Mindfulness (2017) 8:17–26
DOI 10.1007/s12671-015-0428-1

ORIGINAL PAPER

Concentrative Meditation Influences Visual Awareness: a Study with Color Afterimages

Narayanan Srinivasan[1] · **Amrendra Singh**[1]

Abstract While many studies have shown that meditation enhances attentional processing, very few studies have investigated the effect of enhanced attentional processing on visual awareness. We investigate the attentional effects on visual awareness in focused attention meditators using a task that manipulates scope of attention using hierarchical letter stimuli (local and global processing) and single letter stimuli of varying size (small and large). In addition, working memory load was manipulated using a 0-back and 2-back task. Data were collected from Sahaj Samadhi Meditators and an age-matched control group of non-meditators. Visual awareness was tapped using negative color afterimages by measuring the duration and more importantly the clarity and color of afterimages using a rating scale. The afterimage durations were significantly longer for Sahaj Samadhi meditators compared to non-meditators. In addition, the afterimages were sharper for meditators compared to non-meditators suggesting that better attentional focusing associated with meditators might lead to phenomenal changes in visual awareness. Scope of attention influenced not only afterimage durations but also clarity indicating that changes in scope also influence aspects of visual awareness. The results indicate meditation training not only modifies attentional processes but also results in changes in conscious visual perception.

Keywords Concentrative meditation · Awareness · Attention · Working memory · Afterimages · Consciousness

Introduction

Meditation practice has been shown to influence a person's cognitive abilities like visual perception (Carter et al. 2005), attention (Jha et al. 2007; Hodgins and Adairs 2010; Lutz et al. 2009; Raffone and Srinivasan 2010), working memory (Buttle 2011; Jha et al. 2010; Vugt and Jha 2011), emotion regulation (Kemeny et al. 2012; Robins et al. 2012; Goldin and Gross 2010), and self-control (Friese et al. 2012). More specifically, meditation has been shown to improve different attentional processes depending on the nature of the meditation type or practice (Chan and Woollcott 2007; Jha et al. 2007; Tang et al. 2007). Such improvement in attentional processes due to meditation results in better perceptual performance (Brefczynski-Lewis et al. 2007; Slagter et al. 2007; Lutz et al. 2009; Maclean et al. 2010; for review see Lutz et al. 2008).

A large number of studies have shown that attention influences awareness (Dehaene et al. 2006; Posner 1994; Koch and Tsuchiya 2007). Studies based on paradigms like inattentional blindness and change blindness have demonstrated the importance of attention for conscious perception (Lavie 2006; Mack and Rock 2001; Rensink 2002). The question of whether attention influences appearance has been debated for a long time (Fuller and Carrasco 2006; Carrasco 2014). Some studies with perceived color as the dependent measure did not find any effect of attention on perceived color (Prinzmetal et al. 1998; Prinzmetal et al. 1997). Carrasco and colleagues have shown that attention influences the phenomenology of visual awareness including perceived contrast and other visual features not just performance (Carrasco 2009; Carrasco et al. 2004).

A prominent way to investigate the effects of attention on awareness has been through the use of aftereffects based on adapting to specific visual features (Chaudhuri 1990; Rose et al. 2003). For example, color afterimages have been used to understand the relationship between attention and

---

✉ Narayanan Srinivasan
nsrini@cbcs.ac.in

[1] Centre of Behavioural and Cognitive Sciences, University of Allahabad, Allahabad 211001, India

awareness (Baijal and Srinivasan 2009; Lou 1999; Lou 2001; Suzuki and Grabowecky 2003; Tsuchiya and Koch 2005). These studies have also been used to argue for the potential possibility of opposing effects of attention on awareness (Koch and Tsuchiya 2007). Suzuki and Grabowecky (2003) asked the participants to attend to either one of two overlapping inducers and measured the duration of the color afterimages. They found that the afterimage of the attended inducer appeared later than that of the unattended inducer. In another experiment, they presented a stream of letters at the center and asked the participants to either attend to the letters or to the afterimage inducer. Afterimage onset was earlier when participants attended to the letter stream compared to when they attended to inducer (Suzuki and Grabowecky 2003). Attending to the inducer weakened the strength of the color afterimages, and paying less attention to the inducer strengthened the color afterimages.

Selective attention differs in terms of the nature of information used for selection (space vs. objects) and also scope of attention (focused vs. distributed). Focused attention is associated with processing at smaller spatial scales, and distributed attention is associated with processing larger spatial scales (Triesman 2006). Narrow scope or focusing attention enables detailed processing and analysis of specific features, objects and scenes and distributed attention facilitates global registration of scenes (Triesman 2006). Distributed attention might be important for computation of statistical properties (Baijal and Srinivasan 2011; Chong and Treisman 2005; Parkes et al. 2001; Triesman 2006). There is some evidence that focused and distributed attention might be relatively independent based on studies performed with simultanagnosic patients (Demeyere et al. 2008). These patients were sensitive to different forms of information (e.g., color and size) in distributed attention mode rather than focused attention mode.

Using color afterimages as a tool for understanding visual awareness, Baijal and Srinivasan (2009) manipulated the spatial spread of attention (attentional spotlight) and level of attention (global or local) using a central task during the adaptation period without changing the adapting inducer. The stimuli used in the central task were either single letters (small or large) or hierarchical stimuli (with target stimuli appearing at the local or global level). The use of small vs. large letters involves differences in the scope of spatial attention (size of spotlight). The use of local and global tasks also involves differences in the nature of visual information processing (trees vs. forest). They found that scope of attention influenced visual awareness; changing the scope (size and hierarchical level) of the stimulus used in the primary task resulted in changes in the duration of the color afterimages. These results imply that differences in the way attention is deployed have different effects on awareness.

While multiple studies have shown that meditation practice influences perception in attentional paradigms, the dependent measure has mostly been accuracy (Lutz et al. 2009; Slagter et al. 2007). Very few studies have investigated whether meditation practice leads to changes in perceptual awareness (Carter et al. 2005). However, these studies have not manipulated attention and also have not investigated different phenomenological properties of conscious visual content. Color afterimages provide us a natural tool to assess the phenomenology of visual experience. Given that studies with afterimages have shown that attention influences visual awareness (Suzuki and Grabowecky 2003; Baijal and Srinivasan 2009), we investigated whether meditation influences awareness as measured through properties of color afterimages. Similar to Baijal and Srinivasan (2009), we also manipulated the nature of attentional processes employed in performing the central task. We used the basic methodology used in Baijal and Srinivasan (2009) and measured afterimage durations but also assessed other aspects of afterimage experience like perceived clarity (sharpness) with meditators and non-meditators. Given the lack of an attentional effect on perceived color in some earlier studies (Prinzmetal et al. 1998; Prinzmetal et al. 1997), we also measured the perceived color (saturation) of the color afterimages.

In addition to manipulating scope, we also manipulated the cognitive load of the primary task to see how working memory load influences the conscious perception of afterimages given the close relationship between working memory and consciousness (Baars and Franklin 2003). Given the widespread influence of working memory on various cognitive processes including consciousness, it is possible that working memory manipulations might influence the appearance of color afterimages. Given the close relationship between attention and working memory (Cowan 2005), it is possible that meditation training might increase the efficiency of processes involved in working memory and hence also result in changes in appearance of color afterimages as a function of working memory load.

The study focused on a meditation technique called Sahaj Samadhi meditation, which is usually classified as a concentrative meditation technique and is expected to result in better focused attention. Previous studies on Sahaj Samadhi meditation have shown that its practice results in better perception indexed by the larger mismatch negativity amplitudes obtained with an oddball paradigm (Srinivasan and Baijal 2007). Hence, we expected that the practice of Sahaj Samadhi meditation would also influence visual awareness. Previous studies with younger adults have shown that the duration of color afterimages changes as a function of scope of attention (Baijal and Srinivasan 2009). We expected that the scope of attention would influence the strength of color afterimages with both meditators and non-meditators. Given that attending to the task increases the duration of afterimages, and meditators are expected to have better focused attention than non-meditators, we predicted that the duration of afterimages would be longer for meditators. We also predicted that better focus by meditators would result in more clear afterimages and possibly a difference in perceived color (saturation).

Method

Participants

Twenty-five volunteers with normal or corrected-to-normal visual acuity and normal color vision provided informed consent and participated in the experiment. Participants consisted of two groups: a focused attention meditation group ($N=12$) and a control group of non-meditators ($N=13$) that did not differ as a function of age or education. The difference between the age of meditators (mean=40.41 years) and non-meditators (mean=37.61 years) was not significantly different, $t(23)=0.71$, $p=0.48$.

The meditation group consisted of Sahaj Samadhi (SS) meditation practitioners associated with Art of Living Foundation that specializes in Sudarshan Kriya Yoga. Most of the participants were teachers and have been practicing SS for more than 3 years. Sahaj Samadhi meditation is usually performed after a 20-min long pranayama and Sudarsha Kriya Yoga which is a rhythmic breathing exercise. In the SS meditation, the practitioner silently repeats a mantra (typically a specific sequence of words with religious significance), and whenever the mind wanders from this mantra, the practitioner has to bring it back to the mantra. The meditators practiced SS meditation for approximately 20 min every day.

Stimuli and Apparatus

The stimuli used for the attentional task were block letters "S", "H" and numbers "6", "9" (see Fig. 1). The small stimuli subtended $0.64^\circ \times 0.29^\circ$. The large as well as the hierarchical stimuli subtended $5.00^\circ \times 3.14^\circ$. The local level consisted of many small letters/numbers arranged to form a global "8". The stimuli at the global level consisted of many local "8s". The letter stimuli were presented in the center 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, and data were collected using the keyboard. The experiment was designed using E-Prime (Empirisoft Corp, USA).

Procedure

The basic structure of a trial is shown in Fig. 2. The basic procedure was similar to that used in Baijal and Srinivasan (2009). In each trial, a stream of 27 letter stimuli was presented for a duration of 20 s. Each letter stimulus was presented for 500 ms followed by a blank screen for 250 ms. The stimuli were presented at the center with participants performing a set of low load blocks and high load blocks. The order of the blocks was counterbalanced. The low load task was a zero-back task, and the participants counted the number of occurrences of the letter "S". The high load task was a two-back task, and the participants counted the number of times. The current letter/number (at the appropriate level) is the same as the one presented two instances before the current one in the stimulus stream. In both the load conditions, the number of instances of target occurrence was between six and twelve times.

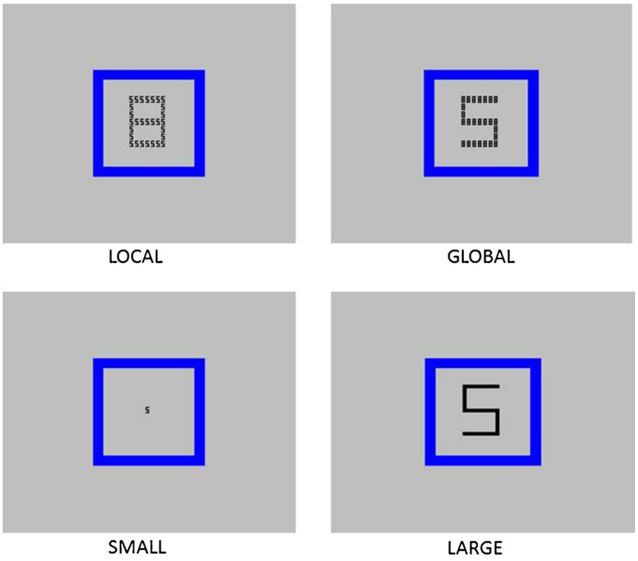
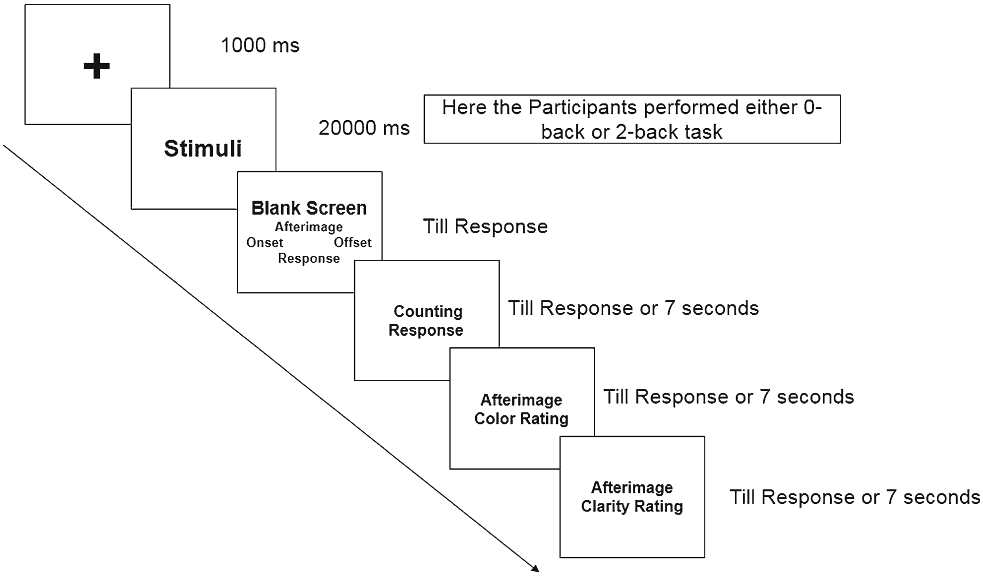


Fig. 1 Example stimuli containing the letter "S" used in the study

The adapting inducer (blue square) remained unchanged in all the trials. The scope of attention was manipulated by changing the size (small or large) or the level (global or local) of the hierarchical stimuli. The participants performed all the low load blocks or high load blocks together (order was counterbalanced across participants). Each experimental block consisted of six trials. The low load and high load blocks were preceded by a practice block consisting of four trials with one trial for each type of stimulus (small, large, local, and global). The participants were informed before the beginning of each block whether they had to do a zero-back or two-back task for a global, local, single large, or single small letter stimuli. In the global task block, participants viewed hierarchical stimuli, that is small 8 s arranged to form a large S, H, 6, and 9. In the local block, the participants viewed stimuli composed of small characters S, H, 6, and 9 forming a large 8. In both the global and local blocks, hierarchical stimuli were always incongruent (the letters at the global and local level were always different). In the small and the large blocks, only single small or large letters appeared respectively.

After the disappearance of the letter stimuli, a blank gray screen was presented on which the afterimage was visible. The participants pressed the space bar key twice, the first time

Fig. 2 Structure of a trial



to indicate the onset and the second time to indicate the offset of the color afterimage. The duration between the two key presses was the duration of the afterimage. After the key presses for onset and offset, participants indicated the number of targets that they counted by pressing the appropriate number keys on the keyboard and then pressing the spacebar key. Next, the participants gave a subjective rating for color (saturation) of the afterimage on a 9-point rating scale (low rating means low saturation and high rating means high saturation) and clarity of the afterimage on a 9-point rating scale (1-less clear and 9-very clear). Participants were asked to maintain fixation at the center and were told not to blink during the time they experience color afterimages.

Measures and Analyses

We measured the mean afterimage duration as well as the mean ratings for color and clarity for the two groups (i.e., the non-meditators and the Sahaj Samadhi meditators) as a function of working memory load and scope of attention (local, global, small, and large) in the central task. A mixed variable ANOVA with groups (non-meditators and meditators) as a between subjects variable and working memory load (low and high) as well as the scope of attention (small, local, large, and global) as within subjects variables was performed on accuracy, afterimage duration, afterimage clarity, and afterimage color.

Results

The accuracy analysis (see Table 1 and Fig. 3) showed that there was no difference in accuracy between the two groups, $F(1, 23)=0.858$, $p=0.364$, $\eta_p^2=0.036$ indicating that meditators and non-meditators did not differ in terms of accuracy. As expected, the effect of load was significant, $F(1, 23)=232.096$, $p=<0.0001$, $\eta_p^2=0.910$ with better accuracy in the low load condition. The effect of scope on accuracy was also significant, $F(3, 23)=3.024$, $p=0.035$, $\eta_p^2=0.116$. However,

Table 1 Mean accuracy in the primary task, afterimage duration, afterimage clarity, and afterimage color (SD in brackets) for meditators and non-meditators as a function of load and scope

	Low load		High load	
	Meditators	Non-meditators	Meditators	Non-meditators
Accuracy				
Small	97.24 (4.6)	97.62 (1.9)	58.13 (18.0)	53.26 (17.9)
Large	96.60 (4.5)	94.28 (6.8)	59.03 (14.9)	54.64 (14.8)
Local	97.24 (1.7)	94.94 (5.4)	58.13 (12.7)	59.28 (12.9)
Global	96.60 (5.2)	95.32 (6.0)	59.03 (19.4)	54.88 (14.4)
Duration				
Small	11.27 (5.8)	4.71 (2.2)	12.52 (7.7)	5.78 (3.9)
Large	9.57 (5.1)	4.62 (2.2)	11.02 (5.4)	4.58 (2.4)
Local	10.39 (5.0)	4.95 (2.9)	11.37 (6.5)	5.65 (3.5)
Global	10.74 (5.7)	4.31 (2.6)	10.71 (4.4)	5.33 (2.8)
Clarity				
Small	6.32 (1.3)	5.74 (1.8)	6.79 (1.7)	5.31 (1.5)
Large	5.65 (1.8)	4.13 (1.6)	6.41 (1.8)	4.38 (1.8)
Local	5.86 (1.4)	5.10 (1.9)	6.06 (1.8)	5.10 (1.9)
Global	5.62 (1.6)	4.27 (1.5)	6.03 (2.0)	4.57 (1.9)
Color				
Small	4.99 (1.2)	4.40 (1.1)	4.60 (2.5)	4.67 (0.8)
Large	5.17 (1.0)	4.59 (1.5)	4.87 (1.8)	5.26 (1.3)
Local	5.18 (1.2)	5.04 (1.2)	4.67 (1.9)	4.90 (1.4)
Global	5.49 (1.0)	4.90 (1.4)	5.04 (1.5)	5.04 (1.2)

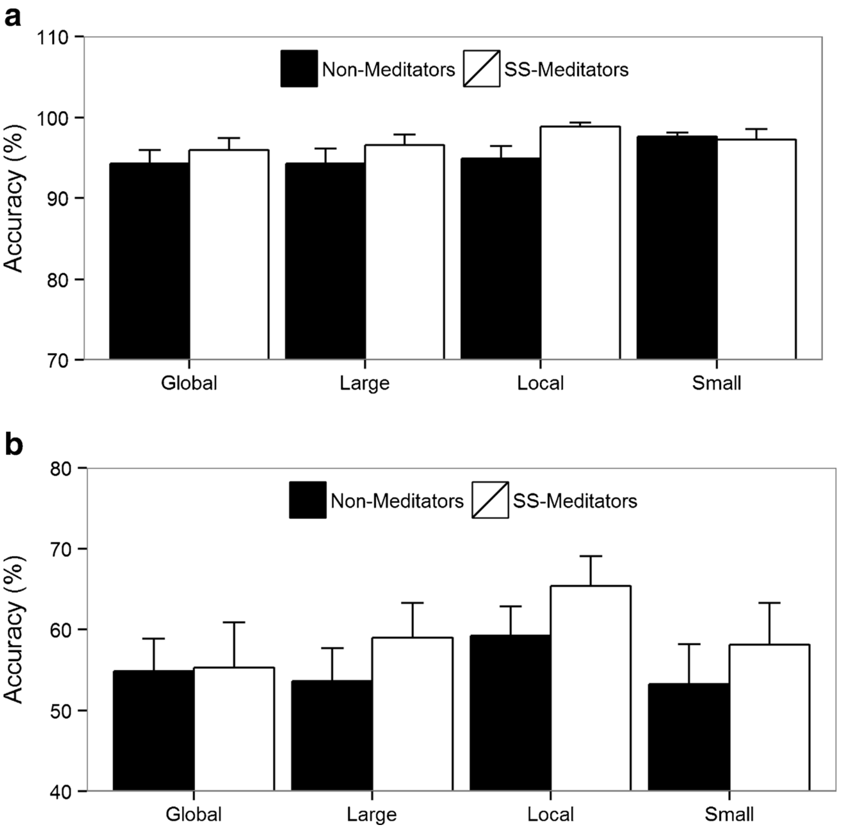


Fig. 3 Accuracy for **a** low load and **b** high load for different scope of attention conditions for meditators and non-meditators (error bar=SE)

none of the post hoc comparisons were significant. The interactions between load and group, $F(1, 23)=0.207$, $p=0.653$, $\eta_p^2=0.009$, as well as scope and group, $F(1, 23)=0.778$, $p=0.510$, $\eta_p^2=0.033$, were not significantly different. The interaction between load and scope, $F(1, 23)=2.661$, $p=0.055$, $\eta_p^2=0.104$, was close to significance. The three-way interaction between load, scope, and group was also not significant, $F(1, 23)=0.338$, $p=0.798$, $\eta_p^2=0.014$.

The analysis with afterimage duration (see Table 1 and Fig. 4) showed a significant effect of group, $F(1, 23)=13.702$, $p=0.001$, $\eta_p^2=0.373$. The afterimage duration for Sahaj Samadhi meditators was significantly longer compared to that for non-meditators. The effect of load was not significant, $F(1, 23)=2.106$, $p=0.160$, $\eta_p^2=0.084$. The effect of scope of attention on afterimage duration was significant, $F(3, 69)=2.828$, $p=0.045$, $\eta_p^2=0.109$. The small stimulus condition had the largest afterimage duration. Post hoc analysis showed the mean afterimage duration for large stimulus conditions is significantly shorter than that of the small stimulus condition, $t(24)=3.951$, $p<0.05$. The two-way interactions between group and scope, $F(3, 69)=1.687$, $p=0.178$, $\eta_p^2=0.068$, group and load, $F(1, 23)=1.089$, $p=0.307$, $\eta_p^2=0.045$, and load and scope, $F(3, 69)=0.928$, $p=0.432$, $\eta_p^2=0.039$, as well as the three-way interaction between group, scope, and load, $F(3, 69)=0.597$, $p=0.619$, $\eta_p^2=0.025$, were not significant.

The analysis on clarity (see Table 1 and Fig. 5) showed a significant effect of group, $F(1, 23)=5.054$, $p=0.034$, $\eta_p^2=0.180$ with a better clarity among Sahaj Samadhi meditators (mean=6.094) compared to non-meditators (mean=4.825). The effect of load was not significant, $F(1, 23)=1.384$, $p=0.251$, $\eta_p^2=0.057$. The effect of scope of attention on clarity was significant, $F(3, 69)=7.482$, $p<0.001$, $\eta_p^2=0.245$. Post hoc analysis showed that the clarity of the afterimage for the small stimulus task (mean=6.039) was higher than that for the large stimulus task, $t(24)=5.698$, $p=0.002$, and the global task, $t(24)=5.838$, $p=0.002$. The two-way interactions between group and scope, $F(3, 69)=0.716$, $p=0.178$, $\eta_p^2=0.068$, group and load, $F(1, 23)=0.041$, $p=0.841$, $\eta_p^2=0.084$, and load and scope, $F(3, 69)=0.394$, $p=0.758$, $\eta_p^2=0.017$, as well as the three-way interaction between group, scope, and load, $F(3, 69)=1.356$, $p=0.263$, $\eta_p^2=0.056$, were not significant.

The analysis on color (see Table 1 and Fig. 6) showed that the main effects of group, $F(1, 23)=0.110$, $p=0.743$, $\eta_p^2=0.005$, and load, $F(1, 23)=0.155$, $p=0.698$, $\eta_p^2=0.007$, and scope of attention, $F(3, 66)=2.234$, $p=0.092$, $\eta_p^2=0.089$, were not significant. The two-way interactions between group and scope, $F(3, 69)=0.379$, $p=0.769$, $\eta_p^2=0.016$, group and load, $F(1, 23)=2.068$, $p=0.164$, $\eta_p^2=0.082$, and load and scope, $F(3, 69)=1.219$, $p=0.310$, $\eta_p^2=0.05$, as well as the three-way interaction between group, scope, and load, $F(3, 69)=0.155$, $p=0.729$, $\eta_p^2=0.019$, were not significant.

Fig. 4 Afterimage for **a** low load and **b** high load for different scope of attention conditions for meditators and non-meditators (error bar=SE)

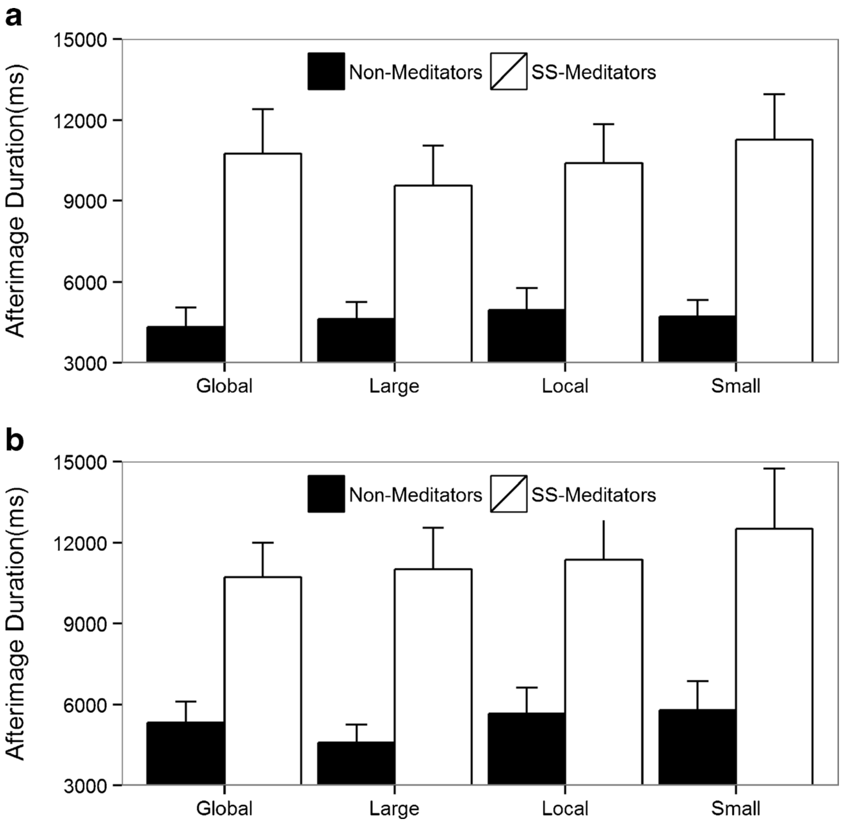
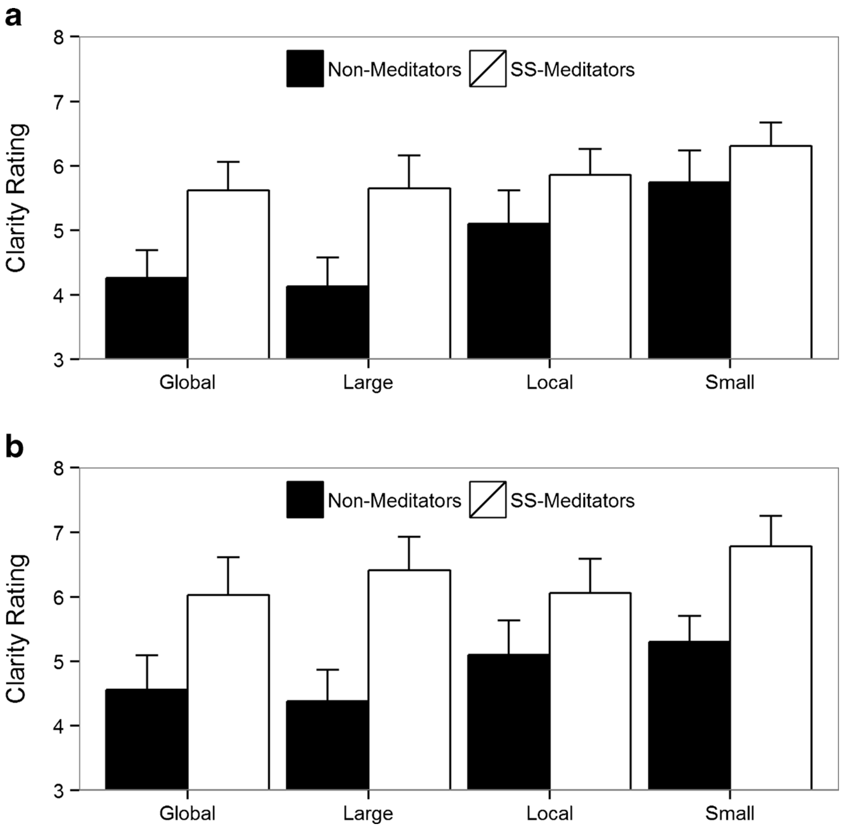


Fig. 5 Afterimage clarity for **a** low load and **b** high load for different scope of attention conditions for meditators and non-meditators (error bar=SE)



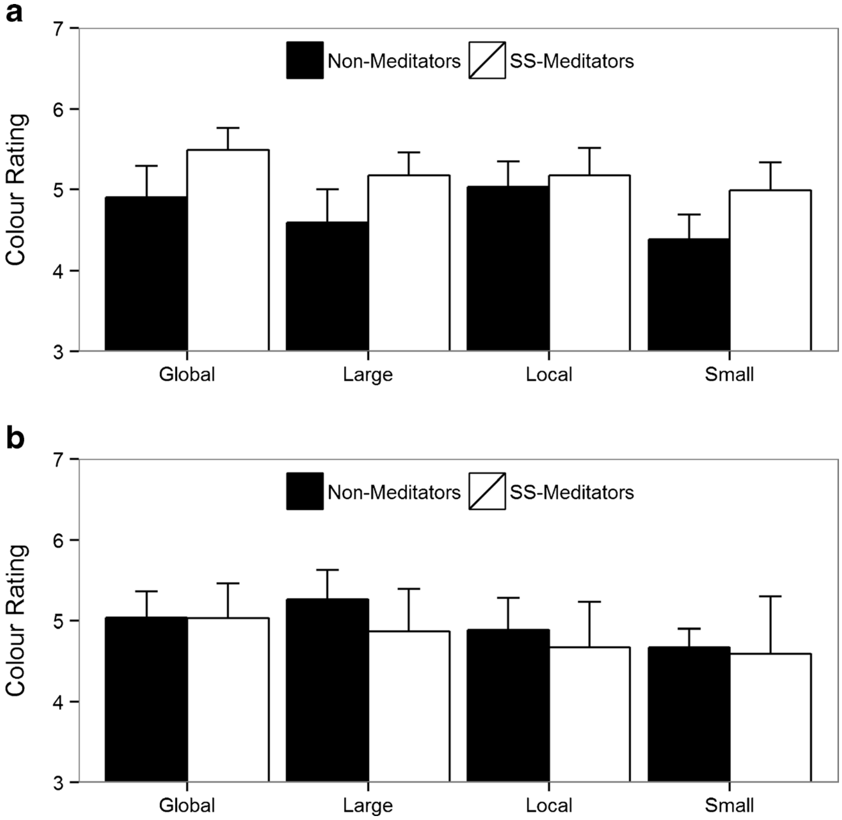


Fig. 6 Afterimage color for **a** low load and **b** high load for different scope of attention conditions for meditators and non-meditators (error bar=SE)

Discussion

The results show that concentrative meditation training influences the duration and clarity of afterimages; however, afterimage color is not influenced by meditation training. The meditators in the present study practice Sahaj Samadhi meditation, which is classified as focused attention meditation. They are well trained to focus their attention simultaneously on their breathing pattern or a mantra. Given that attending to the primary task stimuli and not the inducer increases afterimage duration (Lou 2001; Suzuki and Grabowecky 2003), the results suggest the possibility that more focused attention by concentrative meditation practitioners led to longer afterimage durations and a sharper visual experience than that of non-meditators. The results indicate that the phenomenal experience of meditators differs from that of non-meditators and the concentrative meditation practice influences processes leading to visual awareness. This difference is simply not due to behavioral performance differences in the primary task between the meditators and non-meditators. The results are consistent with other studies indicating that not just performance but visual awareness of meditators is probably different from those of controls due to concentrative meditation training (Carter et al. 2005).

In addition to extending the effects of scope of attention on awareness to meditators, the results also further consolidate findings indicating that attentional scope influences formation and perception of color afterimages (Baijal and Srinivasan 2009; Lou 1999; Suzuki and Grabowecky 2003). Consistent with our previous results (Baijal and Srinivasan 2009), the current study found larger afterimage durations for small and local letter tasks compared to global and large letter tasks. While this study found a significant effect of scope of attention, the specific pattern of effects of scope on afterimage durations was different. One major difference between the two studies is the age of participants with much younger participants (early 20s) in the Baijal and Srinivasan (2009) study compared to older participants (mean=37.6 years) indicating the possibility of a developmental difference in attentional effects on afterimages. Further studies are needed to confirm this possibility. A potential drawback of the current study is the relatively low number of participants. A study with larger sample size involving multiple meditation methods would be helpful in further understanding the effects of meditation on visual awareness.

In terms of clarity, meditators reported perceiving the afterimages to be sharper compared to non-meditators. The better focus of meditators achieved due to extensive concentration on breath or other stimuli perhaps resulted in higher perceived contrast or enhanced resolution making the afterimages sharper for them compared to non-meditators. Clarity was influenced by scope of attention with more focused condition (small letters) resulted in better clarity compared to other letter conditions. It is to be noted that previous studies using color afterimages (Baijal and Srinivasan 2009; Lou 1999; Lou 2001; Suzuki and Grabowecky 2003) did not ask participants to rate for clarity of the afterimages. It would be important to know how other manipulations of attention like load would influence the sharpness of the consciously perceived stimuli.

With respect to saturation, we did not find any effect of meditation training on perceived saturation of afterimages. However, we did find a trend indicating that the scope of attention influences saturation of the afterimages especially a lower saturation value when participants performed a task with small stimuli. These results are consistent with the findings of Fuller and Carrasco (2006) who showed that attention increases apparent saturation. The finding on attentional effects on saturation do differ from earlier studies that did not find any effect on saturation (Prinzmetal et al. 1998; Prinzmetal et al. 1997) but it is to be noted that the earlier studies manipulated attention by cuing and did not manipulate scope of attention. Smaller scope of attention associated with the smaller primary task stimulus resulted in lesser saturation for the afterimage when participants performed the task with smaller stimuli. Once again, these results do indicate that scope of attention do influence different aspects of visual awareness (Baijal and Srinivasan 2009).

There was no interaction between meditation practice and working memory load. Some prior studies with meditators did find significant improvement in working memory after meditation practice (Chambers et al. 2008; Zeidana et al. 2010) using a digit span backward and forward task of the Wechsler Adult Intelligence Scale. More importantly, there was no effect of working memory load on all the three dependent measures even though the two-back task was more difficult as indicated by the reduced accuracy with the two-back task compared to the low load zero-back task. One possibility is that the processes involved in the formation of afterimages are not greatly influenced by working memory load, especially with older adults. Further studies are needed with different manipulations of working memory and visual awareness.

The results of the current study have implications for understanding changes in attention and consciousness due to meditation practice. This particular study used a focused attention type meditation, but other types of meditation in which attention is open minded or distributed might lead to different effects on visual awareness as a function of scope of attention. Given that aftereffects are present for many visual features and provide us a tool to understand process involved in attention and awareness (Kirschfield 1999), further studies can indicate which processes underlying different aftereffects are amenable to meditation training. While we interpret the results of the current study as the result of meditation practice, it is possible that participants who have attributes that might influence the properties of afterimages are more likely to pursue meditation practice. We do think it is less likely given that at least one of the properties of afterimages is not influenced by meditation.

The significant effect of scope on clarity in addition to duration indicates that attention influences multiple aspects of visual awareness. The results are consistent with studies indicating that attention alters appearance (Carrasco 2009; Carrasco 2014; Carrasco et al. 2004). The results add to the important role of attention in influencing visual awareness with implications for theories proposed to explain the relationship between attention and consciousness.

Models that account for the effect of attention on duration of color afterimages (Wede and Francis 2007) would need to incorporate other aspects of afterimages like clarity and color. The two-system model of Wede and Francis (2007) contains a boundary contour system (BCS) and a feature contour system (FCS) in which the FCS processes information about color and other features between the boundaries specified by the BCS. The formation of afterimages is explained through interactions between these two systems. Paying attention to the adapting inducer results in stronger aftereffects in the boundary processing polarity-independent BCS that leads to delayed and weaker afterimages produced in the polarity-dependent FCS. Conversely, lesser attention to the adapting inducer results in stronger afterimages in the FCS. Our results indicate that better focusing of attention of meditators to the primary task results in changes in the BCS system leading to stronger afterimages in the FCS. It is to be noted that though the boundaries of the color afterimages are sharper with meditators. The results of the current study do indicate the need to incorporate top-down effects on conscious visual perception perhaps mediated by recurrent connections from prefrontal cortex to early visual areas (Dehaene et al. 2006; Lamme 2003). In addition, models of afterimage formation need to account for plasticity associated with attention training and incorporate changes in perceptual processes due to meditation practice.

To summarize, the study shows that concentrative meditation training possibly changes visual awareness as indicated by changes in the phenomenal properties of color afterimages. In addition, the study shows that scope of attention influences aspects of visual awareness including clarity and saturation. These results indicate that attentional processes influence not just performance but conscious appearance. Further studies are needed to see whether different meditation techniques that differ in terms of the nature of attentional training (concentrative vs. mindfulness) would differ in terms of the effects of attention on visual awareness. This would enable us to not only to understand processes involved meditation training and its effects but more generally processes leading to visual awareness.

Acknowledgments This study was supported by a research grant (SR/CSI/27/2010) from the Department of Science and Technology, India. The authors thank the Art of Living Organization especially their teachers in Allahabad who agreed to participate in the study. The authors thank the two anonymous reviewers for their comments in improving the manuscript.

References

Baars, B. J., & Franklin, S. (2003). How conscious experience and working memory interact. *Trends in Cognitive Sciences, 7*, 166–172.

Baijal, S., & Srinivasan, N. (2009). Types of attention matter for awareness: a study with color afterimages. *Consciousness and Cognition, 18*, 1039–1048.

Baijal, S., & Srinivasan, N. (2011). Consolidation of statistical information of multiple objects in working memory. *Attention, Perception, & Psychophysics, 73*, 1733–1741.

Brefczynski-Lewis, J. A., Lutz, A., Schaefer, H. S., Levinson, D. B., & Davidson, R. J. (2007). Neural correlates of attentional expertise in long-term meditation practitioners. *Proceedings of the National Academy of Sciences, 104*, 11483–11488.

Buttle, H. (2011). Attention and working memory in mindfulness. *The Journal of mind and behaviour, 32*(2), 123–134.

Carrasco, M. (2009). Cross-modal attention enhances perceived contrast. *Proceedings of the National Academy of Sciences, 106*(52), 22039–22040.

Carrasco, M. (2014). Spatial attention: Perceptual modulation. In S. Kastner & A. C. Nobre (Eds.), *The Oxford Handbook of Attention* (pp. 183–230). Oxford: Oxford University Press.

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

Carte, O. L., Prest, D. E., Callistemon, C., Ungerer, Y., Liu, G. B., & Pettigrew, J. D. (2005). Meditation alters perceptual rivalry in Tibetan Buddhist monks. *Current Biology, 15*(11), R412–413.

Chambers, R., Lo, B. C., & Allen, N. B. (2008). The impact of intensive mindfulness training on attentional control, cognitive style and affect. *Cognitive Therapy and Research, 32*, 303–322.

Chan, D., & Woollcott, M. (2007). Effects of levels of meditation experience on attentional focus: Is the efficiency of executive or orientation networks improved. *Journal of Alternative and Complementary Medicine, 13*(6), 651–657.

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

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

Cowan, N. (2005). *Working memory capacity*. New York and Hove: Psychology Press.

Dehaene, S., Changeux, J. P., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: a testable taxonomy. *Trends in Cognitive Science, 10*(5), 204–211.

Demeyere, N., Rzeskiewicz, A., Humphreys, K. A., & Humphreys, G. W. (2008). Automatic statistical processing of visual properties in simultanagnosia. *Neuropsychologia, 46*, 2861–2864.

Friese, M., Messner, C., & Schaffner, Y. (2012). Mindfulness meditation counteracts self-control depletion. *Consciousness and Cognition, 21*, 1016–1022.

Fuller, S., & Carrasco, M. (2006). Exogenous attention and color perception: Performance and appearance of saturation and hue. *Vision Research, 46*, 4032–4047.

Goldin, P. R., & Gross, J. J. (2010). Effects of mindfulness-based stress reduction (MBSR) on emotion regulation in social anxiety disorder. *Emotion, 10*(1), 83–91.

Hodgins, H. S., & Adairs, K. C. (2010). Attentional processes and meditation. *Consciousness and Cognition, 19*, 872–878.

Jha, A. P., Krompinger, J., & Baime, M. J. (2007). Mindfulness training modifies subsystems of attention. *Cognitive, Affective, & Behavioral Neuroscience, 7*, 109–119.

Jha, A., Stanley, E. A., Kiyonaga, A., & Wong, L. (2010). Examining the protective effects of mindfulness training on working memory capacity and affective experience. *Emotion, 10*(1), 54–64.

Kemeny, M. E., Foltz, C., Cavanagh, J. F., Cullen, M., Giese-Davis, J., Jennings, P., & Ekman, P. (2012). Contemplative/emotion training reduces negative emotional behavior. *Emotion, 12*, 338–350.

Kirschfield, 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.

Lamme, V. (2003). Why visual attention and awareness are different. *Trends in Cognitive Sciences, 7*(1), 12–18.

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

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.

Lutz, A., Brefczynski-Lewis, J., Johnstone, T., & Davidson, R. J. (2008). Compassion meditation: Effects of meditative expertise. *Plos One*, e1897.

Lutz, A., Slagter, H. A., Rawlings, N. B., Francis, A. D., & Greischar, L. L. (2009). Mental training enhances attentional stability: Neural and behavioral evidence. *The Journal of Neuroscience, 29*(42), 13418–13427.

Mack, A., & Rock, I. (2001). *Inattentional Blindness*. Cambridge, Massachusetts: MIT Press.

MacLean, K. A., Ferrer, E., Aichele, S. R., Bridwell, D. A., Zanesco, A. P., Jacobs, T. L., & Saron, C. D. (2010). Intensive meditation training improves perceptual discrimination and sustained attention. *Psychological Science, 21*, 1–11.

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

Posner, M. I. (1994). Attention: the mechanisms of consciousness. *Proceedings of the National Academy of Sciences, 91*(16), 7938–7403.

Prinzmetal, W., Nwachuku, I., Bodanski, L., Blumenfeld, L., & Shizimu, N. (1997). The phenomenology of attention. *Consciousness and Cognition, 6*, 372–412.

Prinzmetal, W., Amiri, H., Allen, K., & Edwards, T. (1998). The phenomenology of attention Part 1: Color, location, orientation and spatial frequency. *Journal of Experimental Psychology. Human Performance and Perception, 24*, 1–22.

Raffone, A., & Srinivasan, N. (2010). The exploration of meditation in the neuroscience of attention and consciousness. *Cognitive Processing, 11*, 1–7.

Rensink, R. A. (2002). Change detection. *Annual Review of Psychology, 53*(1), 245–277.

Robins, C. J., Keng, S., Ekblad, A. G., & Brantley, J. G. (2012). Effects of mindfulness-based stress reduction on emotional experience and expression: a randomized controlled trial. *Journal of Clinical Psychology, 68*(1), 117–131.

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

Slagter, H. A., Lutz, A., Greischar, L. L., Francis, A. D., Nieuwenhuis, S., Davis, J. M., et al. (2007). Mental training affects distribution of limited brain resources. *PLOS Biology*, e138.

Srinivasan, N., & Baijal, S. (2007). Concentrative meditation enhances pre-attentive processing: a mismatch negativity study. *Neuroreport, 18*, 1709–1712.

Suzuki, S., & Grabowecky, M. (2003). Attention during adaptation weakens negative afterimages. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 793–807.

Tang, Y. Y., Ma, Y., Wang, J., Fan, Y., Feng, S., Lu, Q., & Posner, M. I. (2007). Short term meditation training improves attention and self regulation. *Proceedings of the National Academy of Sciences, 104*(43), 17152–17156.

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

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

Vugt, M., & Jha, A. (2011). Investigating the impact of mindfulness meditation training on working memory: a mathematical modeling approach. *Cognitive, Affective, & Behavioral Neuroscience, 11*, 344–353.

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

Zeidana, F., Johnson, S. K., Diamond, B. J., David, Z., & Goolkasian, P. (2010). Mindfulness meditation improves cognition: Evidence of brief mental training. *Consciousness and Cognition, 19*, 597–605.