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Bilateral Eye Movements Enhance the Retrieval of Episodic Memories

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Two experiments examining effects of eye movements on episodic memory retrieval are reported. Thirty seconds of horizontal saccadic eye movements (but not smooth pursuit or vertical eye movements) preceding testing resulted in selective enhancement of episodic memory retrieval for laboratory (Experiment 1) and everyday (Experiment 2) events. Eye movements had no effects on implicit memory. Eye movements were also associated with more conservative response biases relative to a no eye movement condition. Episodic memory improvement induced by bilateral eye movements is hypothesized to reflect enhanced interhemispheric interaction, which is associated with superior episodic memory (S. D. Christman & R. E. Propper, 2001). Implications for neuropsychological mechanisms underlying eye movement desensitization and reprocessing (F. Shapiro, 1989, 2001), a therapeutic technique for posttraumatic stress disorder, are discussed.

Christman and Propper (2001) reported that the explicit retrieval of episodic memories is facilitated by increased interaction between the two cerebral hemispheres. In one experiment, familial left-handedness, associated with lesser cerebral asymmetry and greater interhemispheric interaction (e.g., Gorynia & Egenter, 2000; Marino & McKeever, 1989; McKeever, VanDeventer, & Suberi, 1973), was associated with superior performance on a test of episodic memory. In a second experiment, inter- versus intrahemispheric processing was directly manipulated by sequentially presenting input to either the same or a different visual field. Superior episodic memory was associated with between-hemispheres presentation of input, whereas semantic memory was superior for within-hemisphere presentation. These findings provide a complement to research indicating that patients who have undergone a commisurotomy (split-brain procedure), who exhibit no direct interhemispheric interaction, display impaired episodic but normal semantic memory (e.g., Cronin-Golomb, Gabrieli, & Keane, 1996; Zaidel, 1995).

Further support for an interhemispheric basis of episodic memory comes from brain imaging studies. Cabeza and Nyberg (2000) reviewed 275 studies comparing brain activity during different memory tasks with activity under baseline conditions. During episodic encoding, “prefrontal activations were always left-lateralized” (p. 23), whereas “prefrontal activations during episodic retrieval are sometimes bilateral, but they show a clear tendency for right-lateralization” (p. 26). In contrast, “activity during semantic memory tasks has been almost always found in the left hemisphere but not in the right” (p. 20). Thus, encoding and retrieval of episodic memories is distributed across both hemispheres, whereas semantic encoding and retrieval (at least for verbal material) is restricted to areas within the left hemisphere. These results are consistent with an inter- versus intrahemispheric basis for episodic versus semantic memories, respectively.

The current study addressed the inter- versus intrahemispheric bases for different types of memory by examining a potential method for enhancing interhemispheric interaction, independent of participant (e.g., handedness) and task (e.g., within- vs. between-hemispheres presentation of input) manipulations as used by Christman and Propper (2001). Bilateral eye movements were used as a means of temporarily increasing the amount of interhemispheric interaction. The underlying logic for the use of bilateral eye movements is as follows.

First, there is a link between eye movements and hemispheric activation, with lateral eye movements leading to a sustained increase in activation of the contralateral hemisphere (Bakan & Svorad, 1969). Thus, sequences of left–right bilateral eye movements presumably result in simultaneous activation of both cerebral hemispheres. As the protocol used by Bakan and Svorad (1969) was not designed to measure the time constant of this activation, it is possible that alternating left–right eye movements might result in rapidly alternating, instead of simultaneous, activation of the two hemispheres. For current purposes, however, it is assumed that either possibility may result in increased bihemispheric activation, which in turn is hypothesized to enhance interhemispheric interaction.

Research from our lab (Christman & Garvey, 2001) demonstrated that engaging in 30 s of bilateral saccadic eye

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movements reduces preexisting asymmetries in hemispheric activation as indexed by perceptual asymmetries on a free-vision chimeric faces task (Kim, Levine, & Kertesz, 1990; Levy, Heller, Banich, & Burton, 1983). Bilateral saccadic eye movements also increase Stroop interference, relative to pre–eye movement baseline measures (Christman & Garvey, 2003), and such interference has been suggested to arise at least in part from increased interhemispheric interaction (Christman, 2001).

Second, it is assumed that equalized levels of activation in the two hemispheres facilitate interhemispheric interaction. If the two hemispheres display different levels of activation, it may be difficult for the less activated hemisphere to "keep pace" and interact efficiently with the more active hemisphere. Indirect evidence for this idea can be found in a study by Morrison-Stewart, Velikonja, Corning, and Williamson (1996), who reported that interhemispheric electroencephalograph (EEG) coherence was increased during the performance of tasks involving bilateral cerebral processing, whereas interhemispheric coherence was reduced during tasks involving a single hemisphere. Similarly, Andres et al. (1999) found that interhemispheric EEG coherence increased during the performance of bimanual tasks and decreased during unimanual tasks. There is also evidence that left-handedness, associated with a larger corpus callosum (e.g., Witelson, 1985, 1989), is also associated with increased interhemispheric EEG coherence (Nielsen, Abel, Lorrain, & Montplaisir, 1990).

From a developmental perspective, the amount of interhemispheric EEG coherence increases dramatically between 2 and 7 years of age (Knyazeva & Farber, 1991), a period coinciding with the rapid myelinization and maturation of the corpus callosum (e.g., Giedd et al., 1996; Yakovlev & Lecours, 1967). These results suggest that interhemispheric interaction (as indexed by interhemispheric EEG coherence) may be facilitated by bilateral hemispheric activation and mediated via the corpus callosum. These findings are echoed by Liederman's (1998) discussion of the corpus callosum's role in the equilibration of activation and facilitation of cooperation between the two hemispheres.

Finally, more direct evidence linking bilateral eye movements and facilitation of interhemispheric interaction can be found in studies of brain activity during REM sleep. Evidence indicates that interhemispheric EEG coherence increases significantly during REM sleep (e.g., Barcaro et al., 1989; Dumermuth & Lehman, 1981). Furthermore, the increase in interhemispheric EEG coherence has been specifically linked to the presence of eye movements (Dionne, 1986). Because the majority of eye movements during REM sleep are horizontal (Hansotia et al., 1990), this evidence suggests that bilateral eye movements are associated with increased interhemispheric interaction and coordination.

Bilateral eye movements were thus hypothesized to equalize activation levels of the two hemispheres, thereby enhancing interhemispheric interaction and facilitating episodic memory retrieval. This hypothetical framework was tested in two studies. In Experiment 1 we used standard laboratory tests of episodic versus implicit memory; prior to recall, participants engaged in either 30 s of eye movements (horizontal vs. vertical crossed with saccadic vs. pursuit eye movements) or no eye movements. In Experiment 2 we looked at memories for everyday life events, the recall of which was preceded by either no eye movements or 30 s of horizontal saccadic eye movements.

Experiment 1

Experiment 1 involved participants studying a set of words and later being given either recognition tests (episodic memory) or word fragment completion tasks (implicit memory). Eye movements were manipulated in two different ways. First, horizontal versus vertical eye movements were compared. Lateral horizontal eye movements induce activation of the contralateral hemisphere (Bakan & Svorad, 1969); vertical eye movements, however, are not known to preferentially activate a particular hemisphere. Thus, only horizontal eye movements were hypothesized to enhance interhemispheric interaction and episodic memory.

Second, saccadic versus smooth pursuit eye movements were compared. Saccadic eye movements generate greater frontal lobe activity than do smooth pursuit movements (O'Driscoll et al., 1998), and frontal lobe regions have been specifically implicated in episodic memory (Cabeza & Nyberg, 2000). Thus, saccadic eye movements were hypothesized to produce greater enhancement of episodic memory.

Method

Participants. A total of 280 undergraduate psychology students (214 women and 66 men) participated for course extra credit; the number of men ranged from 4 to 10 per condition. All participants were right-handed, as measured by scores of +50 or higher (responses of "always use right hand" for all 10 activities yields a score of +100) on the Edinburgh Handedness Inventory (Oldfield, 1971). Recruitment of participants was restricted to right-handers only. Informed consent was obtained from all participants, and the experimental protocol received internal review board approval.

Materials. Stimuli were presented on a Power Macintosh 8600 computer with an Apple 17-in. (43.18 cm) monitor. Stimuli were presented under the control of the Reaction Time Module of the MacLaboratory program, Version 3.0.2 (Chute, 1994).

Stimuli consisted of 72 words taken from Tulving, Schacter, and Stark (1982). Words ranged from seven to nine letters in length and were of moderate frequency. The 72 words were divided into two lists of 36 words each. Study lists were counterbalanced across participants and tasks. Words were presented in 28-point uppercase Courier font.

Design and procedure. After each participant signed an informed-consent form and filled out the handedness inventory, he or she was presented with 36 words. Each word was centrally presented on the screen for 5 s and was automatically replaced by the next word on the list. Participants were instructed to "pay attention to each word as this is a memory test and you may see these words again at the end of the experiment." After the final word was presented, participants engaged in a filler task consisting of a series of personality questionnaires. The purpose of this task was to give participants something to do during the 30-min retention interval. If a participant finished the questionnaires early, he or she was asked to wait until the 30 min had passed.

After completion of the questionnaires, participants were randomly assigned to one of the following eye movement conditions:

(a) no eye movements, (b) horizontal saccadic eye movements, (c) horizontal smooth pursuit eye movements, (d) vertical saccadic eye movements, and (e) vertical smooth pursuit eye movements. Within each eye movement condition, half of the participants completed a test of episodic memory (recognition memory) and half completed an implicit memory test (word fragment completion). There were 28 participants in each of the 10 conditions (5 eye movement types × 2 memory tasks).

In the saccadic eye movement condition, participants followed a black dot (approximately 4° of visual angle in diameter) on the white background of the computer screen as it appeared sequentially on the left and right (horizontal eye movement condition) or upper and lower (vertical eye movement condition) portions of the display. The dot changed positions every 500 ms, leading to two eye movements per second. The dots were located approximately 27° of visual angle apart. Because the vertical extent of the display could not accommodate a spatial extent of 27°, the monitor was rotated 90° (turning the horizontal eye movement condition into a vertical eye movement condition).

In the smooth pursuit condition, participants followed a 4° black dot as it moved continuously back and forth across the screen with the same spatial extent (27°) and periodicity (two eye movements per second). The moving dots were created in the form of QuickTime movies and were presented for a total duration of 30 s. Eye movements were not quantitatively measured; however, across all eye movement conditions, the experimenter stood by the participants' side and visually monitored participants' behavior to ensure compliance with the eye movement instructions.

Immediately after the eye movements (or immediately after the 30-min filler task in the no eye movement condition), participants completed tests of either episodic or implicit memory. Participants who completed the episodic memory task were presented with a list of 72 words made up of 36 words from the list they had seen randomly mixed with 36 words that they had not seen. They were asked to "circle the words you remember seeing on the computer screen from 30 minutes ago." Participants who completed the implicit memory task were presented with a list of 72 word fragments, made up from both the word list they had seen and the word list they had not seen. They were asked to "go through the list and complete as many fragments as you can." No mention was made that some of the words had appeared at the beginning of the experiment. Participants generally took 5 to 10 min to complete the memory tests.

Results

The no eye movement condition could not be factorially combined with the eye movement type (saccade vs. smooth pursuit) and eye movement direction (horizontal vs. vertical) variables. Accordingly, data for horizontal versus vertical eye movements were analyzed in separate 3 (eye movement type: saccadic, smooth pursuit, none) × 2 (task: recognition vs. fragment completion) analyses of variance (ANOVAs) conducted on the horizontal versus vertical eye movement conditions. The data from the no eye movement condition were used in both sets of analyses, serving as a baseline measure of memory performance in the absence of any eye movement manipulations.

Raw data were subjected to signal-detection analyses, allowing separate analyses of accuracy and response bias. For the recognition task, correctly recognized items were hits, and false recognitions were false alarms. For the fragment completion task, completed fragments corresponding to words studied at the beginning of the session were considered hits, and completed fragments corresponding to words not studied were considered false alarms. Use of signal-detection analyses for the fragment completion task is somewhat unusual, as completing a fragment of a nonstudied word is not technically an error and hence not a true false alarm. In this context, signal-detection analyses of the fragment completion task serve not as an index of overall performance but as an index of the implicit memory for the studied word fragments. Analyses of the raw hit and false alarm rates for both tasks are presented later in this section in order to examine the effects of eye movement on overall performance, whereas the signal-detection analyses are used to examine explicit and implicit memory for previously studied words.

Signal-detection analyses yielded two dependent variables: d' (discriminability of old items from new items) and β (response bias). A d' of zero indicates no ability to discriminate old from new; higher values denote increasing discriminability. β ranges from 0 to ∞, with β values less than 1 indicating a bias to respond to items as "old" and values greater than 1 indicating a bias to respond to items as "new." Because the distribution of β is skewed, analyses were performed on the log transform of β.

Exploratory analyses of the d' variable indicated no significant main effects or interactions involving sex or familial handedness. Analyses of β yielded a main effect of sex, $F(1, 256) = 10.14$, $p = .002$, and an interaction between task and sex, $F(1, 256) = 7.56$, $p = .006$, reflecting higher β values (i.e., more conservative response biases) for male participants, especially for the recognition task. Because none of these effects involved the eye movement variable, subsequent analyses collapsed across sex and familial handedness.

Horizontal eye movements. The values of d' and β for each condition are shown in Table 1. The d' data yielded a main effect of task, $F(1, 162) = 438.59$, $p = .0001$, reflecting higher discriminability in the episodic task. It should be pointed out that d' comparisons between tasks are virtually meaningless, as discrimination between old and new items is qualitatively different: In the recognition task, d' is a true measure of accuracy, whereas in the fragment completion task, all responses are "correct," and d' is merely a measure of the extent to which completed fragments tend to be previously studied items. There was also a marginal effect of eye movement type, $F(2, 162) = 2.85$, $p = .06$. However, these effects were qualified by an interaction between memory task and eye movements, $F(2, 162) = 3.81$, $p = .024$. Analyses of simple effects indicated that, for the recognition memory task, horizontal saccadic eye movements were associated (a) with better performance than with no eye movements, $F(1, 54) = 3.31$, $p = .006$, and (b) with marginally significantly better performance than with horizontal pursuit movements, $F(1, 54) = 3.86$, $p = .055$. There was no difference between the horizontal pursuit and no eye movement conditions ($F < 1$). For the fragment completion task, there were no differences between any of the eye movement conditions (all Fs < 1).

Analyses of β indicated main effects of task, F(1,

Table 1

Accuracy (d') and Response Bias (Log β) Values From Experiment 1 as a Function of Memory Task and Eye Movement Condition

Memory task	Eye movement condition				
	No eye movements	Horizontal saccade	Horizontal pursuit	Vertical saccade	Vertical pursuit
Episodic recognition					
d'	2.57	3.16	2.75	2.89	2.86
Log β	0.36	0.67	0.44	0.60	0.61
Implicit fragment completion					
d'	0.80	0.85	0.85	0.83	0.80
Log β	0.11	0.18	0.14	0.21	0.17

162) = 53.86, $p = .001$, reflecting higher values of β for the recognition task, and of eye movement type, $F(2, 162) = 5.90$, $p = .003$. This latter effect arose from the presence of higher β values for saccadic eye movements than for pursuit eye movements, $F(1, 54) = 4.32$, $p = .042$, and no eye movements, $F(1, 54) = 12.00$, $p = .001$. There was no difference in β values for the pursuit versus no eye movement conditions ($F < 1$).

Vertical eye movements. The only effect for d' was a main effect of task, $F(1, 162) = 413.93$, $p = .0001$, reflecting higher d' values for the recognition task. The main effect of eye movement ($p = .287$) and the interaction between eye movement and task ($p = .379$) were not significant.

Analyses of β yielded main effects of task, $F(1, 162) = 55.40$, $p = .001$ (reflecting higher values for the recognition task), and of eye movement type, $F(2, 162) = 4.98$, $p = .008$. This arose from the fact that β values for both the saccadic ($p = .013$) and pursuit ($p = .011$) eye movement conditions were larger than for the no eye movement condition. There was no difference between the saccadic and pursuit conditions ($F < 1$).

Hit and false-alarm rate data. Analyses of the raw hit and false-alarm rates for both tasks were also conducted. For the recognition task, these analyses were performed to rule out the possibility that the increase in d' was an artifactual effect of the more conservative response bias induced by the eye movements. Adoption of more conservative response biases (e.g., a greater reluctance to respond "old") can lead to increases in d' without any actual increase in sensitivity and discriminability (Donaldson, 1993; Wiens, Emmerich, & Katkin, 1997). As an illustration, imagine observers with an infinitely liberal response bias, such that they respond positively to all items on a recognition test, giving them 100% hit and false-alarm rates. This would yield a d' of zero. If such observers then adopted a more conservative response bias, fewer positive responses (either hit or false alarm) would result. If the decrease in false alarms is greater than the decrease in hits, d' could increase in the absence of any true increase in sensitivity. Thus, adoption of more conservative response biases in the form of a decrease in the proportion of both hits and false alarms can lead to artifactual increases in d'. This possibility can be readily ruled out in the present experiment, as the horizontal saccadic eye movements, relative to the no eye movement control condition, yielded an increase in the hit rate (from 79.7% to 81.8%) and a decrease in the false-alarm rate (from 6.6% to 1.7%). Thus, the horizontal saccadic eye movement manipulation appears to result in both an increase in discriminability between old and new items and an increasingly conservative response bias.

For the fragment completion task, analyses of hit and false-alarm rates were conducted to determine whether eye movements had any effect on overall performance, independent from the above analyses focusing on whether fragments corresponding to studied words were more likely to be completed than those corresponding to unstudied words. For these analyses, the number of hits (completed fragments of studied words) and false alarms (completed fragments of unstudied words) were combined, yielding the total number of completed fragments. Analyses indicated that there were no significant differences in the total number of completed fragments across the five eye movement conditions, $F(4, 134) = 1.45$, $p = .220$ (no eye movements = 28.6 fragments completed, horizontal saccade = 25.8, horizontal pursuit = 24.3, vertical saccade = 26.9, and vertical pursuit = 23.2).

Discussion

Horizontal saccadic (but not pursuit) eye movements produced an increase in discriminability between old and new items for the recognition (but not fragment completion) task. Vertical eye movements produced no change in discriminability between old and new items for either task. Given that (a) only horizontal eye movement result in the selective activation of the contralateral hemisphere, and (b) saccadic eye movements produce greater cortical activation than pursuit eye movements (O'Driscoll et al., 1998), the simultaneous activation of both hemispheres induced by bilateral horizontal saccades may have enhanced interhemispheric interaction, thereby producing the improvement in episodic memory. The fact that only horizontal saccadic, but not vertical or pursuit, eye movements produced this facilitation helps rule out the possibility that the improved performance reflected a nonspecific arousal induced by oculomotor activity. Thus, these results support and extend the findings of Christman and Propper (2001) that enhanced episodic memory is associated with increased interhemispheric interaction.

It is possible that participants may have approached the fragment completion task as a sort of cued recall task, thus introducing an element of explicit memory contamination. However, to the extent that this occurred, it should have resulted in evidence for eye-movement-induced increases in the completion of previously studied fragments. Given that there were no differences between eye movement and no eye movement conditions for the fragment completion tasks (with all Fs < 1), however, this possibility can be ruled out.

The finding of eye-movement-induced changes in response bias was unexpected. Horizontal saccadic and vertical eye movements, both saccadic and pursuit, resulted in more conservative response biases (e.g., errors were more likely to be misses than false alarms). Although speculative, a possible basis for this effect may be found in a study by Feenan and Snodgrass (1990), who reported that changes in context between encoding and retrieval lead to more conservative response biases. Perhaps the induction of eye movements in the current study resulted in an internal change of mental state, leading to similar context effects.

Experiment 2

In Experiment 2 we attempted to extend the laboratory-based findings of Experiment 1 to the recall of real-world autobiographical memories. Participants kept journals recording personal everyday events and later recalled those events, with some participants engaging in horizontal saccadic eye movements prior to recall (on the basis of the results of Experiment 1, pursuit and vertical eye movements were not used). In addition, Experiment 2 incorporated a new control condition. Instead of the no eye movement condition in Experiment 1 (in which participants did not engage in any sort of visual stimulation), participants looked at a circle that changed color twice a second for a total of 30 s. In this way, participants in the control condition received periodic visual stimulation (as in the eye movement condition) in the absence of actual eye movements.

Method

Participants. Forty undergraduate psychology students (28 women and 9 men, with gender information unavailable for 3 participants) participated in this study for course extra credit (the data for an additional 5 participants were dropped because of failures to follow instructions). All participants were right-handed as measured by scores of +50 or higher on the Edinburgh Handedness Inventory (Oldfield, 1971).

Apparatus and procedure. Participants were given a booklet containing instructions and space for recording life events. They were told to keep a journal for 6 days in which they recorded, in as much detail as possible, 10 unusual events that happened to them. Events were defined as occurrences that differed from their normal routine, and it was specified that events could be mundane (e.g., stubbing one's toe) or highly significant (e.g., attending a funeral). Events were recorded as soon as possible after they occurred to ensure accuracy. The elapsed time between events and their recording in the journal did not differ between eye movement and no eye movement conditions (eye movement = 199.0 min; no eye movement = 199.5 min). Journals were handed in 7 days after the start of journal keeping. Participants were not informed that they would be tested for their memories of the journal entries.

Approximately 2 weeks after journal completion, participants were tested for their memory for the journal events. Prior to testing, participants were randomly assigned to one of two conditions involving either colored circles or moving circles. The colored circle condition involved the presentation on a computer screen of a circle that changed color pseudorandomly such that no color ever appeared twice in succession. The color changed twice per second. Six colors were used (blue, pink, purple, green, orange, and yellow), and each color was repeated 10 times. The moving circle condition was identical to the horizontal saccadic condition from Experiment 1. There were 20 participants in each condition. Presentation of the circle stimuli was under the control of SuperLab Pro, Version 1.75 (Cedrus Corporation, 1997).

Immediately following presentation of the circle stimuli, participants recalled the gist of as many events from their journals as possible. Participants wrote down responses, with no time limit for task completion. Participants' responses were scored by two judges as to whether or not the responses reflected an accurate recall of journal entries; judges were blind to the circle condition of the participants. Judgments were based on whether or not the recall responses captured the gist (e.g., contained one or more of the details) of the journal entries. For example, consider the following journal entry:

> I went to the park with my cousin. While we were there, we played Frisbee with a large brown dog that came over to us. We hung out for a while and then got ice cream when we walked home.

Recall responses such as "I hung out at the park with my cousin," "I went for ice cream with my cousin," and "I played Frisbee with a large dog at the park" would all be considered correct memories (i.e., hits). Responses such as "I went to the park with my Mom," "I drove through the park," and "I went out for clams with my cousin" would all be considered incorrect (e.g., false alarms). Only items receiving 100% agreement among the judges were included in the analyses. Two items were eliminated using this criterion.

Results and Discussion

Hit (i.e., correctly recalled journal entries) and false-alarm (i.e., recalled events that were not from the journal) rates were used to conduct signal-detection analyses, generating measures of accuracy (d') and response bias (β). Analyses of response bias were performed on the log transform of β. These dependent variables were then subjected to a one-way ANOVA contrasting performance in the moving circle versus colored circle conditions. Preliminary analyses of the 37 participants for whom gender information was available indicated no significant effects or interactions involving gender, so subsequent analyses collapsed across this variable.

Analyses of the d' variable yielded a significant main effect, $F(1, 38) = 4.20$, $p = .047$, reflecting higher accuracy in the moving circle condition ($M = 1.79$) than in the colored circle condition ($M = 1.06$; see Table 2). Thus, as in Experiment 1, engaging in bilateral horizontal saccadic

Table 2
Accuracy (d') and Response Bias (Log β) Values From Experiment 2 for Episodic Recall as a Function of Eye Movement Condition

	Eye movement condition	
Variable	No eye movements	Horizontal saccade
d'	1.06	1.79
Log β	0.62	0.88

eye movement enhanced the retrieval of episodic memories, relative to a baseline condition involving no eye movements.

Analyses of the β variable revealed no differences between conditions in response bias, $F(1, 38) = 2.38$, $p = .131$, although there was a trend for higher log β values (i.e., more conservative response biases) in the moving circle condition ($M = .88$) than in the colored circle condition ($M = .62$). Thus, unlike Experiment 1, eye movements did not produce significant effects on response bias, although the results of the current experiment did follow the general trend of eye movements' being associated with more conservative response biases.

As in Experiment 1, it is possible that the eye-movement-induced increase in d' was an artifactual result of the nominally more conservative response bias also associated with eye movements. This was again ruled out, as the eye movement condition, relative to the no eye movement control, yielded both an increase in hits (from 37.0% to 44.0%) and a decrease in false alarms (from 17.7% to 5.3%). The finding across both experiments that the increase in d' was driven more by a reduction in false alarms than an increase in hits suggests that the eye movement manipulation may be particularly effective in reducing instances of false memories.

Finally, given that Christman and Propper (2001) reported superior episodic memory in persons with familial left-handedness, post hoc analyses of this variable were conducted, collapsing across the circle conditions to allow sufficient sample sizes. Although participants with positive familial left-handedness displayed higher d' values ($M = 1.90$, $n = 10$) than participants without familial left-handedness ($M = 1.27$, $n = 30$), this difference was not significant, $F(1, 38) = 2.24$, $p = .143$.

General Discussion

The current experiments demonstrate that the retrieval of episodic memories is selectively enhanced when preceded by bilateral horizontal saccadic eye movements. Given past research indicating that superior episodic memory is associated with increased interhemispheric interaction (Christman & Propper, 2001), the current results are consistent with the hypothesis that bilateral eye movements enhance interhemispheric interaction (and hence episodic memory) by equalizing the levels of activation for the left and right hemispheres of the brain. Although the current study did not directly measure hemispheric activation or interaction, lateral eye movements activate the contralateral hemisphere (Bakan & Svorad, 1969), so bilateral eye movements therefore should activate both hemispheres. Furthermore, bilateral eye movements reduce hemispheric asymmetries in activation level (Christman & Garvey, 2001) and increase interhemispheric EEG coherence (Dionne, 1986). Therefore, the current studies suggest that equalized levels of activation in the two hemispheres, as a result of bilateral eye movements, enhance interhemispheric interaction, resulting in the improvements of episodic memory obtained in the current experiments.

However, the current methodology does not allow firm conclusions about the precise mechanism by which bilateral eye movements enhance episodic memory retrieval. Although previous work from our lab suggests that increases in interhemispheric interaction underlay the observed improvement in episodic retrieval, we cannot definitively conclude that these increases were mediated by an equalization of activation levels over the two hemispheres. Alternate explanations involve increases in interaction mediated by factors other than activation levels, such as increases in interhemispheric EEG coherence.

These results have important implications for the mechanisms underlying the efficacy of eye movement desensitization and reprocessing (EMDR; Shapiro, 1989, 2001), a controversial therapy technique for treating posttraumatic stress disorder (PTSD). EMDR therapy involves alternating left–right eye movements while the patient tries to evoke the traumatic memory. PTSD is a dissociative disorder, in which patients have difficulty voluntarily retrieving memories for traumatic experiences. An important component of PTSD therapies involves patients reliving traumatic memories within the supportive therapeutic context, and one of the professed benefits of the EMDR technique is that it makes traumatic memories more readily accessible to voluntary retrieval; reduces the incidence of involuntary intrusions; and, perhaps most critically, desensitizes the patients to the traumatic nature of past events via a form of cognitive restructuring. It is also important to note that the eye movement procedure, the focus of the current article, represents but one of numerous procedural elements that constitute EMDR.

The considerable controversy surrounding EMDR (e.g., McNally, 2001; Senior, 2001) stems in large part from the fact that the psychological and physiological mechanisms underlying the efficacy of this technique remain a mystery. A recent review (Turner, McFarlane, & van der Kolk, 1996) concluded that the "rationales provided for [EMDR] at this point tend to be largely untested post hoc hypotheses constructed to justify the methods" (p. 549). Another review (Spector & Read, 1999) noted that "a direct link between the theoretical basis of the therapy and observable psychological and neurobiological changes has yet to be established" (p. 165). However, the current experiments provide a potentially important first step in understanding the mechanisms underlying the efficacy of EMDR.

First, the finding of enhanced retrieval of nontraumatic episodic memories when participants made bilateral eye movements suggests that the eye movements used in EMDR activate neurophysiological structures generally involved in episodic–explicit memory retrieval rather than those specific to traumatic information or to the EMDR therapeutic situation in general. Converging support for this neurophysiological framework comes from a study by van der Kolk, Burbridge, and Suzuki (1997), who reported that patients with PTSD who have been successfully treated with EMDR exhibit increased bilateral activity in the cingulate gyrus, a brain structure directly implicated in episodic retrieval (Cabeza et al., 1996; Nyberg, Habib, & Herlitz, 2000).

Second, we propose that bilateral stimulation fosters interhemispheric interaction by increasing and equalizing activation of the two cerebral hemispheres. Increased interhemispheric interaction, in turn, has been implicated in facilitation of episodic retrieval (Christman & Propper, 2001). Thus, the therapeutic benefits of the eye movements used in EMDR therapy may have more to do with helping patients with PTSD overcome their dissociative amnesia and retrieve episodic memories for traumatic events than with directly affecting emotional processes related to the trauma and the therapeutic context.

However, a possible role of eye movements in the modulation of emotional processing, in addition to the memory effects demonstrated in the current experiments, is still possible. Compton and Mintzer (2001) reported that interhemispheric interaction was beneficial in the alleviation of stress and worry. Thus, the hypothesized increase in interhemispheric interaction induced by eye movements might also help clinical patients cope with the anxiety and stress accompanying the enhanced retrieval of traumatic memories. Indeed, reduction in subjective distress levels (i.e., desensitization) is a commonly reported effect of EMDR (e.g., Cusack & Spates, 1999; Ironson, Freud, Strauss, & Williams, 2002; Montgomery & Ayllon, 1994; Wilson, Tinker, Becker, & Logan, 2001). In this sense, the eye movement procedures used in EMDR may well influence emotional processes as well as memory processes. Future work should examine the effects of eye movements on emotional states and on the recall of emotionally charged memories.

Of special importance is the current finding that saccadic, but not smooth pursuit, eye movements result in enhanced episodic retrieval. Although proponents of EMDR stress the importance of bilateral eye movements, virtually no distinction has been made between saccadic versus pursuit eye movements, leading to potentially serious methodological problems. For example, Montgomery and Ayllon (1994) claimed to induce bilateral saccadic eye movements by waving a finger in front of the patient. The finger was moved back and forth two times a second across a spatial extent of approximately 35°–45° of visual angle; this is similar to the stimulation used in the current study to induce smooth pursuit eye movements, leading to the possibility that the participants in this study may in fact have engaged in smooth pursuit, not saccadic, eye movements. This problem is widespread, as many studies of EMDR follow Shapiro's original protocol (e.g., Bates, McGlynn, Montgomery, & Mattke, 1996; Devilly & Spence, 1999; Levin, Lazrove, & van der Kolk, 1999), in which the therapist waves a finger back and forth in front of the patient, a procedure more likely to elicit pursuit than saccadic eye movements. Because pursuit eye movements did not enhance episodic retrieval in the current study, it is possible that many of the negative reports on the efficacy of EMDR (for reviews, see Davidson & Parker, 2001; Lohr, Lilienfeld, Tolin, & Herbert, 1999; Spector & Read, 1999) reflect the fact that their procedures induced smooth pursuit, not saccadic, eye movements. Future work testing the efficacy of EMDR must explicitly distinguish between saccadic and pursuit eye movements.

The current neuropsychological interpretation of the basis for EMDR contrasts in important ways with those in a recent article presenting an alternative neural basis for EMDR (Stickgold, 2002), which argued that "the repetitive redirecting of attention in EMDR induces a neurobiological state, similar to that of REM sleep, which is optimally configured to support the cortical integration of traumatic memories into general semantic frameworks" (p. 61). This framework would predict that the direction (horizontal vs. vertical) and nature (saccade vs. pursuit) of eye movements should not matter, as all involve the redirecting of attention. The fact that only horizontal saccadic eye movements produced significant effects on episodic retrieval suggests that the redirecting of attention, albeit possibly necessary, is not sufficient. The current results strongly suggest that a facilitation of interhemispheric interaction lies at the heart of EMDR's efficacy. In this light, it is interesting to note that Stickgold's (2002) reference to the similarities between EMDR and REM sleep is consistent with the current framework, as (a) there is tentative evidence that REM sleep may be important for the consolidation of various types of memory (Stickgold, Hobson, Fosse, & Fosse, 2001; Titone, 2002), and (b) REM sleep is characterized by an increase in interhemispheric EEG synchrony (Barcaro et al., 1989; Dumermuth & Lehman, 1981), which is a plausible physiological marker for increased interhemispheric interaction.

Of interest, another recent article presenting another hypothesis about the mechanisms underlying the efficacy of EMDR also proposes that bilateral neural activation (specifically, in the anterior cingulate cortex) is important (Corrigan, 2002), although that article concentrates on attentional, not emotional or memory, processing. It is possible, and even likely, that the eye movement procedures in EMDR affect a broad range of neural and psychological processes above and beyond the memory effects studied in the current article.

In conclusion, the current experiments indicate that bilateral horizontal saccadic eye movements selectively enhance the retrieval of episodic memories, presumably by enhancing interhemispheric interaction. In turn, this suggests that at least part of the efficacy of EMDR therapy arises from the role of bilateral eye movements in overcoming dissociative amnesia. Future research should address a number of unresolved methodological and conceptual issues including (a) whether eye movements have any effects on the encoding of episodic memories; (b) the effects on memory of variations in the duration, frequency, and spatial extent of the eye movements; (c) how long the eye-movement-induced enhancement of episodic retrieval persists; and (d) the effects of eye movements on emotional and attentional processing.

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