THE EFFECT OF INTERHEMISPHERIC COMMUNICATION ON MEMORY: LESS THAN MEETS THE EYE

Sarah Ahmed, James Karivalis, Komal Kothari, Kevin Lee, Lisa Ma, Cameron Rogers, Sonali Sanyal, Manvir Singh, Kevin Tien, Steven Tufaro, Jennifer Wu, Julie Xie

Advisor: Patrick Dolan
Assistant: Jennifer Sissman

ABSTRACT

This study was conducted to test whether or not interhemispheric interaction improves memory retrieval. To do so, we divided our subjects amongst four groups, with one as the control and the others engaging in rapid left-right eye movement, bimanual activity, or binaural stimulation. The control group simply stared at one spot while the others shifted their eyes back and forth, alternated clenching their fists, or listened to tones that switched between ears. Each of the groups was presented with a series of tests that assessed their episodic, semantic, and false memories. After analyzing the collected data, we concluded that interhemispheric interaction did not significantly improve either semantic or false memory and binaural treatment was in fact detrimental to episodic memory.

INTRODUCTION

You're about to take a test, but suddenly, you blank. You try to recall the past week's lessons, the worksheets, the homework, but your efforts are in vain. You reluctantly walk into the class, and soon you're staring down at the test, and nothing comes to you. The next day, you discover that you have failed abysmally.

We all wish that we could avoid these situations. In fact, Christman's research laboratory has recently claimed that we can augment our memory retrieval simply through rapid left-right eye movement. Our research will assess this claim across a variety of memory tasks.

Throughout the last decade, it has been reported that an interaction between the two cerebral hemispheres can improve the retrieval of episodic memories, in that memory encoding and retrieval are performed in each hemisphere, respectively [1]. A few years ago, Christman et al. reported that interhemispheric interaction (which was performed through rapid left-right eye movement) improved retrieval of episodic memory of a list of recently studied words. Participants were given a list of words to remember, and were later given a recognition test, which consisted of both studied and unstudied words. Before taking the test, participants were subjected to one of five experimental conditions (no eye movement [EM], horizontal saccadic EM, horizontal smooth pursuit EM, vertical saccadic EM, and vertical smooth pursuit EM). Results showed that participants in the horizontal saccadic EM group had significantly higher accuracy in the episodic recognition memory test [2]. In another experiment Christman claimed that left-handed individuals more easily recalled memories than right-handed individuals, because of greater interhemispheric communication. This interaction is achieved through the moving of signals across the corpus callosum, a white matter structure that links the right and left hemispheres and is thicker in left-handed individuals. Through neuroimaging, scientists have discovered that memory encoding is associated with increased activity in the left hemisphere, whereas memory retrieval is associated with increased activity in the right hemisphere [4]. If the interaction between the two hemispheres is increased, some postulated, the connection between encoding and retrieval may be drastically enhanced.

Whereas Christman and colleagues assessed the effect of eye movement on participants' episodic memory (memory for a particular event in time- what you did for dinner last night or what words were present on the study list), other aspects of memory have not been explored. In contrast to episodic memory, semantic memory is any kind of knowledge-based memory, though it is often simply referred to as general knowledge. An example of semantic memory is one's knowledge of the colors of the US flag or the shape of a ball. Semantic memory can be tested in the laboratory by presenting subjects with lists of trivia questions and assessing how many are answered correctly.

A variation of a semantic test involves presenting a question containing incorrect information and observing whether the participant notices (often termed "semantic illusion" questions). For example, "How many animals of each kind did Moses take on the Ark," in which testers substituted Moses for Noah. Although nearly everyone knows it was Noah, not Moses, who took animals on an ark, a remarkable number of participants overlook the error and answer "two" anyway. [5].

It is often thought that episodic recall is partially dependent on semantic memory, since episodic memories can neither be encoded nor recalled without semantic knowledge [6]. An interesting area of recent research is in the intersection of episodic and semantic memories. Under some circumstances, semantic memory can actually impair episodic memory, leading to memories for events that never occurred ("false memories"). Using what has been termed the DRM (Deese-Roediger-McDermott) paradigm, participants study a list of words for a later memory test. These study words are selected to be semantically related to a general theme, leading participants to falsely remember related words. For example, participants might study "*bed rest awake tired dream wake snooze blanket doze slumber snore nap peace yawn drowsy*" and later falsely remember having studied "*sleep*" [7]. In 2004, Christman conducted an experiment using this DRM paradigm and found that interhemispheric interaction decreases the prevalence of false memories. In this experiment, the participants were given six word lists and then recalled as many words as they could remember after 30 seconds of eye movement. The results showed that those in the eye movement group recalled 33% fewer false memories than those in the control group. [1]

In addition to applying Christman and colleagues' procedures to other forms of memory retrieval (e.g. semantic, false memories, and semantic illusions), our study extends its procedures to other tasks that, arguably, would also increase communication between the two hemispheres. One such task is a binaural condition, in which the participants hear tones that alternate between the ears. Hypothetically, these tones would stimulate both hemispheres of the brain and cause more usage of the corpus callosum, leading to improved memory.

In a study by Frank Andres, the subjects were taught a hand sequence for individual hands and then inter-played the sequences while a continuous EEG was recorded from 28 surface electrodes mounted in a cap. It was found that when the subjects were involved in bimanual skill acquisition, they displayed enhanced interhemispheric functional coupling [8]. Because bimanual movement seems to be directly connected to activity between the two hemispheres from the corpus callosum, we decided to test the relevance of bimanual activity to memory. Christman's research has opened up the potential to test not only other types of memory, but also other interhemispheric tasks that can enhance memory retrieval.

METHODS

Participants

The participants were scholars attending the 2007 New Jersey Governor's School in the Sciences. Seventy-one students were tested, of which 39 were male and 32 were female, ranging in age from 16 to 18 years. Participants were randomly assigned to one of four groups to be tested for the effects of interhemispheric interaction on memory.

Design and Materials

The names of all the subjects were put into Microsoft Excel. Each subject was randomly assigned to one of four conditions under which they were to be tested and to a corresponding study number using the random number generator function in Excel. Condition 1 was the control: participants were instructed to stare at a black dot on the wall for thirty seconds. Condition 2 tested the effect of rapid left-right eye movement. Participants with this condition were asked to move their eyes to dots to their left and right equidistant from a center point about twice per second for thirty seconds. These dots were at a height of 4 ft., 5.5 in.; 3.5 ft. from a center point each; and 3.125 in. in diameter. Condition 3 tested bimanual activity, where participants were instructed to clench and unclench their fists alternating between their left and right hands for thirty seconds. Condition 4 tested binaural stimuli; 440Hz tones were generated with audio software called Audacity and saved to a stereo MP3 file that was played through headphones from Windows Media Player. The tones alternated between the left and right channel twice per second for thirty seconds.

The episodic memory task employed two lists of 30 words that were equated in terms of average length (5.6 letters, ranging from 4 to 7), average concreteness (4.7, ranging from 2.0 to 6.7), and average frequency of occurrence in written text (150.2, ranging from 26 to 498 per million), taken from the Paivio, Yuille, and Madigan norms [9]. Half the participants studied list 1 and the other half studied list 2.

The Deese-Roediger-McDermott (DRM) memory task (Appendix A) employed lists of related words that have been shown to elicit a false memory for a critical non-presented word (e.g. "sleep"), taken from the Stadler, Roediger, & McDermott, norms [10]. Eight 15-item lists were selected based on a percentage of false memory generation (ranging from 78 to 84 percent). Two study lists were formed, each consisting of four DRM lists (60 words total). Half the participants studied list 1 and the other half studied list 2.

The episodic and DRM memory tests were administered by randomly combining words that were studied with words that were not studied. Each participant was asked to respond "yes" or "no" based on whether they remembered the word from the study list. The episodic test list consisted of 30 words from the studied list as well as 30 words from the non-studied list. The DRM test had 20 studied words, the 4 critical non-studied related words, as well as 24 other non-studied words. These words were selected from the norm lists (which were originally 60 words long). The lists were first sorted by popularity of word, and then every fourth word was selected from the sorted lists (5 from each of the studied lists, taken from serial position 1, 5, 9, 13 and 17).

The semantic memory task used 50 general knowledge questions (Appendix B) selected from the Nelson & Narens norms [11]. Items with a difficulty rating of .1 to .6 that were not outdated were selected. Four of the fifty questions were intentionally-incorrectly-worded semantic "illusion" questions; that is to say, a critical word in the question was changed, but the wording of the question was such that it would lead a participant to answer incorrectly out of familiarity of the answer (e.g., "What kind of tree did Lincoln chop down?"). Questions were answered on a sheet with fifty answer spaces, one for each response.

A Visual Basic for Applications program running from Microsoft Excel was used to display the episodic and DRM study and test words and to display the semantic memory test questions. Words were displayed at 72 point font on a 15 or 17-inch computer monitor. A web-based version of The Edinburgh Handedness Inventory was [12] used to determine left/right/mixed-hand bias [13]. As a filler task, participants were also given a conjunction probability reasoning problem (Linda the bank teller problem; Tversky & Kahneman, 1983) [14]. A stopwatch was used to time all experimental treatments.

<u>Procedure</u>

Participants were directed to one of four test rooms based on a schedule determined prior to testing. After being welcomed and given informed consent forms to sign, participants were seated at a computer and given one of two episodic memory lists to study. Words from this list were displayed in the middle of the computer screen for 1500 milliseconds each, followed by the next word. Test subjects were then instructed to fill out the Edinburgh Handedness Inventory to determine their handedness quotient and also to put time between studying the list and taking test. Next, participants were instructed to engage in thirty seconds of a predetermined condition based on random assignment, either: control (staring at a black dot), eye movement (moving eyes from side to side), fist clenching (alternating hands, clenching and unclenching), or binaural stimulation (listening to tones in alternating ears). Immediately after, the semantic memory test was administered to determine the effects of the treatment on semantic memory retrieval. Afterwards the participants engaged in another thirty seconds of the experimental treatment and took a computerized recognition test of the words studied from the episodic list. Upon completion of this task, subjects studied another list of words from the DRM paradigm study list. Words from this list were displayed for 500 milliseconds each. The subjects then completed "Linda the bank teller problem", went through a third experimental treatment and took the final memory test based on the DRM study lists. Afterwards, participants were thanked, offered some candy, and told that they would be informed of the purposes of the study at the final conference.

RESULTS

In order to analyze the results of our experiment, we used the SPSS statistical package. We conducted analyses of variances (ANOVA) for the episodic, Deese-Roediger-McDermott (DRM) paradigm episodic, and semantic memory experiments to compare sample means and to determine if there were any statistical differences between our experimental groups. Our ANOVA was coupled with a Fisher's LSD post hoc test, which helped us identify the categories in which there was a significant difference, if one existed.

Episodic Test

Our analysis showed that, overall, the subjects were able to recognize about 74% of the words that they studied after performing an experimental condition. The average false alarm rate for all four groups, or the percentage of words that the subjects incorrectly remembered, was 25%. Of interest was how the treatment groups differed in their performance on the episodic test. Figure 1 below shows the mean hit rate and the mean false alarm rate segregated by experimental condition.

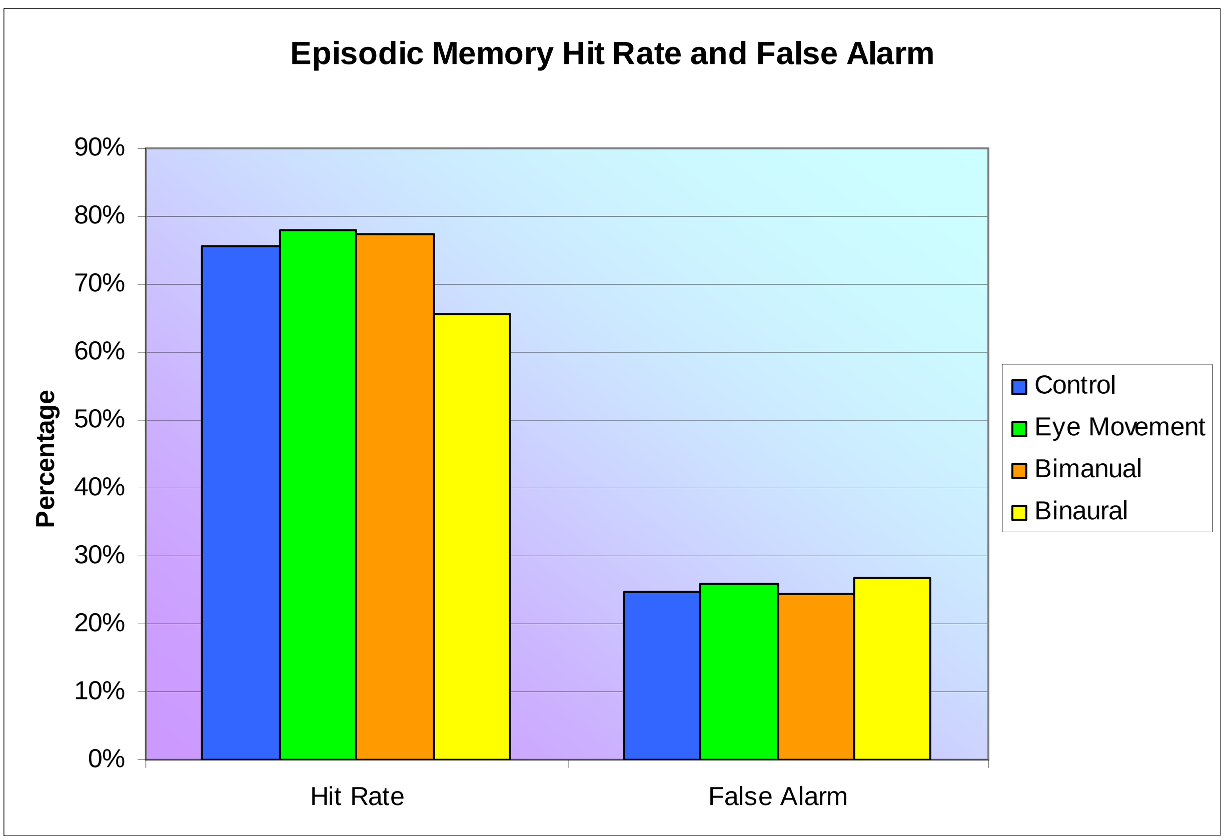

Fig 1. Percentage of "yes" responses for studied and non-studied words in the episodic task

As seen by Figure 1, few differences were found among our four treatment groups. However, looking at the hit rate, an ANOVA [$F(3, 65) = 4.280$, $p < 0.008$] in conjunction with a Fisher's LSD post hoc test reveals that the binaural stimulation condition did significantly worse than the other three conditions (all p values $< .02$). There were no differences among the false alarm rates ($p > .60$)

Deese-Roediger-McDermott (DRM) Memory Test

Three different dependent variables were measured—hit rate, false alarm rate, and false memory rate. The hit rate for all participants was 79%. The false alarm rate, or the percentage of the time that the participants responded "yes" to a non-studied, non-critical word, was 16%. The false memory rate, or the percentage of the time that the subjects responded "yes" to the four critical missing words, was 86%. Of interest was how the four treatment conditions may have differed in performance. Figure 2 illustrates that these groups did not differ in any way (all p values $> .05$).

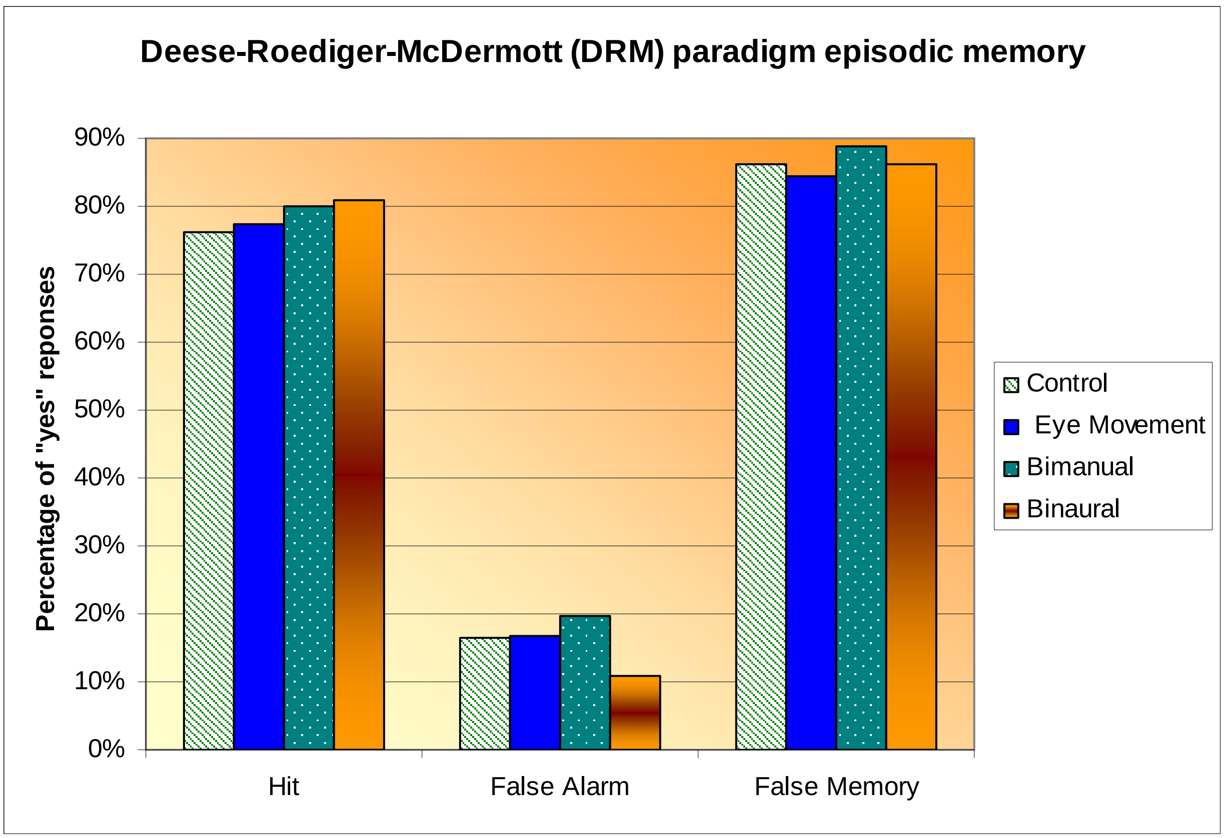

Fig 2. Percentage of "yes" responses for studied, non-studied, and critical missing words in the DRM task

Semantic Memory

In the semantic memory task, 46 questions tested general knowledge and 4 questions were semantic illusions. We calculated four dependent variables in total: percent correct, incorrect, and blank for the general knowledge questions and percent mislead for the semantic illusion questions.

On average, the subjects answered 48% of the general knowledge questions correctly, 15% incorrectly, and left the rest blank. Participants answered the semantic illusion questions incorrectly approximately 45% of the time. Since we were considering differences between the four groups, Figure 3 below displays the semantic memory results according to experimental condition.

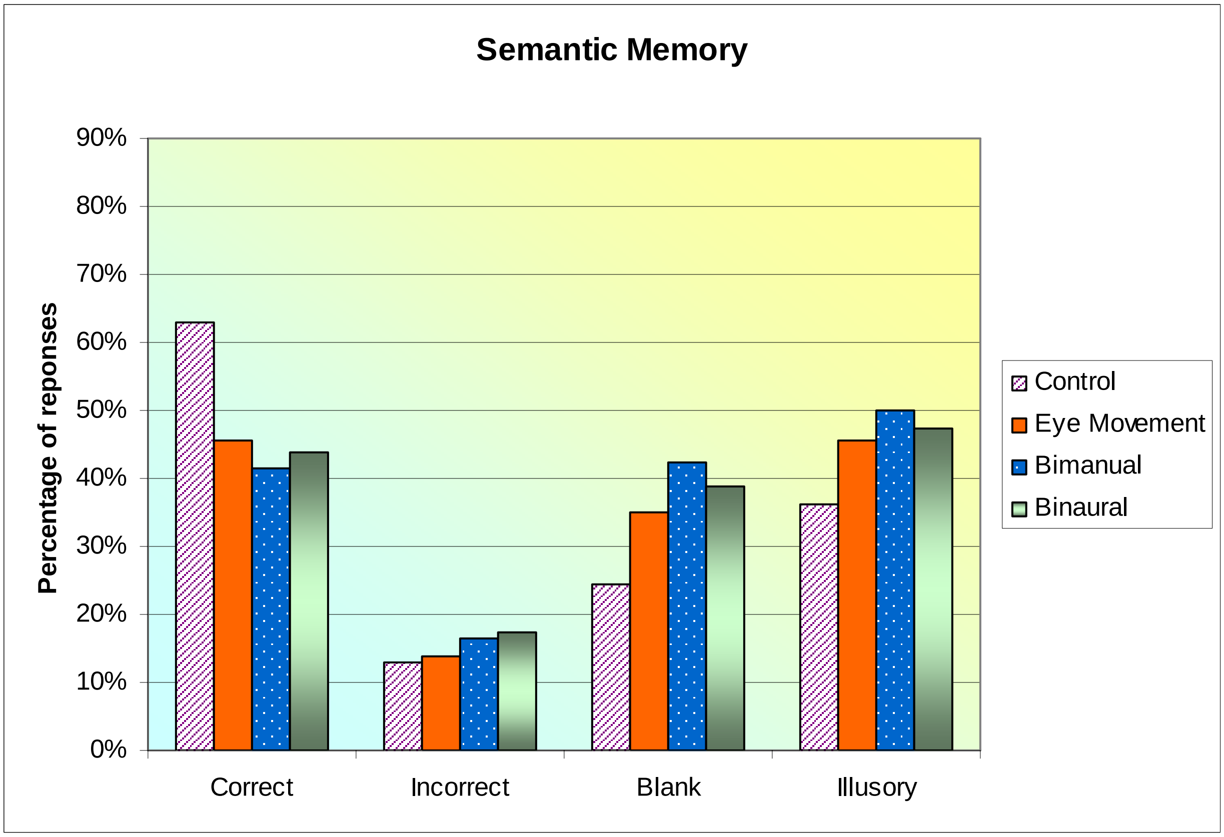

Fig 3. Percentage of semantic responses

An ANOVA reported a significant difference between groups [$F(3, 68) = 3.857$, $p < 0.013$], and a Fisher's LSD post hoc test revealed that the control group answered more questions correctly than the other three conditions (all p values < .02). No other differences were significant.

DISCUSSION

The data presented above do not support the findings of Christman et al., namely that increased interhemispheric interaction also increases memory retrieval. Although the present study tested several methods of stimulating interhemispheric interaction, including one put forth by Christman himself, the data show no evidence of increased memory performance across a wide variety of tests due to enhanced interhemispheric communication.

Tests

Episodic

The present study and the test done by Christman were very similar. Both used approximately the same number of words, the words were of moderate frequency, and both inserted an interim period between study and retrieval. Therefore, it is difficult to attribute the difference in findings to any difference between the procedures.

The findings of Christman et al. focused mainly on a decrease in the false alarm rate from 6.6% to 1.7%. First, both of these numbers are significantly lower than those found by the present study; this can be attributed to the difference in the time given to the participants to study each word: Christman gave each word 5 seconds, whereas the present study allowed only 1.5 seconds per word. It should be noted, however, that Christman's "increase in the hit rate" (page 224) was actually a negligible improvement, from 79.7% to 81.8%. It seems likely that if the horizontal eye movement done by Christman actually did increase the activity of the corpus callosum, linking the coding and retrieval centers of the brain, some increase in a subject's ability to recall words would result, leading to an increase in hit rate.

As seen in Figure 1, the only differences found among the episodic test conditions were in the binaural condition, which scored slightly lower. It is hypothesized that the harsh nature of the sound in the headphones may have disturbed some participants hearing it for the first time. It was found, however, that none of the actions intended to boost interhemispheric interactions had any positive effect on memory.

DRM

The present study also conducted a Deese-Roediger-McDermott (DRM) test, similar to Christman et al (2004). Here too, the results of the present study are inconsistent with their findings. Based on Christman's findings, it was hypothesized that interhemispheric interaction would decrease the number of successful critical lures. In fact, the DRM study further confirmed the findings of the episodic study, for again no evidence to support the idea of interhemispheric interactions boosting episodic memory was found (see Figure 2). Again, all groups did comparably in their hit rate, and no significant decrease in false alarms between the control and interhemispheric groups was found. As was expected, the hit rate increased and the false alarm rate decreased as compared to the pure episodic test (see Figure 1 and 2); this, however, is because of the related nature of the words used in the DRM study.

Also important to note is that the rate of susceptibility to critical lures was comparable across the conditions, again supporting the idea that the conditions designed to increase interhemispheric interactions did not improve the subjects' recall or discrimination. Christman's findings were that the number of critical lures falsely recalled decreased with eye movement, but that hits and false alarms experienced no change. This is unexpected, since the DRM study is another form of episodic study. Therefore it would seem that Christman contradicted himself and supported the findings of the present study, which found no benefit of interhemispheric interaction in either episodic or critical lures.

Semantic

The field of semantic memory was not tested by Christman et al., and so it was hypothesized that perhaps interhemispheric interaction would have some sort of impact on this area of memory as well. As seen in Figure 3, the results of the study found that the control group greatly outscored the interhemispheric groups; all three of the interhemispheric groups performed similarly to each other.

Another possibility, however, is that these tasks actually did stimulate interhemispheric interaction, as they were intended to. One of the studies that found episodic memory was located in both hemispheres, claims that "activity during semantic memory tasks has been almost always found in the left hemisphere but not in the right" [15].This would account for the limiting effect of interhemispheric interaction on semantic memory, since interhemispheric interaction would actually detract from the independent functioning of the single hemisphere. In light of the findings of the two episodic tests, it is uncertain whether the three test conditions did facilitate interhemispheric interactions, but such a hypothesis does account for the findings of the present study.

Another possibility for this finding is that, like the binaural group in the episodic study, the tasks that they had to perform were distracting or annoying.

<u>Conditions</u>

Eye Movement

Of the conditions tested by the present study, the eye movement is the most relevant and comparable, as this is the one proposed by Christman et al. to improve memory retrieval. Eye movements done by the two studies were very similar; both occurred twice per second for thirty seconds, and both followed similar eye angles: 27^{o} for Christman et al. and approximately 40^{o} for the present study. The difference in angle between the studies does not explain the discrepancy between the results, as a slightly larger movement should certainly not have any diminutive effect on interhemispheric interactions. Therefore these observations offer no insight as to why Christman obtained results different from those of the present study.

Other Conditions

To further examine the possibility of interhemispheric interaction boosting memory recall, other methods of stimulating both hemispheres were tried. Like eye movements, the movement of hands and the hearing of tones are controlled by the contralateral hemisphere, and so by the same principle as that which governs eye movement, these activities should also stimulate interhemispheric interaction. No evidence of such interaction was found. Both the bimanual and the binaural condition behaved very similarly to the control, with the exception of the episodic test, when, as mentioned above, the binaural activity might have been distracting. The rapid beeping sounds in the binaural activity command attention from the participants, causing them to focus entirely on the sounds rather than the words they just studied.

Final thoughts

Although bimanual movement, binaural stimulation, or active saccadic eye movements may stimulate interhemispheric interactions, these voluntary activities did not result in increased accurate retrieval. The brain’s process of retrieval memory is very complex, and merely performing simple activities did not improve recollection according to the findings in this study. The ideas upon which Christman’s study were based are found in a controversial technique used in the medical practice. Christman used the effectiveness of eye movement desensitization and reprocessing (EMDR) therapy to support the idea that horizontal saccadic eye movement can improve memory retrieval [2]. During EMDR therapy, posttraumatic stress disorder victims are treated by left-right eye movements to elicit past memories. Our findings do not support these ideas.

This study does not verify Christman’s findings. Future studies on memory may want to try to discover other techniques that positively affect memory. It would be exciting if something as simple as fist clenching or moving one’s eyes could improve memory, but as the results show, it is highly unlikely.

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APPENDICES

Appendix A: DRM lists used (critical non-studied word in caps):

WINDOW	SLEEP	SMELL	COLD	ROUGH	CUP	SOFT	SWEET
door	bed	nose	hot	Smooth	mug	Hard	sour
glass	rest	breathe	snow	Bumpy	saucer	Light	candy
pane	awake	sniff	warm	Road	tea	Pillow	sugar
shade	tired	aroma	winter	Tough	measuring	Plush	bitter
ledge	dream	hear	ice	sandpaper	coaster	Loud	good
sill	wake	see	wet	Jagged	lid	Cotton	taste
house	snooze	nostril	frigid	Ready	handle	Fur	tooth
open	blanket	whiff	chilly	coarse	coffee	Touch	nice
curtain	doze	scent	heat	uneven	straw	Fluffy	honey
frame	slumber	reek	weather	riders	goblet	Feather	soda
view	snore	stench	freeze	rugged	soup	Furry	chocolate
breeze	nap	fragrance	air	sand	stein	Downy	heart
sash	peace	perfume	shiver	boards	drink	kitten	cake
screen	yawn	salts	Arctic	ground	plastic	skin	tart
shutter	drowsy	rose	frost	gravel	sip	tender	pie

Appendix B: Semantic knowledge questions (Semantic illusions questions in italics)

1 What island is the largest in the world excluding Australia?
2 What is the unit of electrical power that refers to a current of one ampere at one volt?
3 What is the name of the ship on which Charles Darwin made his scientific voyage?
4 What is the last name of the author of the book “1984”?
5 What is last name of the man who was president directly after James Madison?
6 What was the last name of the man who was the radio broadcaster for the “War of the Worlds”?
7 What is the name of the Mexican dip made up with mashed up artichokes?
8 In which sport is the Stanley Cup awarded?
9 What is the name of the furry animal that attacks cobra snakes?
10 What is the name of the palace in London in which the monarch of England resides?
11 In the biblical story, what was Joshua swallowed by?
12 What is the name of the navigation instrument used at sea to plot position by the stars?
13 What is the last name of the man who first studied genetic inheritance in plants?
14 What is the name of Batman's butler?
15 Which country was the first to use gunpowder?
16 What is the proper name for a badminton bird?
17 What is the name of Germany's largest battleship that sunk in World War II?
18 What kind of tree did Lincoln chop down?
19 What is the last name of the astronomer who published in 1543 his theory that the Earth revolves around the Sun?
20 What was the name of King Arthur's sword?
21 What is the name of the kind of cat that spoke to Alice in the story “Alice's Adventures in Wonderland”?
22 What are people called who explore caves?
23 What is the last name of the man who assassinated president John F. Kennedy?
24 What is the name of the project which developed the atomic bomb during World War II?
25 What is the name of the organ that produces insulin?
26 What is the last name of the man who invented the telegraph?
27 What is the last name of the composer of the “Maple Leaf Rag”?
28 Who was known as “the father of geometry”?
29 What is the last name of the first signer of the “Declaration of Independence”?
30 What is the capital of Denmark?
31 Who was the most famous Greek doctor?
32 What is the last name of the man who wrote “Canterbury Tales”?
33 What was the name of the Zeppelin that exploded in Lakehurst, NJ in 1937
34 What are people who make maps called?
35 What is the unit of sound intensity?
36 What is the last name of the husband-wife spies who were electrocuted in 1951 for passing atomic secrets to Russia?
37 What is the last name of the man who wrote the “Star Spangled Banner?
38 What is the name of the mountain range in which Mt. Everest is located?
39 What is the last name of the woman who began the profession of nursing?
40 What is the palace built in France by King Louis the XIV?

41 What is the name of the mansion in Virginia that was Thomas Jefferson's home?
42 Of which country is Nairobi the capital?
43 What is the last name of the doctor who first developed a vaccine against polio?
44 What Italian city was destroyed when Mt. Vesuvius was erupted in 79 AD?
45 What is the name of deer meat?
46 What is the last name of the artist who painted “Guernica”?
47 What is the name of the first artificial satellite put in orbit by Russia in 1957?
48 What is the name of the 3-leaf clover that is the emblem of Ireland?
49 What is the name of the North Star?
50 What country was Tony Blair the president of?