The Effects of Bilateral Eye Movements on EEG Coherence When Recalling a Pleasant Memory

Brandon Keller
Larry Stevens
Colleen Lui
James Murray
Matthew Yaggie
Northern Arizona University

In an investigation of the interhemispheric coherence (IhC) model for eye movement desensitization and reprocessing (EMDR) bilateral eye movement (BEM) effects, 30 participants were exposed to a stationary dot, a blinking red/green dot, or saccadic BEMs during the contemplation of a positive emotional memory. Electroencephalographies (EEGs) were measured afterward during an eyes-closed processing stage. Analyses revealed no significant IhC enhancement for the BEM condition but significant increases in Delta and Low Beta EEG intrahemispheric BEM coherence in the right and left frontal areas, respectively, and a trend increase in Right Frontal Low Beta BEM coherence. LORETA neuroimaging was employed to visually present significant amplitude changes corresponding to observed coherence effects. The functional significance of these intrahemispheric coherence effects is presented and a cortical coherence extension of the IhC model is suggested.

Keywords: EMDR; bilateral eye movements; EEG; coherence; episodic memory; PTSD

Eye movement desensitization and reprocessing (EMDR) has been recognized as an effective and efficient therapeutic approach for the treatment of effects of traumatic memories (American Psychiatric Association, 2004; Bisson et al., 2007; Cukor, Olden, Lee, & Difede, 2010; Lamprecht et al., 2004). These positive endorsements notwithstanding, empirical comparisons of EMDR with other popular trauma treatments such as prolonged exposure, stress inoculation training, cognitive behavior therapy, and relaxation therapy have been overall equivocal. Some studies have shown EMDR to be more effective, others have shown it to be less effective, and others have shown it to be equivalent (e.g., Davidson & Parker, 2001; Devilly & Spence, 1999; Ironson, Freund, Stauss, & Williams, 2002; Lee, Gavriel, Drummond, Richards, & Greenwald, 2002; Power et al., 2002; Rothbaum, Astin, & Marsteller, 2005; Taylor et al., 2003). Nevertheless, EMDR remains one of the more popular treatments for posttraumatic stress disorder (PTSD; Pagani, Hogberg, Fernandez, & Siracusano, 2013). Perhaps a better understanding of the components of this therapeutic intervention would lead to subtle refinements in the protocol which would produce even better outcomes and improved assistance to trauma victims.

A core component of EMDR that distinguishes it from other trauma treatment strategies is the use of bilateral stimulation during the contemplation of traumatic target events (Shapiro, 1989; Shapiro & Maxfield, 2002; Solomon & Shapiro, 2008). Following Shapiro's adaptive information processing (AIP) model (Shapiro, 2001; Solomon & Shapiro, 2008), this bilateral stimulation is posited to activate more remote neural networks to allow the linking of dissociated information with the target traumatic events, thus facilitating the reprocessing of these events and their eventual desensitization. Originally, Shapiro (1989) used bilateral visual stimulation through the movement of fingers laterally across the visual field at a rate of approximately two saccadic eye movements per second. However, over the years since her

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discovery of the contributions of this component to traumatic memory reprocessing, bilateral auditory and kinesthetic stimulation has been used as well with equivalent anecdotal effects (Harper, 2012).

Although many theories have now been offered to explain the contributions of bilateral stimulation to the processing and depotentiation of traumatic memories (Bergmann, 2008), the mechanisms of action of this component have to date not been conclusively explicated. One of the more neurobiological models for the effects of bilateral stimulation on PTSD, the amygdala-anterior cingulate (ACC)/prefrontal cortical (PFC) coupling model, has to do with a growing body of evidence for (a) an overactivation of amygdaloid processes involved in the affective experiencing of traumatic events, combined with (b) a deactivation or decoupling of ACC and medial PFC functions that would otherwise permit a cognitive processing and depotentiation of such events in PTSD (Francati, Vermetten, & Bremner, 2007). In an even more reductionistic analysis, this model of PTSD symptomatology further hypothesizes that traumatic memories are locked into reverberating synaptic networks of overpotentiated alpha-amino-3-hydroxy-5-methyl-4-isoxazole (AMPA) receptors within the amygdala (Harper, Rasolkhani-Kaophorn, & Drozd, 2009). (c) This state of pathological processing of trauma is essentially reordered by bilateral sensory stimulation during the reexperiencing of the event by providing the low frequency tetanic stimulation necessary to depotentiate these AMPA receptors and subsequently, the retained amygdaloid memories. (d) Such a depotentiation of locked neural networks then allows these affective memories to spread into AC and PFC regions where they may be more naturally and cognitively reprocessed. Components of this model have received some support from animal and human neuroimaging studies (for a thorough review of this literature, see Pagani et al., 2013).

Shapiro (1989) had early suggested that saccadic bilateral visual stimulation in EMDR may recruit neural networks from opposite sides of the brain and allow heretofore dissociated networks to become linked to targeted traumatic events toward their eventual reprocessing. Initially proposed by Servan-Schreiber (2000) and empirically elaborated by Christman and colleagues (Christman, Garvey, Propper, & Phaneuf, 2003; Christman, Propper, & Brown, 2006; Christman, Propper, & Dion, 2004; Propper & Christman, 2008), this interhemispheric connectivity hypothesis for the effects of bilateral stimulation on episodic memory retrieval has received considerable investigation. If this hypothesis is correct, then two outcomes should occur: (a) Memory retrieval should improve during or immediately following bilateral stimulation and (b) measures of interhemispheric connection should show an increase following bilateral stimulation. These two predictions have received some empirical support from research to date.

For example, Christman et al. (2003) found enhanced word recognition and autobiographical memory retrieval following a 30-second engagement in horizontal saccadic eye movements. These outcomes have been supported by earlier studies of handedness (as a representation of interhemispheric interaction) and the effects of a sequential presentation of bilateral visual input on episodic memory (Christman & Propper, 2001). Additional research showing enhanced behavioral measures of interhemispheric interaction and creativity following bilateral eye movements (BEMs; Shobe, Ross, & Fleck, 2009), improved memory and accuracy for a visual event narrative after BEMs (Parker, Buckley, & Dagnall, 2009), enhanced memory retrieval (Christman et al., 2003; Lyle, Logan, & Roediger, 2008), impaired episodic memory following commissurotomy (Cronin-Golomb, Gabrieli, & Keane, 1996), and other studies (see Propper & Christman, 2008, for a comprehensive review of this literature) strongly support the enhancement of episodic-like memory retrieval following the presentation of bilateral saccadic eye movements.

The research literature has been more sparse and equivocal, however, for the effects of bilateral stimulation on direct measures of interhemispheric connectivity. One such measure of functional connectivity is electroencephalography (EEG) interhemispheric coherence (IhC). EEG coherence is a quantitative measure of EEG waveform or phase consistency between two disparate sites on the scalp (Nunez et al., 1997). Mathematically, coherence values represent the EEG waveform cross-spectral density function normalized by the power spectra and are represented by a squared correlation function having a magnitude between 0 and $+/-1$. Thus, coherence may be interpreted as the functional communication or connectivity between two recording sites, with higher coherence representing higher cooperation and synchronization between measured brain regions in a specified frequency (Knott, LaBelle, Jones, & Mahoney, 2002; Nunez et al., 1997; Weiss & Mueller, 2003). Bergmann (2008) asserts that synchronized neuronal oscillations as indexed broadly by cortical EEG coherence are the basis of human perception and functioning. If the selected recording sites are homologous sites on opposite sides of the cortex

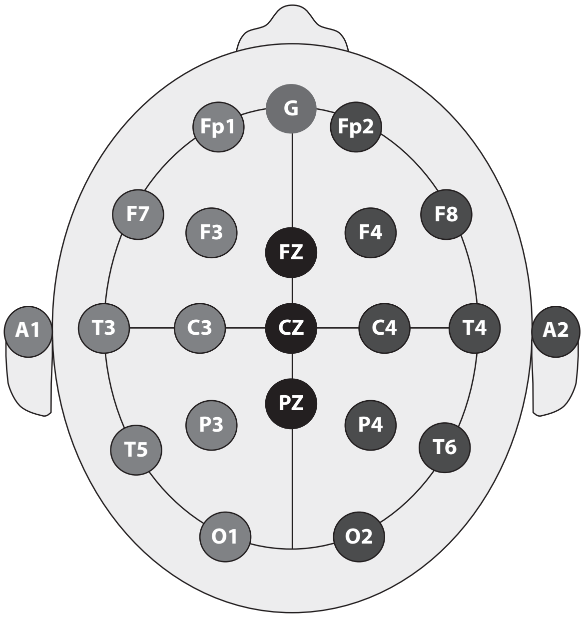

FIGURE 1. Schematic of international 10–20 system for EEG electrode placement.

(e.g., electrodes F7 and F8; see Figure 1), then EEG coherence is an ideal measure of interhemispheric neuroelectrical connectivity.

Only two studies have been published to date, however, examining the effects of saccadic horizontal eye movements on IhC. Propper, Pierce, Geisler, Christman, and Bellorado (2007) examined IhC from two frontal bilateral electrode sites (Fp1 and Fp2) before and after a 30-second presentation of either a two-saccadic-eye-movements-per-second moving dot or a stationary red/green twice per second blinking dot in a between-groups design. Their results obtained, in contradiction to their initial predictions, *decreased* coherence in the Gamma EEG frequency band (35–54 Hz), with no effects on Theta (4–8 Hz) or Alpha (8–13 Hz) bands, following the moving stimulus relative to the control blinking dot condition. The authors' posthoc interpretation of these surprising outcomes as indicating significant eye movement–induced *changes* in interhemispheric coordination notwithstanding, there were several critical problems with this study which render its relevance to EMDR practice and to task-related interhemispheric connectivity questionable. First, they selected two recording sites over the frontalis muscles, which are very sensitive to residual eye movement–induced muscle artifacts and recorded from these sites within 3 seconds of stimulus offset, potentially contaminating the EEG recordings with muscle artifacts which can be reflected in the Gamma and Delta bands. (They failed to report Delta, and approximately 20% of their initial participant pool had to be rejected from analysis because of noisy, unusable EEGs.) Second, their EEG coherence values, particularly for Alpha and Theta, were very high, approaching 1.00, even prior to stimulus conditions, suggesting a ceiling effect and lessening the likelihood of obtaining significant and meaningful coherence changes. And third, there was no episodic memory recall task required during the eye movement condition, as occurs in EMDR, providing no directed task-specific activity as a basis for neural network coordination.

The second well-designed and tightly controlled study by Samara, Elzinga, Slagter, and Nieuwenhuis (2011) computed full-scalp EEG phase and amplitude coherence prior to participation in a neutral and emotional word–recall task and in the same BEM and control conditions as Propper et al. (2007) but using a more powerful within-subjects design. In addition, these researchers recorded electrooculograms to verify BEMs and painstakingly visually and statistically artifacted their EEG data to remove muscle and noise artifacts. Disappointingly for the IhC model, and following multiple and reduced stringency analyses, Samara et al. found no consistent or predicted phase or amplitude EEG coherence changes from pre- to post-BEMs or across eye movement conditions. They did observe significantly decreased Alpha amplitude coherence bilaterally for the F7–F8 electrodes in the BEM condition but an *increase* in Alpha amplitude coherence for these electrodes in the control condition. Although they found a significant improvement in recall of emotional words only for the BEM condition, there was no significant correlation between coherence and word recall. At first glance, this study considerably challenges the IhC model for the reported effectiveness of EMDR and more specifically for the well-documented improvements in memory retrieval following BEMs.

However, an important shortcoming of this study, acknowledged by the authors, was the absence of a true episodic memory retrieval task (Tulving, 1985) during the eye movement component of the study. Indeed, not only was the cognitive task used in this study a semantic memory recall task but also a 30-minute "neutral documentary" film followed word presentation and occurred before EEGs were recorded and BEMs were prompted. As noted earlier, the holding of the traumatic event in working memory during the BEMs is an important and unique characteristic of therapeutic EMDR. Very few of the published studies of the effects of BEMs on memory retrieval, in fact, used personally meaningful episodic memory tasks and instructed their participants to contemplate those memories in working memory during bilateral stimulation. The exceptions to this important omission were the second experiment conducted by Christman et al. (2003), which found selective enhancement of true episodic memories following BEMs, and the study of contemplation of childhood memories during BEMs by Christman et al. (2006), which found earlier offset of childhood amnesia. Neither of these studies, however, measured EEG coherence.

Until IhC is measured during or immediately following bilateral stimulation while the participant is contemplating personally meaningful episodic memories, the IhC model for the effects of EMDR on the reprocessing of traumatic memories remains untested. In addition, because the activation of remote neural networks proposed by the AIP model can also occur *within* hemispheres, this investigation examined intrahemispheric coherence. This study begins this line of investigation by the recording and analysis of multichannel interhemispheric and intrahemispheric EEG coherence following BEMs and two control conditions, during the contemplation of personally meaningful positive episodic memories. Positive memories were used in this investigation to avoid potentially retraumatizing our young nonclinical sample, to facilitate institutional review board (IRB) approval, and because of the practice of installing positive memories with bilateral saccades in the development of The Safe Place and Resources during clinical EMDR.

Methods

Participants

Participants were 30 right-handed female undergraduate students from a southwestern university recruited as nonclinical volunteers from the psychology department subject pool. Mean age was 19.13 years ($SD = 2.56$) and there was no significant age difference among the three treatment conditions ($F = .854$, $p = .437$). No participant reported present pregnancy or a history of head injury, unconsciousness, epilepsy, chronic pain, psychiatric or PTSD history, or neuropathy. Nine reported taking birth control medication, 2 were taking asthma medication, and 2 were taking an undisclosed other medication; medication use was evenly distributed across the three treatment conditions ($\chi^2 = .5$, $p > .05$). Street drug use was minimal and occasional, with 1 participant reporting marijuana use, 5 reporting alcohol use, 3 reporting pain killer use, 1 reporting upper use, and 3 reporting other drug use; no participant reported using amphetamines, cocaine, benzodiazepines, downers, or ecstasy. Each participant was randomly assigned to one of the three treatment conditions in this between-groups design. All participants received course credit for their participation in this study, and the study was approved by the Northern Arizona University (NAU) IRB.

Instruments

Prior to the EEG portion of the study, each participant completed a demographic information form containing relevant identifying information, age, gender, pregnancy status, hand preference, incidence of neurological conditions which could influence the EEG recording, and prescribed and recreational medication/drug use. In addition, each participant completed the Edinburgh Handedness Inventory (Oldfield, 1971) to verify right-hand preference. A 1–10 (10 = *very strong*) visual analogue scale (VAS) was used to record memory strength and vividness at baseline and after each stimulus set for each condition.

The control visual stimulation conditions consisted of (a) a stationary black dot 3 in. in diameter, the eye fixation (EF) condition, selected to control for effects of alternating visual stimulation in general, and (b) an alternating red/green dot also 3 in. in diameter which changed color every 500 milliseconds, the Blinking Dot (Blink) condition, patterned after the control condition reported in Experiment 2 by Christman et al. (2004). Both control conditions were presented on a laptop with a 15-in. monitor positioned directly in front of the participant at eye level and 30 in. away. To be as consistent as possible both with EMDR protocol and across participants, bilateral visual stimulation was provided by an EyeScan 2000S Light Bar (1994, NeuroTek Corporation, Wheat Ridge, Colorado) designed for clinical EMDR use. Bilateral saccades were set at one left–right or right–left saccade every 500 milliseconds, producing two eye movements per second, for 24 seconds. The light bar was positioned at eye level 35 cm (approximately 14 in.) from the participant.

EEG data were recorded using a Lexicor NRS-24C (1989, Lexicor Medical Technology, Inc., Boulder, Colorado) EEG recording system having a 512 Hz digital sampling rate, a 128 Hz low-pass antialiasing filter, and a fixed 0.5 Hz high-pass filter. The Lexicor NRS-24C used a Neurosearch-24 Acquisition Unit containing 24 channels of differential front–end preamplifiers followed by isolation amplifiers/transformers, analog-to-digital (A/D) converters, and optical isolators for participant protection. Resident Neurosearch-24 V4.1E EEG recording and analysis software was used to record raw EEG data into event files for each treatment condition. The 19-channel EEG data were collected with an A/D conversion sampling rate set at 256 Hz, high-pass and low-pass filters set at .5 Hz and 60 Hz, respectively, and notch filter set at 60 Hz. The international 10–20 EEG electrode placement system was followed for the placement of the 19 monopolar Ag/AgCl electrodes onto the scalp using the Electro-Cap System (1983, Electro-Cap International, Inc., Eaton, Ohio) with mathematically linked–ear reference electrodes. Electrode impedances were adjusted to less than 5 kohms and to within 1 kohm of each other. Data were analyzed and artifacted using Nova Tech EEG Eureka! and MHyT data processing and analysis software (2000, Nova Tech EEG, Inc., Mesa, Arizona). Raw EEG data were twice visually artifacted by two trained and independent artifactors blind to treatment conditions using precisely written and exacting criteria to remove EMG and other noise artifact.[1] EEG analysis software was employed to conduct fast Fourier transformations (FFT) and power spectral and coherence analyses of raw data and LORETA neuroimaging software (LORETA: Low Resolution Electromagnetic Tomographic Analysis, Zurich, Switzerland) was used to conduct topographic imaging and cortical localization of treatment effects. FFT analysis employed Hamming time domain tapering, Blackman frequency domain smoothing, an overlapping FFT windows advancement factor of 8, and a moving average smoothing filter of 3. In these analyses, 10 EEG frequency bins were examined: Delta (1–3.99 Hz), Theta (4–7.99 Hz), Low Theta (4–5.99 Hz), High Theta (6–7.99 Hz), Alpha (8–11.99 Hz), Low Alpha (8–9.99 Hz), High Alpha (10–11.99 Hz), Beta (12–30 Hz), Low Beta (12–19.99 Hz), and High Beta (20–30 Hz).

All data were recorded in a sound attenuated research suite, with participants seated comfortably and erect in a recliner. A mirror was positioned on the wall opposite from and oblique to the participant such that the researcher could observe the presence of eye movements and establish whether the eyes were opened or closed without the participant seeing their reflection in the mirror. All instructions were standardized and prerecorded to separate CDs for each condition.

Procedure

Participants were randomly assigned to scheduled EEG study times, and on arrival, they completed the requisite informed consent form and relevant questionnaires while the Electro-Cap was fitted and calibrated to the EEG recording system and clean EEG traces were established. After the participants were made comfortable and the visual stimulus was configured, the CD for the designated stimulus was started. The experimenter remained present throughout the session to operate the EEG equipment and to monitor eye movements.

Before presentation of the visual stimulus condition, a 5-minute EEG baseline was recorded with eyes closed during which the participants were asked to blank their mind and then to “allow whatever thought, feeling, or experience comes up” to be considered. After this baseline, the participants were invited to consider an episodic memory from their childhood which holds very positive emotions for them, to signal when this memory had been selected, to briefly report the memory, and to rate its strength and vividness on the VAS scale. Then they were instructed to focus on the visual stimulus (either the stationary black dot, the blinking red/green dot, or the bilateral moving dot on the light bar) while contemplating the positive episodic memory for 24 seconds. During the BEM condition, the participants were instructed to move only their eyes from side to side and not their head, and their cooperation with this instruction was verified by the researcher’s observation of the reflected image in the mirror. Following the presentation of the visual stimulus condition, the participants were instructed to close their eyes; to blank their mind; and then to “contemplate whatever thoughts, feelings, or experiences come up” while a 1-minute EEG was recorded. At the end of this 1-minute recording period, the participants were asked to again report the “strength and vividness” of the memory on the 1–10 VAS scale. This sequence of visual stimulation, followed by blanking the mind, followed by contemplation during which a 1-minute EEG and memory strength and vividness were recorded was repeated five times for 5 minutes of EEG during contemplation of the positive episodic memory following presentation of the visual stimulus. After this sequence of recordings was completed, the participants were debriefed, the Electro-Cap was removed, extra credit was awarded, and the participants were allowed to leave.

Design and Analysis

Following the recording of the 5-minute eyes-closed baseline and the 5 minutes of eyes-closed poststimulus EEG, data were artifacted and subjected to FFT analysis. The mean number of artifact-free 1-second epochs/participant used in the coherence analyses was 228.10 (*SD* = 39.83) or an average of 3.80 minutes (*SD* = 0.66) of artifact-free EEG data for each participant for baseline and for poststimulus analyses separately. As a part of the Eureka! output, phase coherence values between all possible pairs of electrodes for each designated EEG frequency are generated as cross-spectral density functions normalized by individualized power spectra, presented as a squared correlation matrix for each frequency. Phase coherence analyses used the following formula (Nunez & Srinivasan, 2006):

$$\text{Coherence}\,(f) = \frac{\left|\text{Cross} - \text{Spectrum}\,(f)\,XY\right|^2}{(\text{Autospectrum}(f)(X))(\text{Autospectrum}(f)(Y))}.$$

Reference placements for coherence computations were maintained as mathematically linked ears, given the suitability of this placement for relatively small electrode arrays (Nunez & Srinivasan, 2006; Thatcher, Biver, & North, 2004).

From this squared correlation matrix, coherence values for electrode pairs of interest were obtained. For our interests in IhC and to simplify the analysis by broad functional regions, we selected homologous electrode pairs in each hemisphere clustered by frontal (Fp1–Fp2, F3–F4, F7–F8), central (C3–C4), parietal (P3–P4), temporal (T3–T4, T5–T6), and occipital (O1–O2) regions; for frontal and temporal regions, coherence values for each electrode pair were averaged within each cluster to give five regional EEG coherence values for each frequency band (see Figure 1). As an additional exploratory analysis, intrahemispheric coherence was examined to investigate whether any of the conditions might increase coordination of neural networks within hemispheres. For each EEG frequency, left frontal (Fz–Fp1, Fz–F3, Fz–F7) and right frontal (Fz–Fp2, Fz–F4, Fz–F8), left central (Cz–C3, Cz–T3) and right central (Cz–C4, Cz–T4), left parietal (Pz–P3, Pz–T5) and right parietal (Pz–P4, Pz–T6), and left occipital (Pz–O1) and right occipital (Pz–O2) regional intrahemispheric coherence clusters were compared. To reduce the number of separate analyses, coherence values within each regional cluster (frontal, central, parietal) were averaged. These interhemispheric and intrahemispheric data clusters were then examined for normality and homogeneity of variance assumptions and were found to meet assumptions for further parametric analysis. Coherence values for each brain region were then examined among conditions for each of the 10 EEG frequency bands orthogonally for frequency and hemisphere by between-groups analysis of covariance (ANCOVA), with respective baseline values as the covariate. Because this was a small-*n* investigational study with planned comparisons and there were no more comparisons than degrees of freedom for effect, no adjustment for inflation of family-wise error rate was required (Tabachnick & Fidell, 2013). Alpha for significance was set at .05.

In addition, to better localize functional brain regions potentially affected by visual stimulation during contemplation of positive episodic memories, Low Resolution Electromagnetic Tomographic Analysis (LORETA) was used. LORETA is a three-dimensional brain imaging software companion to contemporary EEG analyses allowing localization of deep cortical source potentials for recorded surface EEG signals (Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002). LORETA algorithms compute a three-dimensional inverse solution space of cortical gray matter and hippocampi mapped onto a probabilistic Talairach atlas partitioned into 2394 7mm^3 volumetric units, or voxels. Brodmann anatomical labels may be reported for relevant regions of interest using the Montreal Neurological Institute realistic head model. For this study, LORETA analyses were conducted on the natural log transformation of FFT relative power spectral output for each identified frequency and relevant statistically significant cortical voxels are reported.

Results

Effects on Memory Strength and Vividness

Figure 2 presents graphically the changes in memory strength and vividness ratings for each condition from baseline across each of the five visual stimulation trials. Repeated measures analysis of variance (ANOVA) results show a significant main effect for time ($F[5, 23] = 7.80$, $p < .0001$, $\eta^2 = .63$) but not for condition ($F[2, 27] = .59$, $p = .56$, $\eta^2 = .04$) and no significant interaction ($F[10, 46] = .54$, $p = .86$, $\eta^2 = .10$), indicating an increase in memory strength and vividness for the positive memory across time for all three conditions and no differences among conditions at any measurement point, including at baseline. An inspection of these graphs, however, reveals a different pattern of responses for the BEM condition compared with the two control conditions, with the latter tending to plateau at the third trial but memory continuing to increase rather consistently across all trials but one for the BEM condition. *T*-test comparisons between successive trials support this visual pattern difference with a significant increase for the EF condition only from Trial 2 to 3 ($t[9] = 4.00$, $p = .002$) and for the Blink condition only from Trial 1 to 2 ($t[9] = 1.81$, $p = .05$) but for the BEM condition from Trial 1 to 2 ($t[9] = 1.96$, $p = .04$), Trial 2 to 3 ($t[9] = 1.81$, $p = .05$), and Trial 4 to 5 ($t[9] = 1.81$, $p = .05$).

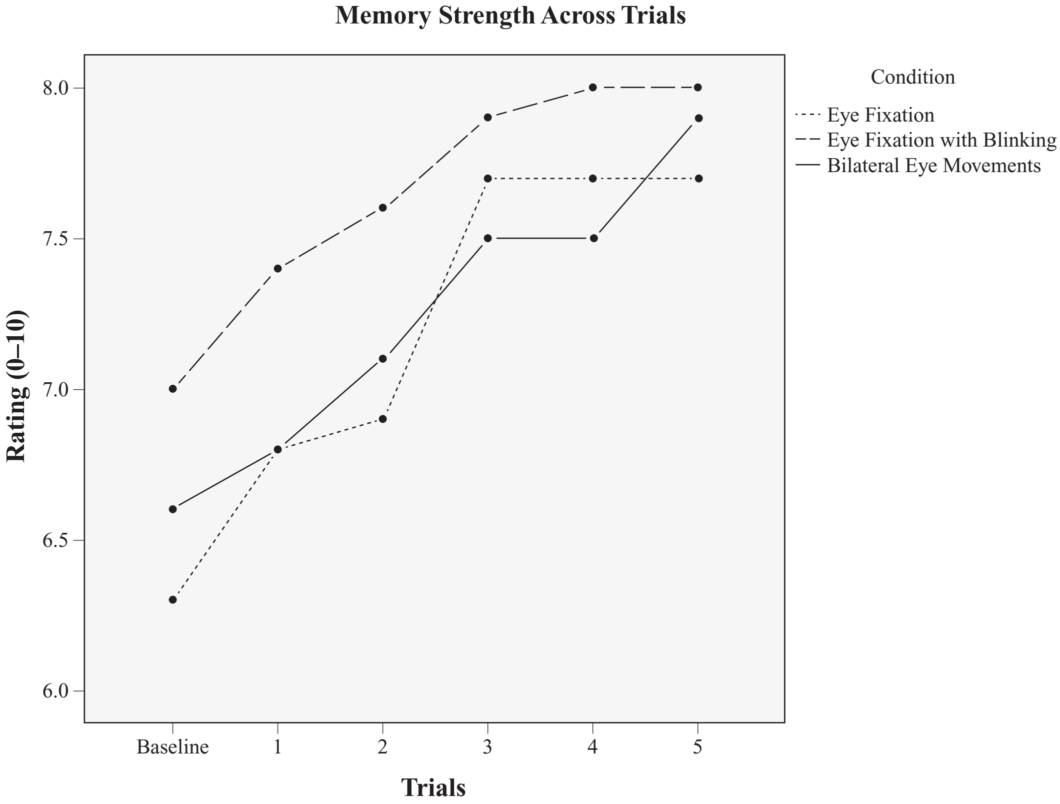

FIGURE 2. Memory strength and vividness ratings across EEG measurement trials for each condition.

Interhemispheric Coherence Effects

The ANCOVA interhemispheric analyses obtained no significant condition main effects (all $p > .05$). Simple effects comparisons between each condition for each frequency revealed only one statistically significant condition effect, with the Blink condition showing higher coherence than EF for Central Theta ($p = .028$). There were statistical trends for BEM to show higher coherence than EF for Frontal Delta ($p = .081$) and than Blink for Occipital Low Alpha ($p = .051$) and for Blink to show higher coherence than BEM for Central Alpha ($p = .054$) and for Central ($p = .066$) and Parietal Beta ($p = .096$). No other conditions for any region or frequency reached statistical significance or trend status.

Intrahemispheric Coherence Effects

ANCOVA intrahemispheric analyses found several significant and trend condition main effects. For Right Frontal Delta, a statistical trend was obtained for condition (ANCOVA $F[2, 26] = 3.161$, $p = .059$, $\eta^2 = .196$). Planned simple effects comparisons found the BEM condition to have significantly higher coherence than the Blink condition ($p = .028$) and a trend toward higher coherence relative to the EF condition ($p = .055$). *T*-tests comparisons of changes before and after exposure to each of the conditions revealed a significant increase in BEM coherence for Right Frontal Delta ($t[9] = -2.50$, $p = .017$) but no significant changes for the EF ($t[9] = -.25$, $p = .43$) or Blink ($t[9] = -.33$, $p = .38$) conditions. Importantly, there were no significant or trend effects of any of the three conditions for Left Frontal Delta.

For Right Frontal Beta, there was a statistical trend for condition (ANCOVA $F[2, 26] = 3.092$, $p = .062$, $\eta^2 = .192$). Planned comparisons found the BEM condition to be significantly higher in coherence than the Blink condition ($p = .022$). To tease out the contributions of the Low Beta and High Beta frequency bins to this Beta effect, analyses of Right Frontal Low Beta (ANCOVA $F[2, 26] = 4.647$, $p = .019$, $\eta^2 = .263$) revealed the BEM ($p = .008$) and EF ($p = .034$) conditions to be significantly higher in coherence than the Blink condition and the Right Frontal High Beta (ANCOVA $F[2, 26] = 2.340$, $p = .116$, $\eta^2 = .153$) BEM condition to be significantly higher than Blink ($p = .044$). For Left Frontal Low Beta (ANCOVA $F[2, 26] = 2.315$, $p = .119$, $\eta^2 = .151$), the BEM condition was found to be significantly higher than Blink ($p = .042$). Figures 3–5 show the changes in Right Frontal Low Beta, Right Frontal High Beta, and Left

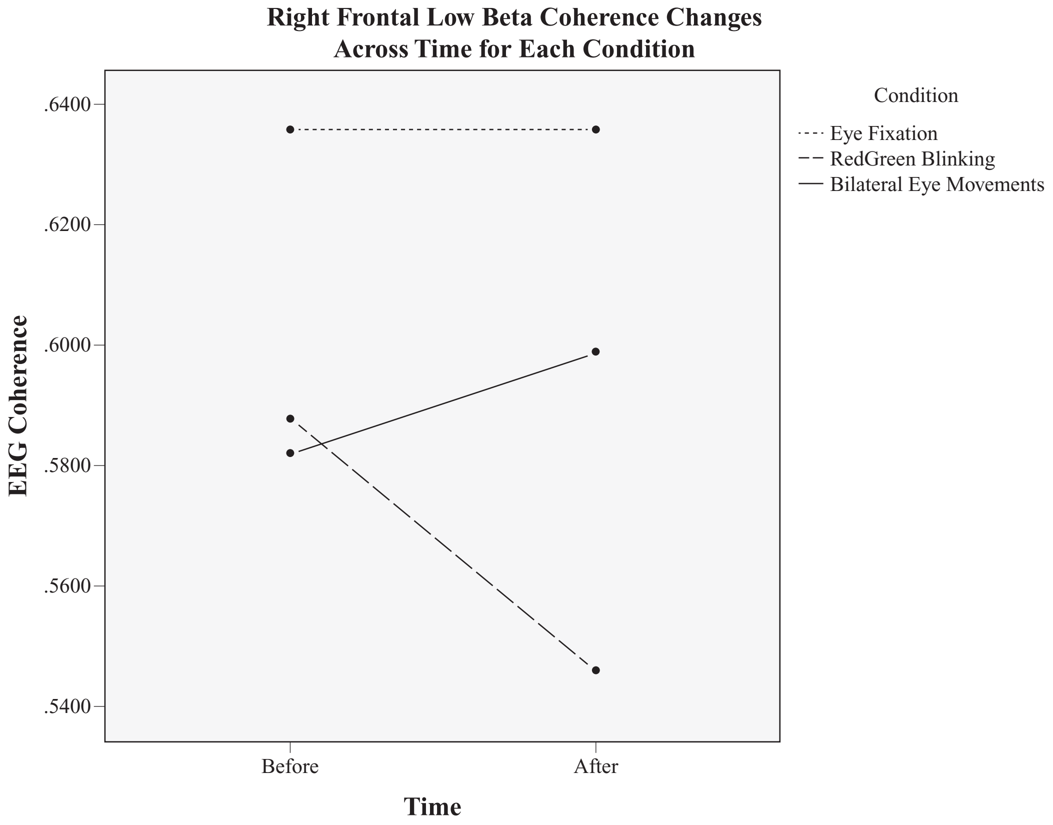

FIGURE 3. Right Frontal Low Beta EEG coherence changes across time for each condition.

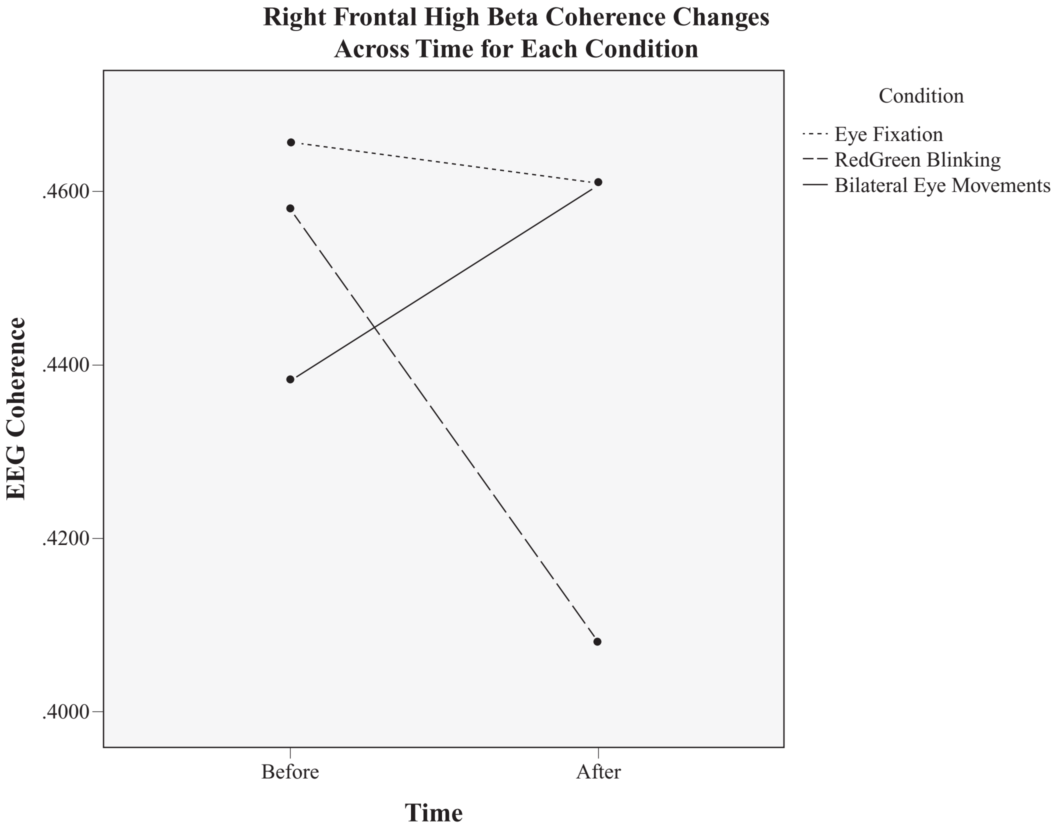

FIGURE 4. Right Frontal High Beta EEG coherence changes across time for each condition.

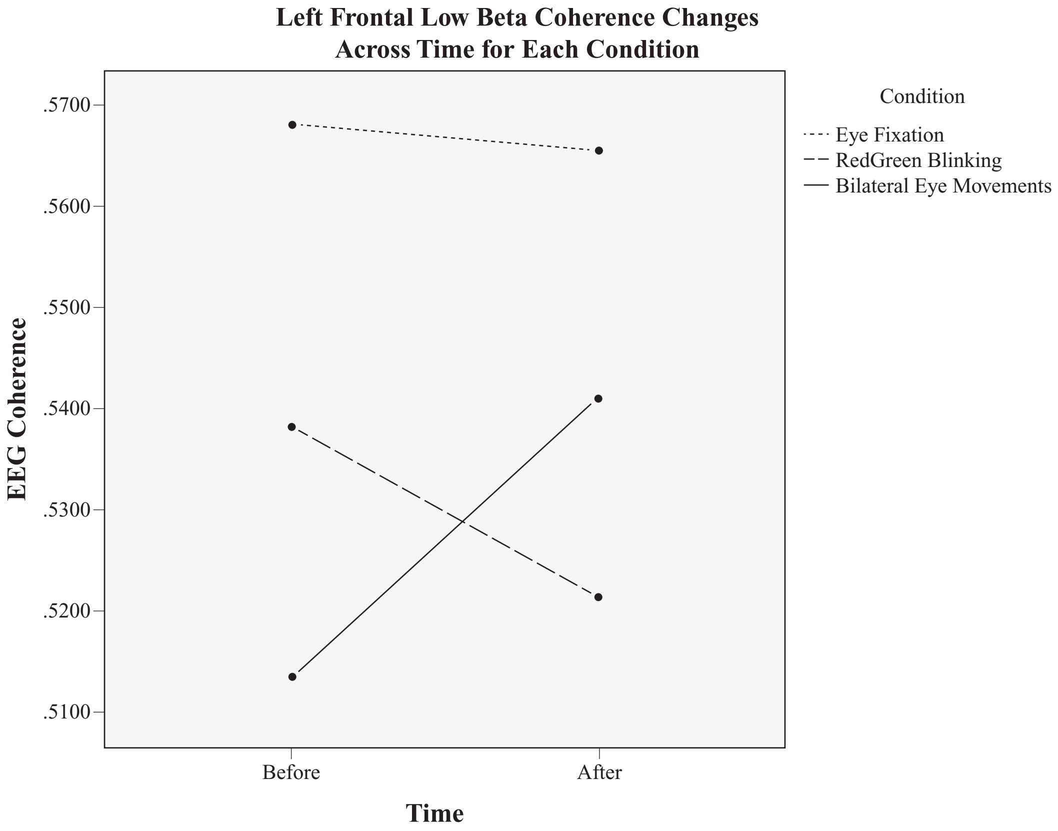

FIGURE 5. Left Frontal Low Beta EEG coherence changes across time for each condition.

Frontal Low Beta coherence descriptively from before to after exposure for each of the conditions, revealing increases in BEM coherence, decreases in Blink coherence, and slight decreases or no remarkable changes in EF coherence. *T*-tests comparisons of these changes before and after exposure to each of the conditions are presented in Table 1, showing a significant increase in BEM coherence for Left Frontal Low Beta and a statistical trend toward an increase for Right Frontal Low Beta, with a corresponding significant decrease in Blink coherence for Right Frontal Low Beta and a trend toward a decrease for Right Frontal High Beta, and with no significant or trend changes in coherence for the EF condition. No other cortical regions or frequencies revealed significant effects of BEMs relative to the two control conditions on EEG intrahemispheric coherence.[2]

Localization of Bilateral Eye Movement Effects

LORETA neuroimaging cortical source localization algorithms were applied to the EEG relative power spectral data derived from the five combined 1-minute recording epochs following engagement in each of the three conditions. This imaging process produces virtual magnetic resonance imaging (MRI) images of the cortical regions significantly activated during each of the conditions. For our interest in this study, only the LORETA images for the BEM condition are displayed. Figure 6 shows superior, posterior, left lateral, inferior, anterior, and right lateral images of Low Beta activation following BEMs. The shaded areas reflect activation in Brodmann Areas 10 and 11 in the right superior and middle frontal gyri.

Discussion

The outcomes of this study provide little support for an IhC model for the therapeutic effects of EMDR. There were only trends for BEMs to show enhanced coherence between hemispheres relative to the EF and alternating red/green light conditions, and these trends were toward slow wave, Delta and Low Alpha, coherence increases, electrocortical frequencies not generally associated with information processing. Klimesch et al. (Klimesch, 1999; Klimesch, Sauseng, & Hanslmayr, 2007) have suggested that alpha synchronization may reflect an inhibitory process in preparation for memory retrieval and subsequent cognitive processing. It is tempting to speculate that this Low

TABLE 1. Paired Samples (Baseline to Posttreatment) *t*-Test Results for Frontal Beta Intrahemispheric Coherence Effects

Condition/Hemisphere/Frequency	Difference Mean (*SE*)	*t* value	*p* value
Eye fixation			
Left Frontal Beta	.016 (.017)	0.922	.191
Left Frontal Low Beta	.003 (.013)	0.194	.426
Left Frontal High Beta	.018 (.015)	1.196	.131
Right Frontal Beta	.006 (.021)	0.274	.396
Right Frontal Low Beta	−.000 (.014)	−0.017	.494
Right Frontal High Beta	.005 (.018)	0.252	.404
Red/green blink			
Left Frontal Beta	.018 (.016)	1.137	.143
Left Frontal Low Beta	.017 (.014)	1.197	.131
Left Frontal High Beta	.022 (.021)	1.012	.169
Right Frontal Beta	.048 (.024)	1.999	.039*
Right Frontal Low Beta	.042 (.017)	2.437	.019*
Right Frontal High Beta	.050 (.028)	1.770	.055
Bilateral eye movements			
Left Frontal Beta	−.026 (.020)	−1.329	.108
Left Frontal Low Beta	−.028 (.015)	−1.869	.047*
Left Frontal High Beta	−.017 (.024)	−0.710	.248
Right Frontal Beta	−.023 (.016)	−1.452	.090
Right Frontal Low Beta	−.017 (.011)	−1.538	.079
Right Frontal High Beta	−.022 (.022)	−1.001	.172

Note. All *t* tests are 1-tailed tests with $df = 9$. Negative difference mean → coherence after treatment was larger than before.

$^{*}p < .05$.

Alpha trend occurring in occipital regions may suggest beginning coherent activity in processing areas involved in retrieval of visual components of the elicited positive memories. This speculation will have to await larger studies for further validation.

There was, however, support from this study for an intrahemispheric coherence model for EMDR effects. For higher EEG frequencies and frontal cortical regions, both well-substantiated as involved in higher order information processing, BEMs were associated with enhanced EEG coherence. Specifically, Left and Right Frontal Low Beta and Right Frontal High Beta frequencies showed increased coherence following BEM stimulation during the contemplation of a positive emotional memory, relative to decreases in coherence for the Blink condition and no changes for the EF condition. Furthermore, this pattern of differential effects among the three conditions was consistent across other cortical regions for the Beta frequency, although these observations did not approach significant or trend levels. And these Frontal Beta EEG changes were associated with a more continuous and unique pattern of increase in the strength and vividness of the targeted positive episodic memory.

LORETA neuroimaging results were also consistent with right prefrontal activation in the Low Beta frequency range. There is a growing body of research indicating the involvement of the right prefrontal cortex in negative affective states (Davidson, 1995, 2002) and in empathic responding (Tullett, Harmon-Jones, & Inzlicht, 2012). It is interesting that our study found increased Low and High Beta coherence and increased Low Beta spectral power in the right prefrontal cortex during the contemplation of positive affective states. These findings would appear to contradict those of Davidson; however, our study also found increased coherence in left prefrontal cortex, a

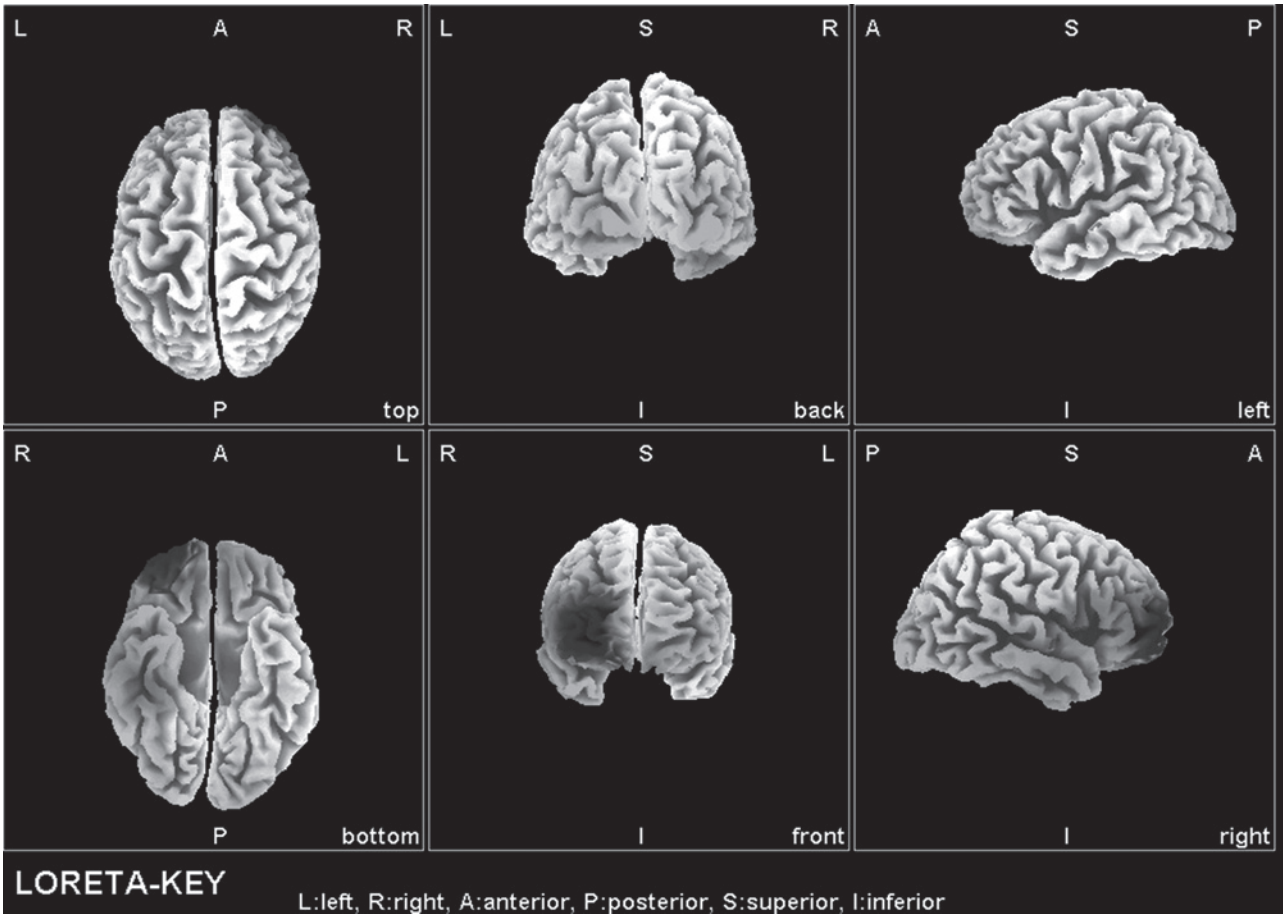

FIGURE 6. LORETA EEG neuroimaging orthographic views for Low Beta spectral power following bilateral eye movements during contemplation of a positive emotional memory (shaded areas represent significantly increased power relative to nonshaded areas).

region reputedly involved in positive affective states as well (Davidson, 2002). We can only speculate at the present time that the cognitive task of contemplation of positive emotional memories during bilateral stimulation involved a balanced recruitment of both left and right emotional processing regions, although not an interconnection of left and right hemispheres as would be seen with increased IhC.

We also found increased coherence for the BEM condition in the Delta frequency in the right frontal lobe. One may be tempted to interpret this increased slow wave coherence as a residual artifact of the BEM activity occurring prior to the EEG recording. There are a couple of reasons for why we believe this not to be the case. First, we painstakingly visually double artifacted all EEG files with particular attention to possible eye movement artifacts in frontal electrodes using written procedures, criteria, and training established in over a decade of EEG research in our laboratories. In addition, if this increased Delta coherence were because of BEM artifacts, it would occur on both the left and right sides, which was not the case in this analysis. We believe that another explanation of this Delta coherence finding is more tenable. Although the Delta EEG rhythm has been historically associated with early developmental stages, sleep, and certain pathological processes, it more recently has been found to be related to brain synchronization with autonomic functions, certain reward-based and defensive motivational states, and attention to and detection of salient environmental stimuli (Knyazev, 2012). Given that our participants had just been treated to a positive, and we hope rewarding, emotional mnemonic experience, it seems more plausible that this enhanced Delta coherence could reflect attention to this positive emotional state.

The prefrontal cortex has long been associated with executive functions, more specifically with the planning of complex behavior, differentiating positive from negative, predicting outcomes, decision making, personality expression, and prosocial behavior—many of the processes involved in the selection and contemplation of a positive emotional memory. Brodmann Areas 10 and 11, identified from the neuroimaging results, are subdivisions of the prefrontal cortex more specifically involved in episodic memory retrieval, reward-mediated behavior, cognitive empathy, and cognitive flexibility and originality (Ramnani & Owen, 2004; Trans Cranial Technologies, 2012). It is consistent with the task demands of this study that these regions showed significantly enhanced activation and coherence following BEMs during the recall of positive episodic memories for the EEG frequency most associated with focus and attention—Low Beta (Bergmann, 2008). Furthermore, these localization outcomes are consistent with single-photon emission computed tomography (SPECT) studies showing increased blood flow in limbic and PFC areas following EMDR and may reflect a recoupling of amygdala-ACC/PFC regions, as described earlier (Pagani et al., 2013).

It is important to note that prior EEG studies of coherence effects of BEMs have not done so during memory contemplation, as occurs in EMDR therapy. We believe this to be an important omission of the few earlier studies because to do so has limited application to the formal process of EMDR. Our study employed positive memory contemplation during BEMs. The constellation of outcomes is very likely heavily influenced by the specific task used in our study, and those outcomes will likely be different or include additional regions for the contemplation of negative or traumatic memories. Indeed, the neuroimaging results and localization of cortical coherence effects appeared to be quite specific to the cognitive processes involved in this unique task. We would expect other distinct cortical regions with functions specific to the directed task to show enhanced coherence and activation. For example, during the contemplation of negative or traumatic memories, we might expect these same regions mentioned earlier to be involved, with the addition of more frontal medial areas reflecting activation of the AC and amygdala subcortices. These speculations await further EEG coherence and neuroimaging studies.

Regarding such future EEG studies of BEMs, observation of the Blink condition outcomes found the alternating red/green visual fixation control condition used in earlier studies by Propper et al. (2007) and by Samara et al. (2011) to have rather remarkable effects on EEG coherence. In a posthoc IhC analysis, Blink Central Theta coherence was found to be significantly higher than in the EF condition ($p = .028$), and in a similar intrahemispheric analysis, Blink coherence was significantly higher than EF coherence for Right Parietal Delta ($p = .04$) and for Left Parietal Theta ($p = .024$), with a similar pattern of trends for other left/right central and parietal sites for these low frequencies. Indeed, the alternating red/green EF condition appeared to rather consistently increase low frequency coherence in central and parietal cortical regions and to decrease high frequency coherence in frontal regions. This effect stands in contrast to a tendency for the BEM stimulus to decrease low frequency coherence and to increase high frequency coherence in specific cortical regions. Given that Delta and Theta frequencies are traditionally associated with sedation, sleep, and trancelike states and that Beta frequencies are associated with focused attention, alertness, and associative functions (Bergmann, 2008; Stevens et al., 2004), the general outcome of this study is consistent with enhanced alertness, focus, and associations during BEM stimulation and a contradictory deactivation of cognitive processing during the Blink condition. Although comparing the BEM condition to the Blink condition may increase magnitude of effect, using an alternating red/green blinking dot as a control condition with which to compare BEMs may not be the best choice for a control comparison condition and may have limited external validity.

Of course, it is possible that our obtained differences between the BEM condition and the controls had somewhat to do with the presentation of the control conditions on a computer screen and the use of a light bar for bilateral stimulation. However, we feel that the light bar better captures and standardizes the BEMs stimulation more commonly found in clinical settings than the alternating dots appearing on either side of a computer screen used in earlier studies. Thus, we feel that our results are more externally valid than those obtained from computer-generated dots. It is noteworthy in this regard that a constructive replication of this study that used the light bar for all three conditions, currently under analysis, obtained a similar differential effect among the three conditions.

An interesting non-EEG outcome of our study concerned the finding of increased memory strength and vividness following all three conditions, with a different pattern of increases for the BEM condition. This outcome is a rather glaring contradiction to an extensive body of research which finds decreased memory vividness for positive and negative memories following BEMs (Engelhard, van Uijen, & van den Hout, 2010; Gunter & Bodner, 2008; Hornsveld et al., 2011; Maxfield, Melnyk, & Hayman, 2008; van den Hout, Eidhof, Verboom, Littel, & Engelhard, 2013; van den Hout & Engelhard, 2012; van den Hout, Muris, Salemink, & Kindt, 2001). The typical design for these studies is to have participants recall a memory, to rate its vividness, then to recall the memory again during several eye movement or fixation conditions, then, after a variable waiting period, to again rate the memory vividness immediately following recall and condition presentation. Most frequently, memories following eye movements are rated as less vivid than memories following EF alone (Maxfield et al., 2008; van den Hout et al., 2013). This basic design and outcomes, called "imagination deflation," have been advanced to support a working memory hypothesis for EMDR, that being a saturation of the visuospatial sketchpad (Andrade, Kavanagh, & Baddeley, 1997) or the central executive (Gunter & Bodner, 2008) in working memory by the simultaneous focusing on the memory and on eye movements, producing a blurring and subsequent weakening of memory vividness.

Yet, as reported in our study, memory strength and vividness ratings were found to significantly increase across all conditions but to more consistently increase for the BEM condition. How do we explain this contradiction to an established body of literature? Well, there is a fundamental difference between our study design and the designs of the studies reported earlier. In our study, more consistent with EMDR practice, ratings of memory vividness were conducted after each of five sequential 1-minute processing periods following presentation of the stimulus condition. In the classic working memory bilateral stimulation research design, vividness is assessed immediately following condition presentation, with no processing period allowed. In fact, our review of this eye movement literature found only one study (Lee & Drummond, 2008) which reported assessing vividness after Phase 4 of clinical EMDR practice, the repeated elicitation of the memory with bilateral stimulation, each time followed by a brief processing period until subjective units of disturbance (SUDs) ratings were reduced to 0 (Shapiro, 2001). And these authors failed to obtain a decrease in vividness when participants were "reliving" the memory but did find a decrease when they were instructed to distance themselves from the memory, and this effect was only found immediately after desensitization and not on follow-up a week later. We feel that this design difference explains our apparently contradictory results.

However, rather than challenge the working memory hypothesis on this procedural discrepancy, we would like to offer an alternative explanation for the effects of BEMs in EMDR practice. We would suggest that EMDR works in a 2-stage process. In the first stage, memories are blurred and deflated via a working memory saturation process, well-described, and supported in research contributions by van den Hout et al. (2013; van den Hout & Engelhard, 2012), Maxfield et al. (2008), Gunter and Bodner (2008), Andrade et al. (1997), and others. However, this desensitization effect is followed in common EMDR practice by a second reprocessing stage during which associative links are formed between the now blurred memory trace and related mnemonic experiences, resulting in an increase in memory vividness of a more constructive reframe of the original memory. Maxfield et al. (2008) have suggested just such a sequence of targeted deterioration of the original memory trace followed by increased vividness through subsequent constructive associative linkages. Our enhanced EEG coherence outcomes with positive memories offer very tentative support for this second stage. Such a two-stage process can easily be tested by simply extending the present working memory paradigm to include an assessment of memory vividness after a subsequent processing period. If this sequence of effects is confirmed by further studies of this nature, they may explain why Dr. Shapiro, quite perceptively, christened this technique Eye Movement *Desensitization* and *Reprocessing*.

Indeed, the support of this study for enhanced intrahemispheric coherence does not at all negate the numerous other models offered to explain the operative mechanisms for EMDR. There are likely multiple mechanisms underlying the efficacy of EMDR, for an intervention so clinically powerful and a brain so virtually infinite in its potential are likely too complex to be subsumed under the propositions of one model alone. This hyperbole notwithstanding, we offer here tentative support for an elaboration of one of the early such models for the efficacy of EMDR, IhC, suggesting a broadening of that model to include functional cortical regions specific to the therapeutic processing of identified memories. Consistent with research outcomes by Lyle et al. (Edlin & Lyle, 2013; Lyle & Jacobs, 2010; Lyle & Martin, 2010; Lyle & Orsborn, 2011) suggesting a primarily intrahemispheric manifestation of saccade-induced cognitive enhancement (SICE), we hypothesize a cortical coherence approach in which diffuse cortical pathways specific to the type of bilateral stimulation employed (visual, auditory, kinesthetic, etc.) establish a heightened level of activation, pathways which are then more easily recruited during the subsequent processing of the target event (positive, negative, or traumatic memories). This recruitment may involve activation of neural networks across hemispheres (interhemispheric), which would then manifest as increased IhC, or within hemispheres (intrahemispheric), which would be reflected in increased coherence in more localized cortical regions.

Of course, this suggestion is based on a rather small-*n* EEG study with a nonclinical population recalling positive memories and must be tentative at this point. However, we hope that these outcomes and theoretical speculations will stimulate follow-up studies to further test our hypotheses.

In our study of positive emotional memories, as would likely occur during Safe Place or Resource installation in the early stages of EMDR, cognitive activities perhaps not requiring additional processing and consequent involvement of dissociated or remote neural networks, it appears that rather circumscribed right and left neural networks were recruited. An investigation of negative or traumatic memories, which have yet to be thoroughly processed and integrated, would be expected to see the recruitment of more and remote networks into the targeted memory through these bilateral stimulation pathways and thus both inter- and intrahemispheric coherence increases within and across specific cortical regions. This extended hypothesis has yet to be more comprehensively examined, but research currently being analyzed in our laboratory is hoped to better illuminate these proposed mechanisms.

Notes

1. We routinely do not use automated independent component analysis (ICA)/principal component analysis (PCA) artifacting procedures in our EEG lab because over a decade of experience has shown us that when we use this software, we still must followup with visual artifacting to remove remaining noise artifacts. We have opted to instead adopt a detailed written protocol for artifacting, and the second author (LS) conducts a hands-on workshop with research assistants every year in which these criteria are taught and checked with real data to see that they are being followed. In addition, all EEG files are blind and double artifacted to ensure that our data files are clean of any non-EEG noise. Our protocol is available on request from the second author (LS).

2. As a further check on the possible contribution of eye movement muscle artifacts to observed frontal pole EEG effects, these analyses were run again with the Fp1 and Fp2 electrodes removed. The same pattern of significant and trend effects were obtained in this reanalysis.

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Correspondence regarding this article should be directed to Dr. Larry Stevens, Northern Arizona University, Department of Psychological Sciences, Box 15106, Flagstaff, AZ 86011. E-mail: Larry.Stevens@nau.edu