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The Blindside: Impact of monocular occlusion on spatial attention

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Abstract

Monocular occlusion has been posited to reduce activation of the contralateral hemisphere (“Sprague effect”), thus inducing a contralateral spatial bias (toward the viewing eye). Healthy right-handed participants bisected horizontal lines during monocular eye viewing. Although subjects tended to deviate away from the viewing eye, only left eye viewing deviated significantly right of midline. These results suggest that eye patching may induce an attentional compensation similar to hemianopic patients. Alternatively, increased activation of higher cortical regions mediating spatial attention in contralateral hemispace may be an adaptive response to decreased activation of its ipsilateral superior colliculus induced by contralateral eye patching.

Keywords

monocular occlusion; eye patching; constrained monocular viewing; Sprague effect; attention; intention; line bisection; spatial neglect; hemianopia; rehabilitation

Introduction

Spatial neglect is a failure to orient, report or respond to novel or meaningful stimuli presented in a portion of space when this failure cannot be attributed to either elementary sensory or motor defects (Heilman & Valenstein, 1979). Horizontal line bisection is a simple and reliable bedside test for hemispatial neglect. Patients with contralesional neglect can deviate on attempted horizontal line bisections toward the ipsilesional side of the line due to 1) an inattention to the contralateral half of the line, 2) an increased attention to the ipsilesional portion of the line or 3) an ipsilesional action-intentional bias. This disorder is most often noted and is most severe in those patients with right hemispheric lesions (Albert, 1973; Costa, Vaughan, Horwitz, & Ritter, 1969; Gainotti, Messerli, & Tissot, 1972).

Contralesional attentional neglect is most often induced by posterior temporoparietal lesions. Sprague (1966) noted that following the unilateral removal of the right posterior neocortex in cats, these animals had a contralesional defect of visually guided behavior, probably a form of hemispatial neglect. After removal of the colliculus that was contralateral to the lesion, these animals had an improvement of their defective visually guided behavior. Based on these observations, Sprague posited that the initial contralesional defect in visually

guided behavior (hemispatial neglect) was due to depression of function of the colliculus ipsilateral to the cortical lesion. This depression was maintained by influx of inhibition from the contralateral colliculus. Thus, removal of the contralateral tectum, or splitting of the collicular commissure, abolished this inhibition and allowed the return of function in the ipsilesional colliculus along with recovery of visually guided behavior. This phenomenon is now known as the “Sprague effect.”

Animal models have shown that there is a greater concentration of retino-collicular fibers from each eye that decussate to the contralateral superior colliculus (SC) than fibers that travel to the ipsilateral SC. Based on this asymmetry and the Sprague effect, Posner & Rafal (1987) proposed that monocular occlusion (or eye patching) may reduce the activity of this retino-collicular pathway and could be used as a rehabilitation strategy for reversing hemispatial spatial neglect. Thus, based on the Sprague effect, the ipsilesional eye (or right eye in case of right hemispheric strokes with left sided spatial neglect) could be patched; this should elicit a reduction in the level of activation of its contralateral (or left) SC. Since the activation of each SC helps to activate the ipsilateral hemisphere, covering the ipsilesional (or right) eye should reduce the activation of the contralesional (or left) SC and improve the symptoms and signs of left hemispatial neglect by reducing the asymmetry of hemispheric activation.

There have been several reports of patients with left hemispatial neglect who were treated with ipsilesional (right eye) eye patching. Butter & Kirsch (1992) found that some, but not all of their patients with neglect improved with ipsilesional eye patching. Serfaty, Soroker, Glicksohn, Sepkuti, & Myslobodsky (1995) treated 26 patients with unilateral neglect with ipsilesional eye patching and found that about one-half improved. Barrett, Crucian, Beversdorf, & Heilman (2001), however, found the opposite results, such that ipsilesional eye patching increased left sided neglect with an increase rightward deviation on the line bisection task. Barrett et al’s (2001) results appear contrary to those predicted by the Sprague effect. Thus, these mixed results suggest that there are other factors that may influence the allocation of attention during monocular viewing.

When patients with hemianopsia without neglect or anosognosia for their hemianopia attempt to bisect lines, they often deviate in the direction of their hemianopia or contralateral to their lesioned hemisphere (Reuter-Lorenz & Posner, 1990). This has also been demonstrated in healthy subjects (Mitra, Abegg, Viswanathan, & Barton, 2010; Ogun, Viswanathan, & Barton, 2011) when using an apparatus that mimicked a hemianopia such that when these normal subjects attempted to perform line bisections they deviated to the side of their hemianopia. These results suggest that the attentional bias associated with hemianopia may be compensatory rather than induced by brain injury. With unilateral ocular occlusion, there is a lateral reduction of the visual field on the side of the occluded eye. Thus, it is possible that with unilateral ocular occlusion, healthy subjects may use a compensatory strategy and allocate their attention toward the hemispace on the same side as the occluded eye.

Objects that are relatively unattended appear to have less of a magnitude than objects that receive attention. When performing the line bisection task, deviation to one side suggests relative inattention to the opposite side. The Sprague effect predicts that in healthy participants the asymmetrical hemispheric activation induced by monocular viewing would elicit deviation on the line bisection task toward the viewing eye. In contrast, the attentional compensatory hypothesis predicts that healthy individuals would deviate toward the occluded eye. Kunnapas (1958) study of bisection performance during monocular viewing appears to provide some support for the compensatory hypothesis. However, Kunnapas (1958) noted that the macula is positioned on the nasal half of the retina; and with

monocular viewing, foveal vision would be biased. Therefore, he posited that it was this monocular bias that may cause one side of the line to look longer than the other side. Thus, the purpose of his study was to have the subjects wear glasses to correct this asymmetry and learn if wearing these glasses would eliminate healthy subjects' bias when performing monocular line bisections. Kunnapas found that these glasses did reduce, but not eliminate the contralateral bias induced by monocular viewing. Additionally, he could not account for the asymmetrical bias, greater rightward deviation with right eye patching than leftward deviation with left eye patching. Unfortunately, there were several other problems with this study by Kunnapas (1958). This study only included 8 subjects and did not report the subjects' hand preference. In addition, instead of having subjects manually attempt to bisect lines, Kunnapas (1958) had them rotate a knob in either a clockwise or counter-clockwise direction with their right hand and this knob was always located on the right side of an apparatus. The rotation of this knob moved a peg to the left or right on these test lines. In addition, studies of patients with hemispatial neglect (Mennemeier, Pierce, Chatterjee, Anderson, Jewell, Dowler, et al., 2005) as well as studies with normal subjects (Benwell, Harvey, Gardner, & Thut, 2012) have revealed that line bisection performance with short lines is different than with longer lines. In his study, Kunnapas (1958) used only short lines (10 cm) at a relatively close distance (30 cm) from each viewing eye. This procedure may have altered these subjects attentional bias but not necessarily altered an action-intentional bias.

Studies of right-handed healthy subjects performing the line bisection task have reported that subjects often deviate to the left side of the line, a deficit called 'pseudoneglect' (Bowers & Heilman, 1980; Jewell & McCourt, 2000). This bias has been attributed to the finding that the right hemisphere is dominant in mediating spatial attention (Heilman & Van Den Abell, 1980) or that the line bisection task requires global attention, primarily mediated by the right hemisphere (Lee, Kim, Kang, Park, Kim, Adair, et al., 2004). Based on this hemispheric attentional asymmetry hypothesis as well as the collicular (Sprague effect) or the compensatory effect, with right versus left eye monocular viewing, we posited that we should also observe spatial asymmetries. Thus, the purpose of the current study, similar to testing for pseudoneglect (Bowers & Heilman, 1980; Jewell & McCourt, 2000), was to test a larger population than tested by Kunnapas of healthy right-handed participants to learn if monocular viewing induces a bias toward or away from the occluded eyes during the line bisection task, as usually performed clinically, and to learn of their right-left spatial asymmetries.

Methods

Participants

We recruited 34 subjects self-described as right-handed according to their preferred hand for writing. These subjects' ages averaged 48.13 years $\pm$ 17.79, their mean education was 17.38 $\pm$ 4.63 years, and 21/34 of these right-handed subjects were women. To learn if there might be an influence of hand preference, we also tested a small pilot group of 6 participants who were left-handed (2 women, age 52.17 years $\pm$ 14.73, education 13.50 years $\pm$ 1.52) [Table 1].

Procedure

Each subject signed an informed consent form in accordance with the Institutional Review Board at the University of Florida. Subjects sat comfortably in a chair facing a wall that was approximately 3 feet (or approximately 90 cm) from their eye(s). Twelve horizontal solid lines were presented to the subjects at the intersection of the coronal and transverse plane at eye level. These lines measured 26 cm long with a width of 2 mm. Each line was placed on a

separate sheet of white 8.5 × 14 inch (21.6 × 35.6 cm) paper. Subjects donned a pair of glasses with either the left or right lens patched with opaque paper (Figure 1). The viewing eye had a “funnel” placed so that the subjects were able to view the entire line and not the edges of the paper on which the line had been placed. This was done to prevent bisection of the paper rather than the line itself (Figure 2). The funnel’s length was 9 cm. The diameter of the funnel was 7 cm at the most proximal portion and 9 cm at the most distal portion. The funnel was attached to the glasses and angled toward midline at approximately 75 degrees in order to maintain the head position at midline and limit any potential neck rotation. The order of monocular occlusion was randomized with half of the subjects viewing first with their right eye followed by the left eye; the remaining half of the subjects viewing first with their left eye followed by the right eye. The subjects were instructed to mark the middle of the line or bisect the line. Each subject was asked to complete the entire session while using the self-reported preferred writing hand.

Analysis

The deviations of the subjects’ mark from midline were measured to the closest millimeter. Deviations to left of center was assigned a negative “−” value and deviations right of center a positive “+” value. All data were analyzed statistically with the SPSS software, version 20.

Results

We compared the deviations to the left or right during monocular viewing using the left eye (mean +4.09 mm, SD = 6.64) versus monocular viewing using the right eye (mean deviation = −0.45 mm, SD = 5.50) with a paired-samples t-test in right-handed subjects [Table 2]. These subjects significantly differed in their estimations of midline when viewing lines with the left eye versus the right eye $t(33) = -4.020, p < 0.001$. We then compared the deviation from actual midline for monocular viewing with each eye. Viewing with the left eye (right eye patched) produced rightward deviations that were significantly different than zero, $t(33) = 3.59, p = 0.001$. In contrast, the leftward deviation produced by viewing with the right eye (left eye patched) was not significant, $t(33) = -0.48, p = 0.634$.

To further clarify the direction of subjects’ deviation when viewing with one eye or the other, we analyzed the data using a chi square test. We dichotomized performance on the task (deviate left or deviate right). Subjects deviated to the right during left eye viewing significantly more than they deviated to the left during right eye viewing, $\chi^2(1) = 9.53, p = 0.002$. In addition, they were equally likely to deviate to the left or right side when viewing with the right eye, $\chi^2(1) = 0.00, p = 1.00$.

To learn if handedness may have influenced deviation on the line bisection tasks during monocular viewing, we also conducted a similar analysis on a limited sample of left-handed participants according to the preferred writing hand. By conducting a paired-samples t-test in this group of left-handed subjects, we compared deviations to the left or right during monocular viewing using their left eye (mean +0.97 mm, SD = 12.01) versus monocular viewing using their right eye (mean deviation = −7.38 mm, SD = 5.03) [Table 2]. We found no statistically significant differences in either the directions of deviations to the left vs. right during monocular viewing ($t(5) = -1.276, p = 0.258$). We also compared deviation from actual midline for monocular viewing with each eye. When these left-handers were viewing with their right eye, they significantly deviated left of midline (mean −7.38 mm, SD = 5.03, $t(5) = -3.59, p = 0.016$). In contrast, when these left-handers were viewing with their left eye, they showed no significance in deviation from actual midline (mean 0.97 mm, SD = 12.01, $t(5) = 0.20, p = 0.851$). Furthermore, when viewing with the right eye, all six left handed subjects’ bisections were to the left and when viewing with the right eye, five out of six subjects’ bisections were to the left.

Discussion

Prior to Sprague's work, Denny-Brown's study (1962) with primates demonstrated that injury to the superior colliculus leads to hemispatial neglect contralateral to injury of this subcortical structure. Later, Sprague (1966) induced left hemispatial neglect with right posterior cortical lesions and subsequently reduced this left sided neglect by ablating the left SC in cats. According to Posner and Rafal's hypothesis, by decreasing visual input by patching the eye ipsilateral to a hemispheric lesion, there should be a relative deactivation of the contralateral superior colliculus ("de-afferentation)." In patients with hemispatial neglect, there is a relative hyperactivation-arousal of the uninjured hemisphere. It was posited that this "de-afferentation" of the colliculus would reduce the relatively increased arousal-activation of the uninjured contralateral hemisphere and thus, reduce the patient's ipsilesional attentional bias. Based on Posner and Rafal's monocular occlusion-collicular hypoactivation hypothesis, we would expect that when performing a line bisection test normal subjects would deviate toward the viewing eye (or away from the patched eye). For example, the decrease in the visual input to the colliculus in the left hemisphere by patching the right eye should also reduce left hemispheric activation and induce relative inattention to right hemispace resulting in a leftward bias in line bisection. In contrast, when patching the left eye, the visual input to the right SC should be relatively diminished compared to the input to the left SC. This asymmetrical input should induce leftward inattention and a rightward bias in line bisection. Overall, based on Sprague's collicular hypothesis together with Posner and Rafal's visual input corollary, we would expect the deviation to occur in the direction of the viewing eye. In contrast, we found the opposite.

Our participants were more likely to deviate their attempted horizontal lines bisections away from the viewing eye, particularly with left eye viewing (right eye patch). These results are similar to deviations noted in hemianopic patients (Reuter-Lorenz & Posner, 1990) who tend to deviate their attempted bisections of horizontal lines into the same side of hemispace as their visual field deficit. Whereas the patients with hemianopsia who are aware that they are not seeing a full image and thus possibly attempting to compensate for this loss of vision by increasing their attention to that side, our subjects were able to see the entire line. Normally, when one eye is closed the lateral part of the visual field on the same side is less visible. Thus, it is possible that our subjects may have remained aware that one eye was patched and this knowledge may have induced them to intentionally allocate their attention toward the space on the side of the occluded eye.

The brain mechanism by which this "compensatory attentional deviation" takes place is not known. One potential explanation includes a compensatory increase activation of the superior colliculus contralateral to the patched eye in response to the decreased visual input. Alternatively, if reduced visual input reduces activity of the contralateral colliculus, this reduction in excitation of the SC could potentially lead to a "compensatory" increase in top-down activation at the cortical level. For example, since the SC has reciprocal connections with the superior temporal lobe-inferior parietal lobe on the same side, a region important in allocating attention into contralateral hemispace. An asymmetrical compensatory increase in temporoparietal activation may have induced an attentional bias and this attentional bias could explain the deviation in line bisections. Future studies using electrophysiological or functional imaging studies will have to test these hypotheses.

Unfortunately, neither of these compensatory hypotheses can fully account for our result that there was greater deviation on line bisection with right eye patching compared to left eye patching, such that when subjects viewed the line with their left eye, there was greater rightward deviation from true center on attempted line bisections than leftward deviation when they viewed the line with their right eye. This asymmetrical deviation is in a direction

that is opposite from that seen with pseudoneglect (Bowers & Heilman, 1980; Jewell & McCourt, 2000); however, this asymmetrical deviation parallels that seen with left hemispatial neglect from right hemispheric strokes. Patients with hemispatial neglect even with binocular vision will often deviate their line bisection toward ipsilesional space. Many investigators reported that the neglect syndrome is more often associated and more severe with right than left hemisphere lesions (Albert, 1973; Costa, Vaughan, Horwitz, & Ritter, 1969; Gainotti, Messerli, & Tissot, 1972). In humans and monkeys, damage to the temporoparietal region induces unilateral neglect (Heilman & Valenstein, 1979). Studies using functional imaging have provided converging evidence that the posterior temporoparietal region is important for allocating attention (Fink, Marshall, Weiss, & Zilles, 2001).

To account for hemispheric asymmetry of neglect in humans, Heilman & Van Den Abell (1980) suggested and provided electrophysiological evidence that the temporoparietal regions of the left hemisphere activate when normal participants attend to right hemispace; however, the right hemisphere activates when participants attend to either left or right hemispace. Pardo, Fox, & Raichle (1991) and Fink, Marshall, Weiss, & Zilles (2001) used functional imaging to provide converging evidence for this asymmetry. In patients with left hemispatial neglect from right temporoparietal lesions, there is relatively greater activation of the left than right hemisphere. Thus in this study, perhaps when the right eye is occluded, the left hemisphere increases its activation to compensate. This activation deviates attention to right hemispace. In contrast, since the right hemisphere can attend more to ipsilateral (right) hemispace than the left hemisphere can attend to ipsilateral (left) hemispace, when the left eye is occluded and the right hemisphere increases its compensatory activation, since the right hemisphere can attend to both hemispatial fields there is not as much deviation as when the right eyes is occluded and the left hemisphere increases its compensatory activation. Whereas this right versus left hemispheric attentional-spatial asymmetry may help to explain the asymmetries we found with monocular viewing, further physiological studies with monocular occlusion will have to test this hypothesis.

When a vector (magnitude and direction) analysis was performed on these normal subjects' performance, we found that with right eye occlusion (and left eye viewing) these normal subjects primarily deviated rightward on the line bisection task. However, when magnitude of deviation independent of direction was analyzed, there were no hemispheric differences in the magnitude of deviation. This finding helps support the postulate that with left eye occlusion the right hemisphere may have increased its attentional activation. As mention, unlike the left hemisphere, the right hemisphere can attend to both the right and left hemispatial fields. Therefore with right hemisphere activation, there is minimal overall leftward deviation on the line bisection task. Although neglect is typically noted with patients who have posterior temporoparietal lesions, cases of neglect have also been described with frontal lobe lesions (Heilman & Valenstein, 1972). Similar lesions in monkeys were noted to have greater motor deficits in a particular direction or hemispace as in human case studies (Watson, Miller, & Heilman, 1978; Heilman & Valenstein, 1995). This disorder was termed 'motor neglect' or as an "action-intentional disorder." Action-intentional disorders are defined as the failure or reduced ability to respond to a stimulus despite an intact awareness (attention) and/or strength to respond (Heilman, 2004). Action-intentional disorders include limb akinesia or hypokinesia (motor neglect), directional akinesia, and hemispatial akinesia. Therefore, in addition to being caused by an attentional bias, the deviation on the line bisection task may be related to the directional or hemispatial forms of akinesia. In our study, however, we did not attempt to dissociate an attentional from an intentional bias and future studies of the effects of monocular viewing on line bisection tasks may be directed at attempting to learn the relative role of perceptual-attentional versus action-intentional biases.

Although the primary goal of this study was not to learn how hand preference may influence the spatial biases induced by monocular viewing, we performed a pilot study in an attempt to learn if there may be an influence of handedness, as determined by preferred writing hand, on extent and asymmetries of participants' spatial bias with monocular viewing. With binocular viewing, Scarisbrick, Tweedy, & Kuslansky (1987) found that left-handed normal subjects deviated in the opposite direction than did right-handed subjects. Although statistically insignificant, possibly due to limited sample size, we found that with monocular viewing our left-handed subjects generally deviated in the direction that was opposite to the direction in which our right-handed deviated. Whereas the left-handed subjects' deviations were almost uniformly to the left of center, the right-handed subjects deviated to the right with left eye viewing; but they did not significantly deviate to the left with right eye viewing. In contrast, our left-handed subjects deviated significantly more to the left from midline with right eye viewing but deviated less to the right of center with left eye viewing. These results suggest that these left-handed subjects may also have an asymmetrical hemispheric organization of the networks that mediate spatial attention, but their asymmetry is opposite to those participants who are right-handed. However, when performing these attempted line bisections, the right-handed participants used their right hand and the left-handed subjects used their left hand. Thus, it remains unclear if the differences in deviation between the right and left handed subject groups are related to differences in the organization of their attentional systems, their action-intentional systems or related to differences related to hand use. Further studies with a larger group of left-handed subjects will be needed to fully explore these potential differences.

In summary, we attempted to understand the effects of eye patching as it relates to the opposing collicular (based on the Sprague effect) versus compensatory attentional hypotheses. Constrained monocular viewing (by unilateral eye patching) has been shown to be effective for some, but not all patients suffering from hemispatial neglect due to a hemispheric lesion, and especially those with right hemispheric strokes. With left eye monocular viewing, we found that right-handed subjects deviated to the right when performing the line bisection task with their right hand, but did not significantly deviate to the left with right eye viewing. Overall, these results provide support for the compensatory hypothesis and may be similar to the deviation reported with hemianopic patients who deviate into the blind visual hemifield. Alternatively, the asymmetry in deviation observed in our healthy participants may suggest that the compensation occurs in a top-down manner as the higher cortical regions important for spatial allocation of attention increase their activity in response to the decrease in the activation of the superior colliculus induced by contralateral eye patching. Although based on the Sprague effect, Posner and Rafal suggested that ipsilesional eye patching may help patients with contralesional neglect, some patients had the reverse effect and this top-down compensatory mechanism may explain why eye patching either worsened some of these patients neglect.

Several factors may prove to be important when assessing the effects of monocular viewing including handedness and hand used to perform the task. In addition, physiological studies may also be helpful in attempting to understand the mechanisms that account for this asymmetrical bias induced by right versus left eye viewing. Monocular viewing is a simple and non-invasive procedure that when further tested may serve as a valuable tool for the treatment of attentional, intentional and cognitive disabilities. In addition, a monocular loss of vision is a common occurrence and clinicians should be aware that monocular viewing may induce an attentional bias that may compromise peoples' safety when performing activities such as driving.

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Figure 1.
Left monocular viewing goggles. To view a color version of this figure, please see the online issue of the Journal.

Figure 2.
View of line through funnel.

Table 1

Demographics

	Right-Handers (n=34)	Left-Handers (n=6)
Gender	13 males/21 females	4 males/ 2 females
Mean Age	48.13 years +/- 17.79	52.17 years +/- 14.73
Mean Education	17.38 +/- 4.63	13.50 years +/- 1.52

Table 2

Mean Deviation on Horizontal Line Bisections.

	Right-Handers (n=34)	Left-Handers (n=6)
Left Eye Viewing	Mean +4.09 mm, SD = 6.64	Mean +0.97 mm, SD = 12.01
Right Eye Viewing	Mean -0.45 mm, SD = 5.50	Mean -7.38 mm, SD = 5.03

(+) Right of Center Bias; (-) Left of Center Bias