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Frontal Lobe Regulatory Control Mechanisms: Evidence for Diminished Frontal Eye Field Capacity in Hostile Violence-Prone Men

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SUMMARY

Background: The experiment was designed to test the relationship between self-reported hostility and the capacity of frontal eye field regulatory control over visual smooth pursuit eye movements. Previous research has demonstrated a relationship between hostility, violence-prone aggression, and poorly regulated sympathetic control including traditional measures of cardiovascular risk. Capacity Theory (see Harrison, 2015) specifically predicts diminished reflex regulation, dystonia, or spasticity with conditions which exceed the capacity of the frontal systems involved in the response. For visual smooth pursuit eye movements, the frontal eye fields regulate/inhibit ipsilateral visuomotor reflexes under directional control of the superior colliculi and pontine region. Moreover, directional eye movements reflecting intentional direction of visual smooth pursuit derive from premotor regions at each dorsolateral frontal eye field and with directional intent toward the contralateral hemispace (e.g., right frontal eye field directs intentional eye movements toward the left hemispace and inhibits saccadic movements toward the right hemispace).

Material/ Methods: We tested a total number of 48 college-age men evenly divided between two groups, twenty-four low-hostiles and twenty-four high-hostiles. All subjects were acquired from the undergraduate Psychology pool and the project was approved by the Human Subjects Committee and the Institutional Review Board. In order to continue in the experiment, subjects had to have scored within either the low (0-19) or high (29-50) range of self-reported hostility on the Cook-Medley Hostility Scale (CMHS). Due to their relatively heightened cerebral lateralization, only men were used to ensure as much homogeneity as possible within the experiment, so as to draw conclusions based solely on independent variable differences. Hostile men were compared with low hostile men using the electrooculogram (EOG). Smooth pursuit errors were identified in the EOG record as phasic errors in the analogue record.

Results: Hostile men produced significantly more smooth pursuit irregularities in comparison with low hostiles, consistent with the predictions of Capacity Theory, supporting the contention of diminished frontal eye field integrity in hostile, violence-prone men.

Conclusions: These findings sit collectively among a systematic line of research with accumulating evidence implicating capacity limitations for frontal lobe regulatory control in hostile, violence-prone individuals. The broader research implication is suggestive for remediation and preventative techniques for the amelioration of confrontative and/or coercive stress using these brain systems. Moreover, the theory specifically is predictive of heightened sensitivity for the sensory and emotional analyzers residing at the other end of the longitudinal tracts and within posterior brain regions. Emotional sensitivity reflecting coercive threat analysis, feelings of external control by others, and sensitivity to the emotional array presented by others' facial expressions, tone of voice, and by innuendo may ultimately be a social disability. This effect may be propagated further in any social interaction where others may evaluate the hostile, violence-prone individual as insensitive and callous, perhaps.

Keywords: frontal lobe, emotion, hostility, violence, eye movements, nystagmus, saccadic eye movement, health

INTRODUCTION

Evidence associates (a) deactivated right orbitofrontal regions with problems inhibiting anger (directed towards social space) and resultant rage behaviors, juxtaposed to (b) activated right orbitofrontal regions with diminished anger activity and higher levels of contented pacification (e.g., Fulwiler, King, & Zhang, 2012; Agustín-Pavón et al., 2012). Conversely, (a) stimulation of the region that is regulated by the right orbitofrontal cortex (i.e., the right amygdala) is related to increased anger activation (Everhart & Harrison, 1996; Everhart, Demaree, & Harrison, 1995; Demaree & Harrison, 1997b; see also Blackford, Allen, Cowan, & Avery, 2012; see also Fulwiler, King, & Zhang, 2012), whereas (b) right amygdala deactivation is correlated with reductions in anger and increases in contentedness/pacification (Butter, Snyder, & McDonald, 1970). Altogether, these findings support the functional, dynamic interplay between the right orbitofrontal region and regulatory control over negative emotions involving anger and rage behaviors with the implication that diminished capacity (see “Capacity Theory”: Carmona, Holland, & Harrison, 2009; Williamson & Harrison, 2003; Foster, Drago, Ferguson, & Harrison, 2008; Mitchell & Harrison, 2010; see also Klineburger & Harrison, 2015) for regulatory control may underlie anger and violence-prone response tendencies.

Beyond the negative emotion/anger regulatory role that is played by the orbitofrontal region, the capacities of other local frontal areas are important for optimal functioning promoting well regulated responses to stressors, including external threats. Much of the topographical arrangement of the frontal lobe has been discovered along with the functional mechanisms subject to reflexive or regulatory control. Stimulation of the dorsolateral frontal region resulted in Ferrier’s (1876; 1886) discovery of the “frontal eye fields” in the primate brain. Activation of the left frontal eye field prompted intentional eye movements directed towards the right hemispace, whereas activation of the homologous right frontal eye field prompted intentional eye movements directed towards the left hemispace.

Regulatory control or inhibition by the frontal eye field is exerted over the ipsilateral brainstem system and most notably the superior colliculus for reflexive or saccadic visuomotor responses (e.g., Guitton, Buchtel, & Douglas, 1985; see Harrison, 2015; pp. 308-312). Discrete visual presentations to the eye cup have been shown to generate activity in the superior colliculus within as little as 40 ms (Guitton, 1992). Sparks (1986) further demonstrated that electrical stimulation of the superior colliculus establishes an ipsilateral saccade in short order (20 ms) capable of reaching stereotypical velocities of 900 degrees per second (Wurtz & Goldberg, 1989). The reflexive saccade is often triggered by the abrupt appearance of a visual event within the peripheral field providing for relocation of the stimulus onto the foveal area of the retina to promote acuity and perceptual analysis (Carpenter and Reddi, 2000). However, diminished regulatory control over these brainstem systems has been found to closely underlie distractibility in individuals with executive function deficits or minimal frontal lobe capacity.

Thus, by extension here, impaired smooth visual pursuit with component saccades might provide evidence for the incapacity of frontal regions and specifically the frontal eye fields to regulate reflexive responses. In the present experiment, it is expected that evidence will be found in support of diminished frontal eye field capacity in hostile, violence-prone men. This experiment follows a systematic line of research providing evidence of altered perceptual analysis and comprehension of emotional events within visual, auditory, and somatosensory modalities and altered motoric processing of facial motor and hand movements in individuals with high levels of hostile cynicism and violence-prone aggression (for review see Harrison, 2015, Chapter 22).

Deficiencies were found in hostiles' regulatory control over sympathetically mediated cardiovascular functioning (Carmona, Holland, Stratton, & Harrison, 2008; Shenal & Harrison, 2004; Williamson & Harrison, 2003; Demaree, Harrison, & Rhodes, 2000) and glucose mobilization (Walters, Campbell, & Harrison, 2015). Further, this line of research is suggestive of an underlying diminished frontal lobe capacity for down regulation along the longitudinal tracts (intracerebral pathways; see the "Right Hemisphere Theory of Emotion;" reviewed in Demaree, Everhart, Youngstrom, & Harrison, 2005), the corpus callosum (intercerebral pathways; see the "Balance and Valence Theories of Emotion;" reviewed in Demaree, Everhart, Youngstrom, & Harrison, 2005), and the descending upper motor neurons (corticospinal tracts; see Luria's Functional Cerebral System Theory; Luria, 1973; 1980; see also Harrison, 2015, Chapter s 4 & 9).

To continue the progression of research from our laboratory and to extend research on the frontal eye fields from the perspectives of Capacity Theory (see Harrison, 2015), this experiment employed EOG measures to analyze the irregularities in eye movements during visual smooth pursuit tracking of an image viewed using a common laptop visual display in a sample of high- and low-hostile individuals, as identified using the Cook-Medley Hostility Scale (Cook & Medley, 1954).

Hypothesis

High-hostile subjects were predicted to show heightened irregularities in visual smooth pursuit tracking as a function of diminished frontal eye field capacity for regulatory control over the superior colliculi.

MATERIAL AND METHOD

We tested a total number of 48 college-age men evenly divided between two groups, twenty-four low-hostiles and twenty-four high-hostiles. All subjects were acquired from the undergraduate Psychology pool and the project was approved by the Human Subjects Committee and the Institutional Review Board. In order to continue in the experiment, subjects had to have scored within either the low (0-19) or high (29-50) range of self-reported hostility on the Cook-Medley Hostility Scale (CMHS). Due to their relatively heightened cerebral lateralization, only men were used to ensure as much homogeneity as possible within the experiment, so as to draw conclusions based solely on independent variable differences. Subjects received course credits for their participation. Confidentiality was maintained throughout data collection and analysis.

In addition to the CMHS, subjects were required to complete surveys related to medical history and hemibody preference. In order to continue in the experiment, subjects had to have reported an unremarkable medical history as pertaining to head injury, learning disability, neurological dysfunction or cardiovascular abnormalities. Further, subjects had to report a sufficient right hemibody preference based on the Coren, Porac, & Duncan handedness questionnaire (+7 or above).

Self-Report

All potential subjects were initially seen during group screening sessions, at which time they were required to read and sign an informed consent form. A questionnaire assessing medical history was also given. Subjects then completed the Coren, Porac, and Duncan handedness questionnaire (CPD; Coren, Porac, & Duncan, 1979) to determine hemibody preference. This self-report measure assessed right (+1) and left (-1) hemibody preference based on reported preferred use of eye, ear, arm, and leg for various functional activities. Test scores range from -13 to +13, indicating extreme left and right „handedness," respectively. A score of +7 or higher was required for further participation in the experiment.

Subjects were then administered the Cook-Medley Hostility Scale (CMHS; Cook & Medley, 1954). The Cook-Medley is the most often used measure of hostility and shows construct validity as a predictor of interpersonal, medical, and psychological outcomes (Contrada & Jussim, 1992). Subjects had to report hostility levels corresponding to well-documented research findings within this research setting. Specifically, subjects scoring less than 19 were classified as low-hostile, while those scoring 29 and above were classified as high-hostile.

The subjects further completed mood-related questionnaires, including the Beck Depression Inventory (BDI) and the State-Trait Anxiety Inventory (STAI).

Apparatus

The laboratory chamber consisted of a chair facing into a flat-white curtain enclosure and computer laptop display programmed to show a colored dot against a black background screen. The dot was moved back and forth horizontally across the screen to provide a visual target for smooth pursuit.

EOG activity was recorded from electrodes placed over the bilateral frontalis muscle regions, with signal amplification and recording by the standard psychophysiological recording equipment from Biopac instruments.

Procedure

High and low hostile subjects were scheduled for further testing in the experiment within one week of their group screening session. Subjects were required to read and to sign a second informed consent form upon entering the laboratory chamber. Once subjects had read and signed the second informed consent form, they were seated in the experimental chamber and fitted with physiological recording equipment. Once the subject's head was stabilized and fixed on the stereotaxic support, EOG readings were collected for nine concurrent five-second samples.

RESULTS

Descriptive Measures

To compare groups (low- and high-hostiles) on descriptive measures taken during the initial screenings, t-tests were conducted on scores from the CMHS, the BDI, the STAI, and the CPD handedness questionnaire.

High-hostiles scored significantly higher than low-hostiles on each of the descriptive measures except for age and the CPD handedness questionnaire. High-hostiles scored significantly higher on the CMHS (M=32.04, SD=3.96) than did low-hostiles (M=14.46, SD=5.42), $t(46)=12.82$, $p<.05$. On the BDI, high-hostiles (M=8.63, SD=4.64) evidenced significantly higher depression scores than the low-hostiles (M=3.13, SD=2.67), $t(46)=5.03$, $p<.05$. Likewise, anxiety scores from the STAI for both State and Trait measures were significantly higher for high-hostiles as compared to low-hostiles. STAI-State scores were significantly higher for high-hostiles (M=40.54, SD=10.75) than low-hostiles (M=28.04, SD=7.79), $t(45)=4.54$, $p<.05$. Similarly, high-hostiles (M=45.21, SD=10.28) evidenced significantly higher STAI-Trait scores as compared to low-hostiles (M=29.96, SD=8.88), $t(45)=5.43$, $p<.05$.

In contrast to the other descriptive measures, and in accordance with the inclusionary criteria, only the subjects' age and scores on the CPD handedness questionnaire failed to show significant differences between the groups. There was no significant difference in age between the high-hostile group (M=21.46, SD=3.63) and the low-hostile group (M=20.83, SD=3.21), $t(46)=.631$, $p=.531$. For the CPD handedness questionnaire, high-hostiles (M=9.25, SD=3.04) were not found to be significantly different from low-hostiles (M=8.13, SD=2.45), $t(46)=1.411$, $p=.165$.

Electrooculographic Measures

Analysis of the EOG data (MV) revealed significant main effects. The effects listed here remained significant when corrected with the Greenhouse-Geiser correction factor. The main effect of Direction (lateral, medial) was significant, $F(1, 10)=5.77$, $p<.037$ with heightened EOG smooth pursuit errors on return to midline, irrespective of Group (see Figure 1). The main effect of Trial (Trials 1 – 5) was also significant, $F(4, 40)=9.60$, $p<.0001$ with heightened EOG smooth pursuit errors on Trial 1 and with a general tendency for reductions in EOG smooth pursuit errors from Trial 1 (Mean = 2.69) through Trial 3 (Mean = 1.77).

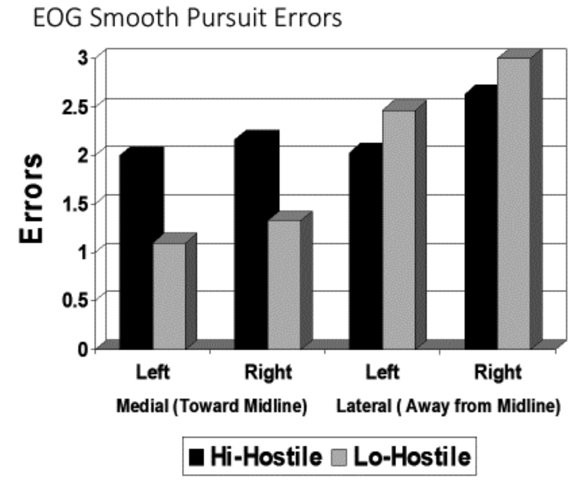

Figure 1.

The Location x Trial interaction effect was also significant, F(4, 40)=7.59, p<.0001 with heightened errors in visual smooth pursuit evident irrespective of group during return toward midline.

In addition to the previously listed main effects, there were also significant interaction effects. The Group x Direction x Location interaction was significant, F(4, 40)=33.40, p<.002 (see Figure 1). Post hoc analyses showed that High Hostiles displayed significantly more smooth pursuit errors specifically on movement toward midline, whereas the post hoc comparisons among the means for smooth pursuit eye movements away from midline were not significant.

There were no additional significant main effects or interaction effects using EOG data.

DISCUSSION

The results partially support the *a priori* hypothesis of differential frontal eye field capacity for regulatory control over brain stem reflexes derived from the superior colliculi and pontine systems. The high-hostile subjects displayed significantly higher EOG visual smooth pursuit errors and this effect was evident on return to midline following either leftward or rightward pursuit movements.

Current findings also constitute the next step in the progression of hostility research in our laboratory, specifically. The development of the limited capacity theory (see “Capacity Theory”: Carmona, Holland, & Harrison, 2009; Williamson & Harrison, 2003; Foster, Drago, Ferguson, & Harrison, 2008; Mitchell & Harrison, 2010; see also Klineburger & Harrison, 2015) stemmed from research testing the effects of high levels of self-reported hostility on multiple brain systems and its manifestation in visual (e.g., Shenal & Harrison, 2004), auditory (e.g., Everhart, Demaree, & Harrison, 2008; Demaree & Harrison; 1997), vestibular

(Carmona et al., 2008; Carmona, Holland, & Harrison, 2009), somatosensory (e.g., Herridge, Harrison, & Demaree, 1997), premotor (Foster & Harrison, 2004), and gross motor systems (e.g., Demaree et al., 2003). In this experiment, high-hostile subjects were proposed to show difficulties in frontal eye field regulation of visual smooth pursuit movements. This expectation was confirmed.

Neuropsychological research on visual spatial processing has largely focused on a complex circuit with its primary anatomical foci including the frontal eye fields for regulatory control, the parietal eye fields for sensory perceptual integration and analysis and the superior colliculi for reflexive eye and hand or arm movements. In one project, for example, functional magnetic resonance imaging was used to image subjects while they visually searched for embedded targets (Gitelman, Parrish, Friston, & Mesulam, 2002). Visuomotor search activated the posterior parietal cortex and the frontal eye fields. Moreover, a greater number of activated voxels was recorded on the right brain, which the authors found to be consistent with "the known pattern of right hemispheric dominance for spatial attention." The superior colliculus showed prominent activation in situations demanding visual search versus eye movement, demonstrating for the first time in humans, activation of this region specifically related to an exploratory attentional contingency. The researchers conclude that the search-dependent variance in the activity of the superior colliculus was significantly influenced by the activity in a network of cortical regions, including the right frontal eye fields and bilateral parietal and occipital cortices.

Lesion, functional incapacity or excessive stressor demand over the right frontal eye field characteristically results in a right gaze bias, ipsilateral to the lesioned frontal lobe (Guitton, Buchtel, & Douglas, 1985; Ladavas, Zeloni, Zaccara, & Gangemi, 1997; Pierrot-Deseilligny, Rivaud, Gaymard, & Agid, 1991) and heightened distractor responsivity at the right side (e.g., Suzuki & Gottlieb, 2013). Also, transcranial direct current stimulation over the right frontal lobe promotes anger rumination (Kelley, Hortensius, & Harmon-Jones, 2013), revealing the combined role of the premotor cortex in the regulatory control over behavior, cognition, and emotion.

In the present experiment, visual smooth pursuit errors were heightened as a function of the grouping variable with high levels of hostile cynicism, a negative view toward others, and a desire to see others harmed. It was expected that poorly regulated anger or negative emotional cynicism would result with diminished frontal capacity also impacting visual smooth pursuit errors. However, the restriction of the predicted effect to data acquisition periods involving a return to midline was not expected. The effect is reminiscent of clinical manipulations using a passive and active range of motion techniques, where rigidity or notching occurs rather than a smooth motor process. These effects are often subsumed under discussions of the extrapyramidal motor system in comparisons with the resistance or synergy evident with upper motor neuron damage (e.g., Ivanhoe & Reistetter, 2004; see also Harrison, 2015, Chapter 9). Potentially relevant to this discussion are the rich interconnections of the premotor cortex and the frontal eye fields to the extrapyramidal motor systems (see Nambu, 2015), including the basal ganglia and brainstem pathways (e.g., the substantia nigra). Relatedly, there exists a well established literature linking damage to these neuroanatomical systems with depression and other mood disorders (e.g., Cummings, 1992; Gilley, Wilson, Fleischman, Harrison, Goetz, & Tanner, 1995).

Collectively, the accumulating evidence implicating capacity limitations for frontal lobe regulatory control in hostile, violence-prone individuals is suggestive for remediation and preventative techniques for the amelioration of confrontative stress using these brain systems. Moreover, the theory specifically is predictive of heightened sensitivity for the sensory and emotional analyzers residing at the other end of the longitudinal tracts within posterior brain regions. Emotional sensitivity reflecting coercive threat analysis, feelings of external control by others, and sensitivity to the emotional array presented by others' facial expressions, tone of voice, and by innuendo may ultimately be a social disability. This effect may be propagated further in any social interaction where others may evaluate the hostile, violence-prone individual as insensitive and callous, perhaps.

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