twenty seconds. The stimuli were single letters or hierarchical letters whose presentation was blocked during the experimental session. The participants counted the number of targets (“U” rotated to the left) while adapting to the inducer frame. There were four blocks of trials. The participants were informed before the beginning of each block whether they had to look for a global, local, single large, or single small letter target. Hierarchical stimuli were presented in both the global and local blocks. In a global block, participants

viewed hierarchical stimuli and had to count the number of such stimuli that had the global structure of a left-facing 'U', regardless of the shape of the stimuli's constituent elements. In a local block, participants viewed similar stimuli but had to count the number of stimuli composed of small left-facing 'U' shapes, regardless of the stimuli's global shape. In both the global and local blocks, hierarchical stimuli were incongruent (the letters at the global and local level were always different). In the small and the large blocks, only small or large letter stimuli appeared respectively.

After disappearance of the letter stimuli, a blank screen was presented on which the afterimage was formed. The participants pressed two separate keys to indicate both the onset (left arrow key) and offset (right arrow key) of the afterimage that was used to calculate the duration of afterimage. After the responses to the afterimage, the participants indicated the number of targets that they counted by pressing the appropriate number keys on the keyboard. Participants were asked to maintain fixation at the centre and were told not to blink during the duration of afterimage appearance.

Results & Discussion

We measured the duration of the afterimages as a function of letter stimuli of different sizes and levels of processing used in a central task. Trials with more than two errors in counting the target were removed from analysis (similar to Suzuki & Grabowecky, 2003). The accuracy in the counting task was high with all types of stimuli (local – 96%, global – 99%, small – 99%, large – 97%). The tasks with global and large stimuli were matched in their spatial extent and differed in the object-based properties. Afterimage durations were largest for the identification and counting task

with small stimuli followed by the local stimuli, the global stimuli, and then the large stimuli (see Fig. 2). A repeated measures ANOVA with stimulus type (global, local, large, small) as the variable showed a significant effect $F(3, 57) = 6.70, p < 0.01$. Comparisons with paired-sample t-tests showed that afterimage durations were longer when the identification and counting task was performed with small compared to large stimuli (by 1518 ms, $SE = 580$ ms) $t(19) = 2.61, p < 0.01$, local compared to global stimuli (by 1014 ms, $SE = 320$ ms), $t(19) = 3.16, p < 0.01$ and small compared to local stimuli (by 933 ms, $SE = 563$ ms), $t(19) = 1.66, p = 0.057$. As predicted, duration of afterimage was longest when attention was most focused to the centre of the display. Moreover, as the attentional spread increased, the afterimage duration decreased. These results indicate that either the spatial extent of attention or levels of processing affect afterimage duration. There was no significant difference with central tasks involving global and large stimuli, $t(19) = 1.21, p = 0.13$.

The results from Experiment 1 showed that variation in the spatial spread of attention during adaptation has different effects on afterimage durations. Attending to a smaller region at the centre away from the inducing stimulus resulted in strong afterimages. It is possible that participants attended to intermediate size regions during the task with the local letter (given that the local level is constituted by many small letters and there may be local grouping of the small letters) resulting in medium strength afterimages. Attending to a large region for processing global or large letters produces weaker afterimages. In other words, perceptual awareness is sensitive to the spatial extent of attention. However, the results for the effect of different levels of processing were equivocal. The results from Experiment 1 cannot be solely explained based on the spatial extent of focused attention. These results are also attributable to the nature of attentional processes engaged by different hierarchically structured

stimuli that may have different effects on perceived duration of afterimage. The lack of difference in afterimage duration in the task with large and global letters might be due to their proximity to the inducing stimulus, which may have resulted in attention spilling over to the inducing stimulus. Hence, in order to examine the effects of object-based selection, we reduced the size of the large letter and the hierarchical letter to an intermediate size in Experiment 2 to reduce its proximity to the inducer frame.

Experiment 2

Given the putative role of object-based attention in perceptual awareness (Koivisto, Revonsuo & Lehtonen, 2005; Leopold & Logothetis, 1999; Mitchell, Stoner & Reynolds, 2004), we wanted to further investigate this issue using afterimages. We used spatially invariant stimuli that differed only on the grounds of their object-based properties.

Method

Participants

Sixteen adult volunteers (age range - 19 to 25) from University of Allahabad provided informed consent and participated in the Experiment. All had normal or corrected-to-normal vision. Data from one participant (greater than 3 standard deviations from the mean) was not included in the analysis.

Stimuli & Apparatus

A hierarchical letter and a single letter of the same size subtending $3.58^\circ \times 3.15^\circ$ were used in Experiment 2.

Procedure

In Experiment 2, the procedure was the same as in Experiment 1 except that only the identification and counting of global target and large letter with letters of the same size were used. The experimental session consisted of ten trials per condition preceded by four practice trials.

Results & Discussion

The global and the large letter stimuli were kept to be of equal size and their distance from the inducing frame was reduced compared to Experiment 1. The accuracy in the counting task was 95% for global and 96% for large stimulus type. Afterimage durations were measured and a paired sample t-test showed a significant effect of the levels of processing ($t(14) = 3.18, p < 0.01$). The afterimage duration was affected by the central task with longer afterimage durations with the central task (by 748 ms, $SE = 235$ ms) involving a global target compared to a large single letter of same size (See Fig. 3). Our results demonstrate that even when spatial extent of the global and the large stimulus was matched, the object-based properties or representations that differed between the two stimuli with global letter involving distributed attention and the single large letter involving focused attention produced differences in the perceived duration of color afterimages.

The results showed that when attending to large spatial scales, stronger afterimages are produced when distributed attention is deployed compared to focused attention. Our results are consistent with the reports of interaction between awareness related cortical activity and types of attention (Koivisto, Revonsuo & Lehtonen, 2005)

and other studies on multistability demonstrating that perception of stimuli can be facilitated by high level object-based information such as object-class (see Leopold & Logothetis, 1999). Our findings also support the idea that when information from larger spatial scales have to be processed, distributed attention has a greater facilitatory effect on performance compared to focused attention (Treisman, 2006).

Experiment 3

The first two experiments indicated that the spatial extent of attention and levels of processing affect afterimage durations. However, the previous experiments used stimuli that may have allowed the observers to use different strategies of directing their gaze to the periphery when performing the counting task using different stimuli. For example, while during the task with the small stimuli, the observers may have fixated at the center, but during the local task, the observers may have adopted a different strategy of fixating at any of the peripheral locations where the local elements appear. Moreover, even with the large and global stimuli, the results may have been confounded by fixating at a peripheral location, especially the left side to look for the absence of a vertical line or a vertical line of elements that defined the target in the previous experiments. It is to be noted that the differences between large and global conditions in Experiment 2 indicate that a common strategy (look at the left side in the periphery) was probably not used and if used would not explain the obtained differences between global and large conditions. To ensure that gaze direction related strategies did not play any role in the findings from the previous experiments, we performed Experiment 3 in which a different set of stimuli was used which cannot be identified easily by using a gaze direction related strategy. This

would also enable us to see whether our findings would generalize with different stimuli.

Method

Participants

Twenty-two adult volunteers (age range - 17 to 26) from University of Allahabad provided informed consent and participated in the Experiment. All had normal or corrected-to-normal vision. Data from two participants (greater than 3 standard deviations from the mean) was not included in the analysis.

Stimuli & Apparatus

The stimuli were block letters “S”, “H” and numbers “6”, “9”. Similar to Experiment 1, four types of stimuli were used (See Figure 4). The small stimuli subtended $0.64^\circ \times 0.29^\circ$ and the large as well as the hierarchical stimuli subtended $5.00^\circ \times 3.14^\circ$. The local level consisted of many small stimuli arranged to form a global ‘8’ and the global level consisted of many local ‘8’s. Both the global and local stimulus sets are completely different in Experiment 3. Other parameters and the apparatus were the same as Experiment 1.

Procedure

The procedure was the same as in Experiment 1 except that the observers had to identify and count the target letter “S”. which could be a small, a large, a local or a global stimulus. The small, local, large and global conditions were blocked as in Experiment 1.

Results & Discussion

We measured the duration of the afterimages when the central task was performed with small, large, global and local stimuli (See Fig. 5). The accuracy in the counting task was high with all types of stimuli (local – 92%, global – 95%, small – 95%, large – 97%). A repeated measures ANOVA with stimulus type (global, local, large, small) as the variable showed a significant effect $F(3,57) = 18.28, p < 0.001$. Comparisons with paired-sample t-tests showed that afterimage durations were longer when the identification and counting task was performed with the small compared to the large stimuli (by 4162 ms, $SE = 773$ ms), $t(19) = 5.38, p < 0.01$, the local compared to the global stimuli (by 1266 ms, $SE = 562$ ms), $t(19) = 2.25, p < 0.05$, the small compared to the local stimuli (by 2343 ms, $SE = 691$ ms), $t(19) = 3.39, p < 0.01$ and the global compared to the large stimuli (by 552 ms, $SE = 257$ ms), $t(19) = 2.14, p < 0.05$. These results are consistent with the results from Experiment 1 & 2. The duration of afterimage was longest when attention was most focused to the centre of the display. Moreover, as the attentional spread increased, the afterimage duration decreased. These results indicate that the spatial extent of attention affect afterimage duration. The longer afterimage durations for global identification task compared to the large letter identification task shows that the levels of processing also affect perception of the afterimage. Hence, global or distributed attention produces longer afterimage durations at larger spatial scales. Since all the stimuli appeared in this experiment appeared at the centre and directing gaze at any location in the periphery would not help in uniquely identifying the target, these effects can not be attributed to differences in eye movements or gaze direction.

General Discussion

The results from the three experiments are consistent with findings from other studies on attention and afterimages (Lou, 2001; Suzuki & Grabowecky, 2003). While previous studies showed that inattention to adapting stimuli resulted in longer lasting afterimages, we argue that the type of attention (focused or distributed) is important and affects the strength of afterimages. A major finding is that the spatial extent with more spatially focused attention to the central task (small or local letters compared to large or global letters) produces stronger afterimages. It is to be noted that this difference is present even though there are nearly no differences in performance in the central task with different size stimuli. These effects can not be attributed to differences in gaze direction or eye-movements. A simple concept of inattention would not be able to account for the differences in afterimage durations as a function of spatial extent of attention. Lavie (2006) has argued for the role of perceptual load in visual awareness given the differences in conscious identification of stimuli under low and high load conditions. Unlike the studies on perceptual load, the differences in the duration of afterimages are present even when the central tasks are roughly equal in difficulty and do not show any differences in performance.

More interestingly, we found that an afterimage was perceived for a longer duration with a small letter compared to local stimuli, although this difference was not enough to show that levels of processing or object-based selection independently affect afterimage durations. The difference in duration of afterimage with small and local stimuli may be due to differences in the spatial spread of attention between them, with local stimuli involving greater spatial spread of attention due to grouping (of many small letters) compared to small stimuli. The identification of a global letter compared to a letter of the same size does not rely on spatial spread but highlights

differences in the levels of processing associated with object-based selective attention. Even when the spatial extent is matched with global and large stimuli, stronger afterimages were obtained with global compared to large letter in both Experiments 2 and 3. A simple model with focused attention cannot explain these results. Instead, we support the recent claims of differences in the mechanisms of focused compared to distributed attention (Chong & Treisman, 2003, 2005a, 2005b; Treisman, 2006) by showing that focused and distributed attention have different effects on awareness. Our results indicate that object-based mechanisms of selection independently modulate awareness with globally directed (or distributed) attention resulting in stronger afterimages. This is consistent with the idea that focused and distributed attention mechanisms differ in the way they inform us about the environment (Treisman, 2006).

Our study provides evidence for the association between different levels of processing, spread of attention, and access to awareness. The results are consistent with the critical importance of competitive selection mechanisms in visual scene perception and the selection of relevant objects in a display (Mitchell, Stoner & Reynolds, 2004). We showed that the stimulus driven attentional influences are not just limited to enhanced visual processing, but instead interact with mechanisms involved in perceptual organization to affect perceptual awareness. This may be possible due to the higher integrative centers of the brain that act upon perceptual representations to ensue awareness (Leopold & Logothetis, 1999).

One possible account for the differences between small letter task and the other task conditions especially in Experiment 1 and 2 could be differences in gaze direction. The use of another set of stimuli in which gaze direction strategies may not play any role in Experiment 3 and the replication of the results from the first two

experiments indicate that the differences in afterimage durations obtained with different attention conditions is not due to selective gaze direction in the periphery.

Another factor that might have played a role resulting in larger afterimage durations for the global compared to the large task is the incongruent nature of the global stimuli. Given the requirement to ensure that the participants attend only to the specified level in the experiments, only incongruent stimuli were used. The incongruent global stimuli might be more difficult to identify than the large stimuli used in the Experiments. It is to be noted that the accuracy values across the conditions were the same. The local task also contained incongruent stimuli in both Experiments 1 and 3. It is possible that any difficulty with global or local stimuli identification was masked by ceiling effects. Compared to Experiment 1, we also simplified the local and global stimuli by ensuring that the stimulus at the unattended level (global when observers were attending to the local level and vice versa) remained unchanged. This would have further reduced the complexity of the local and global tasks since given that it would have been easier to ignore the unattended level especially if the stimulus at that level remains unchanged. The lack of difference in accuracy in all experiments and different hierarchical stimuli indicates that the incongruent nature of the hierarchical stimuli might not have played a critical role in the afterimage durations between the two conditions.

Unlike afterimages (Lou, 1999; Lou, 2001; Suzuki & Grabowecky, 2003; Tsuchiya & Koch, 2005), focused attention to a secondary task has been shown to increase the strength of motion, tilt and depth aftereffects (Chaudhuri, 1991; Rose et al., 2003; Spivey & Spirm, 2000). For example, attending to motion increased the strength of motion aftereffects whereas reduced attention to motion decreased the strength of motion aftereffects (Chaudhuri, 1991). However, in color afterimage

studies, attending to a secondary task increased the afterimage strength. A possible account for these contrasting effects on adaptation is the difference in attentional effects on polarity dependent and independent processes (Suzuki & Grabowecky, 2003). The polarity independent (or attribute invariant) processes respond to their preferred stimuli independent of luminance or color contrast. However, the polarity dependent processes selectively respond to stimulus properties (e.g. the contrast polarity selective cells discriminate between light and dark stimuli) and contribute to formation of color afterimages.

Suzuki & Grabowecky (2003) postulated that the attention to the inducer weakens color afterimages by facilitating polarity independent processes rather than polarity dependent processes. However, with the motion, tilt, and depth aftereffects, attention aids polarity dependent processes to produce stronger afterimages. Another important distinction between these aftereffects is the presence or absence of a test stimulus. While motion, tilt, and depth aftereffects coincide with the presentation of a test stimulus, the color afterimages is elicited without the presence of a test stimulus and can be produced on a uniform white field. In our study, we show variable effects of attention on the adaptation of color afterimages that depend on the properties of the attentional state. The results suggest that attentional processes have different modulatory effects on polarity dependent or independent processes thereby leading to different effects on adaptation. Future work directed towards exploring the effects of attentional state on polarity dependent and independent processes by using neurophysiological measures would be important in understanding the role of attention in adaptation aftereffects.

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 & Francis, 2007a). The BCS processes edge/boundary information and the FCS processes information about surfaces including filling of color and brightness between the boundaries specified by the BCS. According to the model based on BCS and FCS (Wede & Francis, 2007a), more attention on adapting stimuli generates stronger aftereffects in the orientation (or boundary) dependent and polarity independent BCS, thereby resulting in the delayed and weaker color afterimages produced in the polarity dependent FCS.

In the context of this model, distributed attention that operates on larger spatial scales may weaken boundaries thereby resulting in weaker aftereffects in BCS. This would enable stronger color afterimages produced in the FCS. There is some evidence that global processing is more dependent on low spatial frequency processing (Badcock et al., 1990; Fink et al., 1999; Sasaki et al., 2001; Shulman, & Wilson, 1987). The processes based on low spatial frequency would produce weaker effects in BCS due to suppression of boundary information. Due to the opposing relationship between the BCS and FCS, the end result would be stronger afterimages based on aftereffects in the FCS (Georgeson, & Turner, 1985; Wede, & Francis, 2007b).

It is also quite possible that weakened afterimages of attended stimuli might be necessary for clear awareness of subsequently attended stimuli, something akin to the phenomenon of inhibition of return in which previously attended locations are inhibited to facilitate allocation of attention to the following locations of interest. Future experiments are needed to explain the mechanisms underlying the formation of afterimages and the role of attention in afterimage formation.

Irrespective of the specific mechanisms involved in color afterimages, the results from the current study pose a challenge to theories that argue that attention and consciousness can have opposing effects on each other. Theories on attention and

awareness need to consider the attentional state and processing strategies employed in performing a given task. In addition, the differences between attention and awareness with different kinds of aftereffects also need to be considered for explaining the link between attention and awareness.

Given the findings from our study, we argue focused and distributed attention have different effects on afterimage durations. Future studies may show consciousness with the complete lack of attention but we argue that different types of attention need to be considered in understanding the relationship between attention and 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 their relationship.

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Figure 4: Examples of stimuli used in Experiment 3: (a) a single small letter, (b) a single large letter, (c) a hierarchical stimulus with the local target, and (d) a hierarchical stimulus with the local target.

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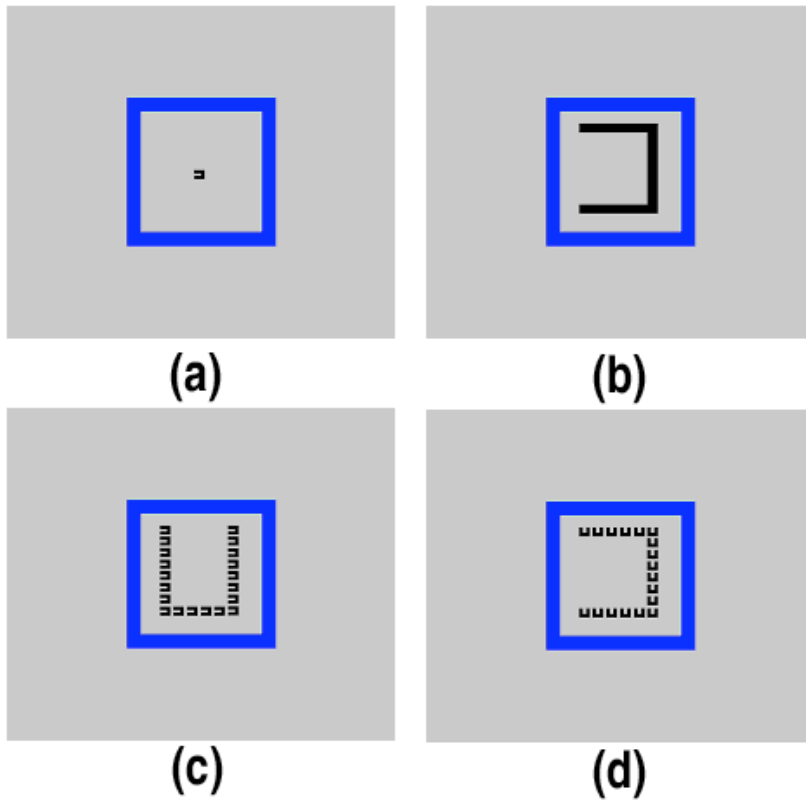


Figure 1

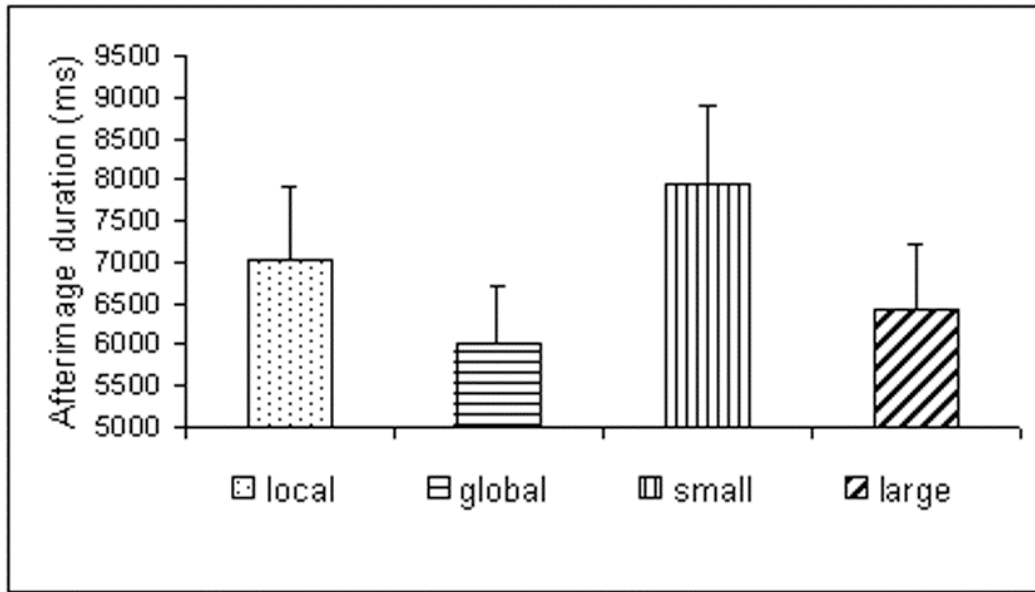


Figure 2

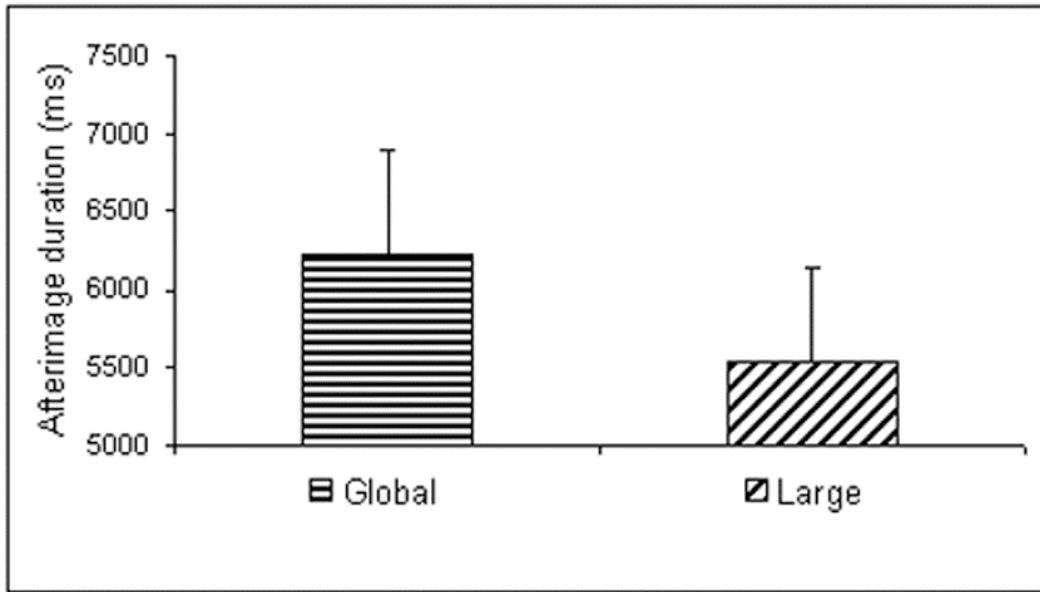


Figure 3

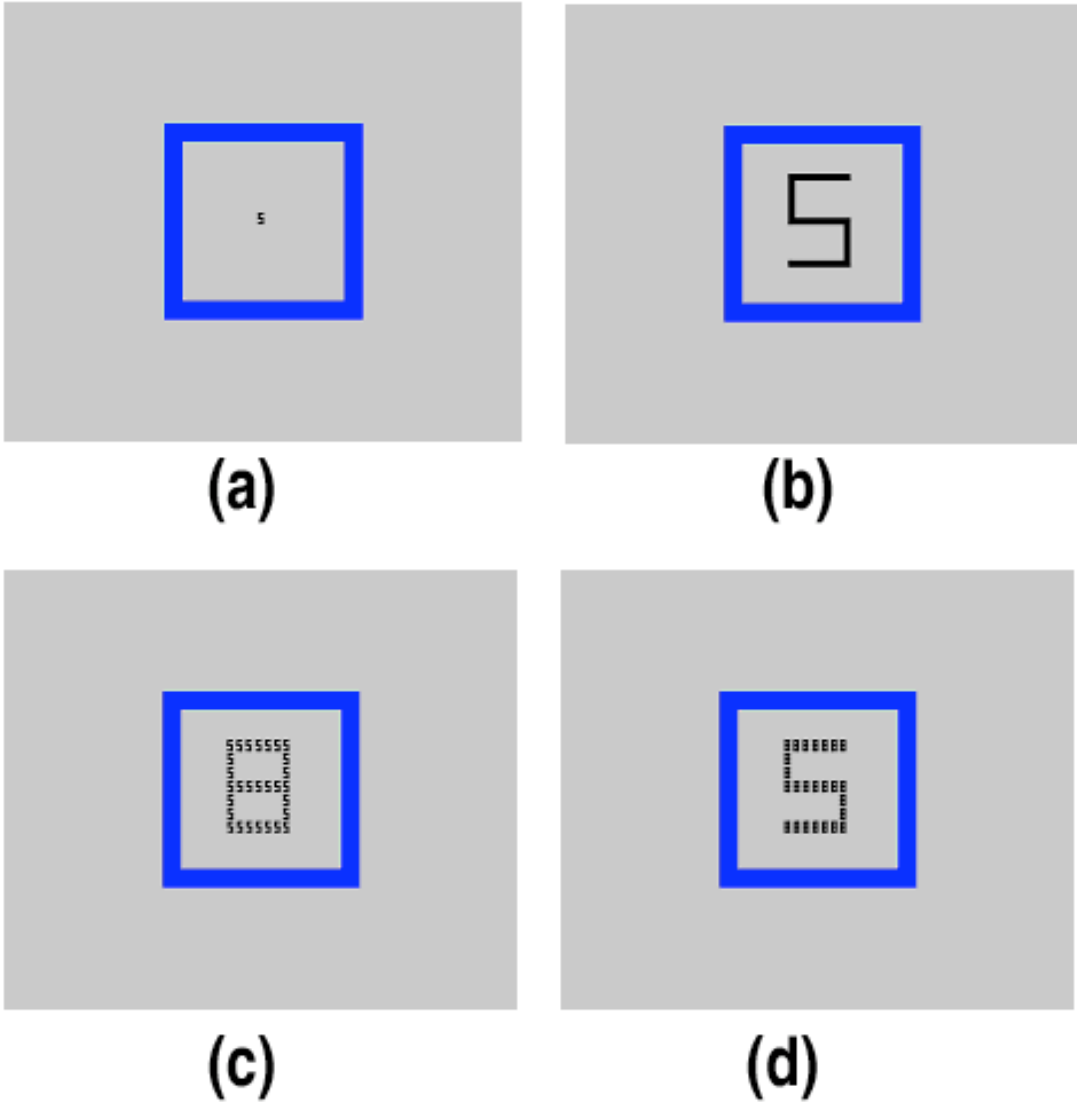


Figure 4

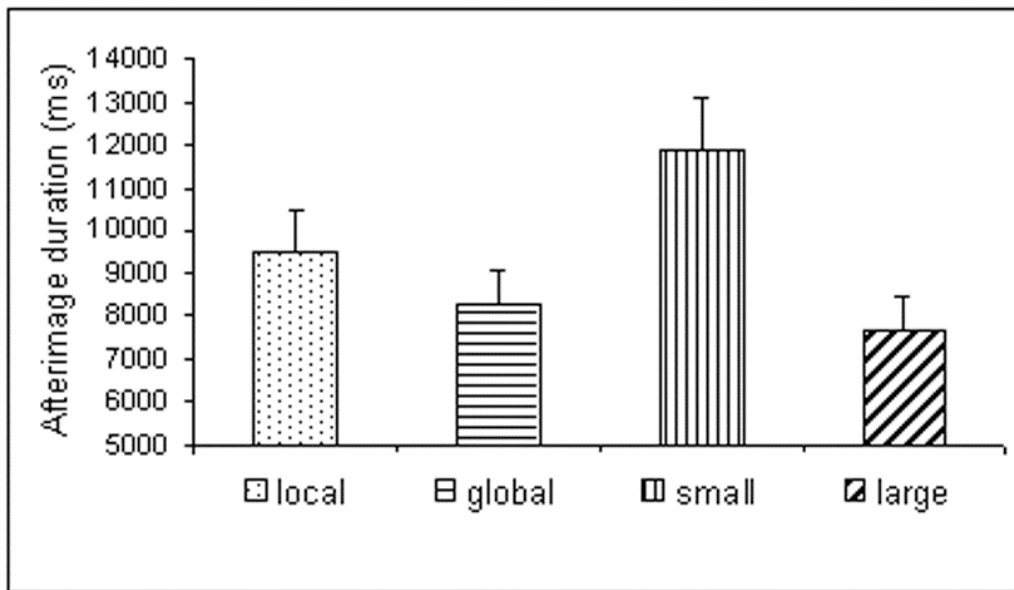


Figure 5