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The effects of constrained left versus right monocular viewing on the autonomic nervous system☆

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ABSTRACT

Asymmetrical activation of right and left hemispheres differentially influences the autonomic nervous system. Additionally, each hemisphere primarily receives retinocollicular projections from the contralateral eye. To learn if asymmetrical hemispheric activation induced by monocular viewing would influence relative pupillary size and respiratory hippus variability (RHV), a measure of parasympathetic activity, healthy participants had their left, right or neither eye patched. Pupillary sizes were then recorded with infrared pupillography. Pupillary dilation was significantly greater with left than right eye viewing. RHV, however, was not different between eye viewing conditions. These differences in pupil dilatation may have been caused by relatively greater activation of the right hemispheric-mediated sympathetic activity induced by left monocular viewing or relatively greater deactivation of the left hemispheric-mediated parasympathetic activity induced by right eye patching. The absence of an asymmetry in RHV, however, suggests that hemispheric asymmetry of sympathetic activation was primarily responsible for this ocular asymmetry of pupil dilation.

1. Introduction

The autonomic nervous system (ANS) plays a critical role in the involuntary control and regulation of the organs and systems involved in maintaining homeostasis and helping the body adapt to its environment. The two major divisions of the ANS are the sympathetic and parasympathetic systems. Beginning with Lowenstein and Loewenfeld (1950a, 1950b), it has been demonstrated that the ANS controls the size of the pupils with activation of the cholinergic parasympathetic nervous system (PNS) constricting the pupil (miosis) and the adrenergic sympathetic nervous system (SNS) dilating the pupil (mydriasis).

Both animal and human studies suggest lateralized hemispheric differentiation of ANS control. For example, researchers (Hoffman & Rasmussen, 1953; Oppenheimer, Gelb, Girvin, & Hachinski, 1992; Oppenheimer, Kedern, & Martin, 1996) demonstrated that right insular cortex stimulation increases sympathetic activity (increase heart rate) and left insular cortex increases parasympathetic activity (decreases heart rate). Right hemispheric infarction in the rat is associated with elevated catecholamines with corresponding increases in heart rate and blood pressure (Hachinski, Turner, & Thompson, 1992) and in the human with tachyarrhythmias (Lane, Adcock, & Burnett, 1992). The volume of right insular cortex infarction correlates well with the degree of catecholamine elevation (Sander & Kingelhofer, 1995). A right insular lesion is also associated with greater probability of death within one year, possibly related to pathological sympathetic activation of the cardiovascular system (Colivicchi, Bassi, Santini, & Caltagirone, 2005).

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Further, using tachistoscopic visual half-field stimulation, Wittling, Block, Genzel, and Schweiger (1998) provided evidence that the left hemisphere appears to be dominant in the parasympathetic control heart rate. Measures of hand perspiration reflect sympathetic arousal levels of the brain. Whereas right hemispheric strokes reduce shock-induced hand sweating, left hemispheric strokes increase hand sweating (Heilman, Schwartz, & Watson, 1978). This finding is consistent with the subsequent demonstration that the right hemisphere tends to have stronger connection with the lateral (sympathetic) than medial (parasympathetic) hypothalamus (Lemaire et al., 2011).

While additional studies also appear to support these asymmetries of cerebral hemispheric control of the ANS (Hilz et al., 2001; Rosen, Gur, Sussman, Gur, & Hurtig, 1982; Zamrini et al., 1990), there are also some studies which suggest right hemispheric dominance in parasympathetic control of heart rate (Ahern et al., 2001; Thayer & Lane, 2009). These investigators reported that with selective hemispheric anesthesia, by means of injecting a barbiturate into the right or left carotid artery, heart rate variability decreased more with right than left carotid injections, suggesting greater right hemisphere dominance for vagal control.

Though beyond the scope of the current paper, there appears to be some inter and intra-hemispheric relationships in the control of the ANS. One possibility is that the hemispheric laterality of autonomic control functions in a manner that is similar to the hemispheric control of attention and emotion in that the right hemisphere may be dominant for both sympathetic and parasympathetic nervous system control and the left hemisphere may be more facile in the allocation of parasympathetic resources than sympathetic.

Whereas each side of the retina primarily projects to the ipsilateral hemisphere's geniculo-calcarine system, there is also evidence the entire retina in each eye has greater projections to the contralateral superior colliculus. According to Perry and Cowey (1984), about 7–10% of retinal ganglia cells project to the superior colliculus. Furthermore, these investigators as well as others (Pollack & Hickey, 1979; Rafal, Smith, Krantz, Cohen, & Brennan, 1990) reported that the majority (~70%) of the retinocollicular pathway project to the contralateral superior colliculus. Additionally, tectoreticular fibers from the colliculus project to the mesencephalic reticular formation that mediates hemispheric arousal, with ipsilateral fibers more abundant than contralateral fibers (Truex & Carpenter, 1964) and stimulation of the each colliculus induces an ipsilateral hemispheric arousal response (Jefferson, 1958). Thus, each superior colliculus via the tectoreticular system appears to be able to activate-arouse the ipsilateral hemisphere. Based on this connectivity, monocular visual input into the brain may be able to asymmetrically activate the cerebral hemispheres; however, little research has been performed in an attempt to understand the influence of monocular visual input on the cerebral hemispheric interactions with the components of the ANS as assessed by measuring alterations of pupillary size, a sensitive and reliable means of assessing autonomic function (Bär, Boettger, Till, Dolicek, & Sauer, 2005).

A demonstration of this shift in hemispheric arousal can be inferred from behavioral studies of neglect. Studies of animals and patients have revealed that damage to elements of one hemisphere's thalamic and mesencephalic reticular activating system can induce the ipsilesional attentional and action-intentional biases that are characteristic of the unilateral neglect syndrome (Watson, Heilman, Miller, & King, 1974; Watson, Valenstein, & Heilman, 1981). Patients with unilateral neglect have revealed that their injured hemisphere is relatively hypoaroused (Watson, Andriola, & Heilman, 1977). Thus, these patients' ipsilesional attentional and action-intentional bias appears to be caused by the relative hyperactivity of the unlesioned contralesional hemisphere (Heilman, 1979), and this relative contralesional hemispheric hyperactivity can be related to an injury-induced hemispheric reduction of activity, as well as perhaps a lesion-induced loss of inter-hemispheric inhibition of the uninjured hemisphere. Support for the loss of inter-hemispheric hypothesis comes from studies which have demonstrated improvement in patients with hemispatial neglect who are treated with slow transcranial magnetic stimulation (TMS) applied to the unlesioned hemisphere, which reduces the unlesioned hemisphere's activation (Koch et al., 2008).

Sprague (1966) induced what appeared to be contralesional neglect in animals with a posterior cortical lesion. Subsequently, by ablating the contralesional colliculus, he demonstrated the reversal of this neglect-like behavior. Since the retinocollicular pathway primarily projects contralaterally, Posner and Rafal (1987) posited that occlusion of the eye on the same side as the hemispheric lesion would reduce the activation of the contralateral colliculus, and thereby reduce the spatial bias associated with neglect. Thus, in those patients with a right posterior cortical lesion who have left hemispatial neglect, patching the ipsilesional (right) eye should theoretically produce relative deactivation of the superior colliculus contralateral to the lesion while reducing the relatively heightened activation of the unlesioned hemisphere (the Sprague effect). However, studies on unilateral neglect have revealed that ipsilesional eye patching showed mixed results by helping some, but not all patients (Barrett, Crucian, Beversdorf, & Heilman, 2001; Butter & Kirsch, 1992; Serfaty, Soroker, Glicksohn, Sepkuti, & Myslobodsky, 1995).

Based on the above studies demonstrating right-left hemispheric asymmetries in autonomic control and the potential impact of monocular viewing on hemispheric activation, the goal of this study was to learn if monocular viewing would affect pupillary size as controlled by the sympathetic and parasympathetic divisions of the autonomic nervous system. Occlusion of the left eye may reduce the activation of the right superior colliculus and induce relative inactivation of the right hemisphere. Since the right hemisphere appears to preferentially mediate activity of the sympathetic nervous system, occlusion of the left eye may lead to a relative reduction of pupillary diameter, miosis. In contrast, right eye occlusion and relative reduced inactivation of the left hemisphere, which may mediate the parasympathetic nervous system, may induce pupillary dilation, mydriasis.

In healthy individuals without hemispheric injury, it remains uncertain if the change in pupillary diameter results from deactivation of the colliculus-hemisphere from contralateral eye patching or activation of the opposing hemisphere from the viewing eye, or a combination of both via inter-hemispheric inhibition (i.e., activation of one hemisphere inhibits the other via callosal communication, affecting both sympathetic and parasympathetic behaviors). With pupillary dilation, this effect could be explained solely from activation of the sympathetic mediated right hemisphere with *left (versus right) eye monocular viewing*. However, pupillary dilation can result from both a direct inactivation induced by reduced left collicular-hemispheric arousal with left (versus right) eye patching according to the Sprague effect, as well as inter-hemispheric inhibition with further deactivation of the left hemisphere mediated parasympathetic system from the opposing activated right collicular-hemisphere. Similarly, but opposite effects may be seen with *right (versus left) eye monocular viewing.*

To learn if these alterations in pupil diameter during monocular viewing can be explained primarily by alterations of either the sympathetic or parasympathetic components of the autonomic nervous system or an interaction of both systems, it may be valuable to have an additional measurement to aid in determining this distinction. Experimental spectral analysis of respiratory frequency rhythmic oscillations of pupil diameter, or hippus variability (RHV), may offer a further means of assessing the degree of parasympathetic