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A mixed-handed advantage in episodic memory: A possible role of interhemispheric interaction

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Recent behavioral and brain imaging data indicate that performance on explicit tests of episodic memory is associated with interaction between the left and right cerebral hemispheres, in contrast with the unihemispheric basis for implicit tests of memory. In the present work, individual differences in strength of personal handedness were used as markers for differences in hemispheric communication, with mixed-handers inferred to have increased interhemispheric interaction relative to strong right-handers. In Experiment 1, memory for words was assessed via recall or word fragment completion. In Experiment 2, memory for real-world events was assessed via recall. Results supported the hypothesis, in that mixed-handers displayed better episodic memory in comparison with strong right-handers.

Christman and Propper (2001), in part on the bases of previous imaging literature (Cabeza & Nyberg, 2000; Tulving, Kapur, Craik, Moscovitch, & Houle, 1994) and previous examinations of split-brain patients (Cronin-Golomb, Gabrieli, & Keane, 1996; Zaidel, 1995), proposed that within Tulving's (1985, 1986) episodic–semantic memory framework, explicit tests of episodic memory involve greater corpus callosum–mediated interhemispheric interaction than do implicit tests of memory. In support of this hypothesis, Christman and Propper reported that individuals with familial left-handedness, a characteristic associated with lesser cerebral asymmetry and greater interhemispheric interaction (see, e.g., Gorynia & Egenter, 2000; Marino & McKeever, 1989; McKeever, Van Deventer, & Suberi, 1973), demonstrated superior performance on a test of episodic recall, in comparison with individuals without familial left-handedness. In a subsequent experiment, inter- versus intrahemispheric processing was directly manipulated by sequentially presenting stimuli to either the same visual field or different ones. Better episodic memory was associated with between-hemispheres presentation (different visual fields) of input, but semantic memory was superior for within-hemisphere presentations (same visual field); these results further support the hypothesis that interhemispheric interaction is associated with superior episodic memory (Christman & Propper, 2001).

Recently, Christman, Garvey, Propper, and Phaneuf (2003) demonstrated increased episodic memory for laboratory stimuli as well as for real-world autobiographical memories in individuals who had undergone a manipulation that has been proposed to increase interhemispheric communication. Specifically, it has been suggested that bilateral saccadic eye movements could temporarily increase interhemispheric interaction, and that this would in turn result in increased episodic memory. The rationale behind the eye movement manipulation derives from the fact that lateral eye movements result in selective activation of the contralateral hemisphere (Bakan & Svorad, 1969). It was thus assumed that bilateral eye movements would result in bilateral hemispheric activation, which in turn was hypothesized to facilitate interhemispheric interaction, and hence episodic memory.

In Christman et al.'s (2003) Experiment 1, participants who made saccadic left–right horizontal eye movements were better able to recognize previously presented words (episodic task) than were participants who made vertical or smooth pursuit eye movements. Furthermore, increased episodic memory ability following bilateral eye movements was not matched with increased implicit memory (as reflected in a word fragment completion task); that is, bilateral eye movements did not generally enhance overall performance, but rather enhanced only recognition of episodic-type memories, supporting the hypothe-

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ses that bilateral stimulation may increase interhemispheric interaction and that interhemispheric interaction is associated with increased episodic, but not implicit, memory performance.

In their Experiment 2, Christman et al. (2003) showed that these findings can be generalized from the laboratory to real-world autobiographical memories. For 1 week, participants kept a journal wherein they recorded 10 unusual events that happened to them. Participants then handed in their journals and, approximately 2 weeks later, engaged in either bilateral saccadic eye movements or central fixation for 30 sec, immediately after which they recalled the gist of as many items from their journals as possible. Results replicated those of the laboratory-based study, supporting the hypothesis that increased interhemispheric interaction is associated with superior episodic memory; individuals engaging in bilateral eye movements immediately prior to memory testing were better at recalling items from their journals than were individuals who did not make such eye movements. The present experiments used a similar methodology to determine whether personal handedness would produce the same pattern of results that was produced by the eye movement manipulation.

Personal non-right-handedness has been linked with increased corpus callosum size (Burke & Yeo, 1994; Clarke & Zaidel, 1994; Cowell, Allen, Kertesz, Zalatimo, & Denenberg, 1994; Habib et al., 1991; Kertesz, Polk, Howell, & Black, 1987; Witelson, 1985, 1989). Although the functional consequences of a larger corpus callosum have not been conclusively demonstrated, it has been suggested that increased size of this structure results in greater interhemispheric integration (Christman, 1993, 1995; Dimond & Beaumont, 1972; Honda, 1982; McKeever & Hoff, 1983; Moscovitch & Smith, 1979; Potter & Graves, 1988; Verillo, 1983). In fact, there is evidence that individuals with personal non-right-handedness do behaviorally demonstrate increased interhemispheric interaction (Christman, 1993, 1995, 2001; Hellige, 1993; McKeever, 1990), suggesting that corpus callosum size, indirectly assessed through measures of personal handedness, may be associated with increased integration of information between the cerebral hemispheres. In the present framework, such increased hemispheric interaction in non-right-handers would be associated with superior episodic, but not implicit, memory ability.

EXPERIMENT 1

Experiment 1 replicated the basic procedures of Christman et al. (2003), in that participants studied a list of words and were later given either explicit tests of recall (episodic memory) or word fragment completion tasks (implicit memory). The only changes involved the use of handedness instead of eye movements as a (quasi-) independent variable and the use of a recall rather than a recognition test. Recall may be a better measure of explicit/episodic memory than recognition, because recognition memory can be based on two distinct memory processes: explicit "remembering" of old items or implicit, familiarity-based "knowing" that old items had been previously encountered (e.g., Gardiner, 1988). Propper and Christman (2004) reported no difference in overall recognition accuracy between right- and non-right-handed individuals. However, they found a handedness difference in the extent to which recognition responses were based on judgments of implicit "knowing" versus explicit "remembering": Right- and non-right-handers were significantly biased toward "know" and "remember" responses, respectively. In order to provide a purer test of explicit/episodic memory, the present study used a test of recall.

Method

Participants. Ninety-eight undergraduate psychology students (68 women and 30 men) participated for extra course credit. Handedness was assessed via the Edinburgh Handedness Inventory (EHI; Oldfield, 1971). Individuals scoring $+85$ and above were considered strongly right-handed (SRH; $n = 46$), and those scoring between -80 and $+80$ were considered mixed-handed (MH; $n = 52$). There were no participants with scores below -80. This cutoff point for distinguishing between strong- and mixed-handedness was chosen because it represented the median EHI score for the sample, ensuring roughly equal numbers in both handedness groups. It should be noted that by this criterion, "mixed-handed" is not equivalent to "ambidextrous." The upper limit for classification as mixed-handed, an EHI score of $+80$, could be obtained by a person who always did nine of the ten assessed activities with the right hand and did only one with the left hand always. In essence, *mixed-handedness* refers to any pattern of hand use that involves some level of both left- and right-hand use, and *strong right-handedness* refers to virtually exclusive use of the right hand.

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

Stimuli consisted of 72 words and their corresponding fragments taken from Tulving, Schacter, and Stark (1982). Words ranged from seven to nine letters in length and were of moderate frequency. Each word fragment had only one correct way of being completed. The 72 words were divided into two lists of 36 words each. The 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, each was presented with 36 words. Each word was centrally presented on the screen for 5 sec and was automatically replaced by the next word on the list. The 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, the participants engaged in a filler task consisting of a series of personality questionnaires. The purpose of the questionnaires was to give the 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.

Immediately after the 30-min filler task, the participants were randomly assigned to one of the two memory task conditions, so that half of the participants completed a test of episodic memory (recall task) and half of implicit memory (word fragment completion). The participants in the episodic memory task were given a blank sheet of paper and asked to write down as many words as they could that had been presented at the beginning of the experimental session. The participants in the implicit memory task were presented with a list of 72 word fragments (taken from Tulving et al., 1982), half derived from the word list they had seen and half from the word list they had not seen. They were asked to complete as many fragments as they could. The participants generally took 5–10 min to complete the memory tests.

The following numbers of individuals were in each handedness × task group: MH recall task, $n = 29$; MH word fragment completion task, $n = 23$; SRH recall task, $n = 20$; SRH word fragment completion task, $n = 26$.

Results and Discussion

For the recall task, correctly recalled items were *hits* and false recalls 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. See Table 1 for means and standard error values as a function of task and handedness. Exploratory analyses of both the hit and false alarm variables indicated no significant main effects or interactions involving sex (all ps $> .289$). Subsequent analyses of variance (ANOVAs) were performed, with numbers of hits and false alarms as dependent variables and task (recall vs. fragment completion) and handedness (strong right vs. mixed) as between-subjects variables.

Analyses of the raw numbers of hits and false alarms for both tasks were conducted. Analysis of the hit rate yielded main effects of both task [$F(1,94) = 120.31$, $MS_e = 22.27$, $p = .0001$] and handedness [$F(1,94) = 4.81$, $MS_e = 22.27$, $p = .031$], indicating a higher number of hits in the word fragment completion task ($M = 19.1$) than in the recall task ($M = 10.8$) and a higher number of hits by the MH ($M = 14.8$) than by the SRH ($M = 12.6$) group. The interaction was not reliable, suggesting that mixed-handedness was associated with better performance on both tasks.

Analysis of the false alarm rate yielded a main effect of task [$F(1,94) = 110.88$, $MS_e = 6.47$, $p < .0001$] and a marginal main effect of handedness [$F(1,94) = 2.89$, $MS_e = 6.47$, $p = .09$]. The task main effect reflected a higher number of false alarms in the word fragment completion task than in the recall task. These main effects were qualified by an interaction between task and handedness [$F(1,94) = 6.59$, $MS_e = 6.47$, $p = .012$], reflecting a lower number of false alarms in the recall task for the MH ($M = 0.9$) than for the SRH ($M = 1.7$) group, and the fragment completion task yielded lower false alarm numbers (i.e., completion of nonstudied fragments) for the SRH ($M = 5.8$) than for the MH ($M = 7.7$) group. The fact that a task × handedness interaction was obtained for number of false alarms but not number of hits suggests that the handedness difference may reflect differences in source monitoring (which leads to fewer false alarms) more than it does differences in memory trace strength (which leads to increased hits); this finding is supported by a recent report that strong right-handedness is particularly associated with an increased tendency toward false memories (Christman, Propper, & Dion, 2004).

To assess overall accuracy on the recall task, we also analyzed corrected scores (see Graf & Mandler, 1984) that consisted simply of the number of hits minus the number of false alarms. A main effect of handedness was found [$F(1,47) = 4.57$, $MS_e = 19.57$, $p = .038$], reflecting better performance for the MH ($M = 8.5$) than for the SRH ($M = 5.7$) group. A comparable analysis for the fragment completion task, which yielded a measure of the increased tendency to complete fragments corresponding to studied relative to nonstudied items, showed no effect of handedness ($F < 1$). These results offer further support that individual differences in interhemispheric interaction, as inferred from participant handedness, modulate episodic memory performance per se rather than producing a general increase in memory ability or overall performance. The finding of handedness differences in the recall task but not the fragment completion task also suggests that there was little or no con-

Table 1
Mean Numbers of Hits and False Alarms (Completion of Nonstudied Words in the Fragment Completion Task in Experiment 1) and Corrected Scores (Hits Minus False Alarms), With Associated Standard Error (*SE*) Values, as Functions of Task and Handedness for Experiments 1 and 2

		Mixed-Handers		Strong Right-Handers	
Task	Measure	*M*	*SE*	*M*	*SE*
	Experiment 1 (Lab Based)				
Recall	Hits	9.4	1.025	7.4	0.888
	False alarms	0.9	0.570	1.7	0.494
	Corrected scores	8.5	0.965	5.7	0.836
Fragment completion	Hits	20.0	1.077	17.8	0.857
	False alarms	7.7	0.599	5.8	0.477
	Corrected scores	12.2	1.015	12.1	0.808
	Experiment 2 (Real World)				
Recall	Hits	6.2	0.326	5.2	0.320
	False alarms	0.2	0.191	0.7	0.188
	Corrected scores	5.9	0.405	4.6	0.398

tribution of episodic memory during fragment completion, despite the instructions to participants during encoding that the experiment involved a "memory test." If participants had been using episodic memories of the study items to guide their fragment completion, we would have expected a mixed-handed advantage in overall accuracy across both tasks.

Because degree of handedness can be conceived of as a continuous rather than a discrete dimension of individual difference, correlational analyses were also performed for each memory task. These analyses correlated numbers of hits and false alarms with both the raw and absolute values of the EHI scores. Scores for the EHI range from a minimum of -100 (perfectly left-handed) to $+100$ (perfectly right-handed). The current theoretical framework views variations in strength of handedness as existing on a continuous dimension. One anchor of this dimension is strong right-handedness, but there are two ways to think about the other anchor: One is fairly traditional, with left-handedness representing the other anchor point; this framework is exemplified by the raw EHI scores. The second is in terms of strength of handedness and uses scores collapsed across variations in direction of handedness; this framework is exemplified by the use of the absolute values of EHI scores, with scores ranging from 0 (perfectly ambidextrous) to $+100$ (perfectly single-handed). For the recall task, both the raw ($r = -.276$, $p = .055$) and the absolute ($r = -.306$, $p = .033$) values of the EHI scores were negatively correlated with number of hits—stronger degrees of right-handedness were associated with poorer recall performance. There were no significant correlations between the handedness scores and false alarm rates. Finally, there were significant negative correlations between the corrected scores and both the raw ($r = -.321$, $p = .024$) and the absolute ($r = -.563$, $p < .001$) values of the EHI scores. The fact that the correlations were stronger for the absolute than for the raw EHI scores indicates that handedness may best be thought of as ranging from perfectly mixed-handed (i.e., an EHI score of 0) to perfectly strong-handed (i.e., an EHI score of ± 100). For the fragment completion task, neither raw nor absolute values of the EHI scores were correlated with hit or false alarm rates.

Finally, analyses of the total number of word fragments completed were conducted, in order to rule out the possibility that non-right-handedness, although not associated with better implicit memory, may still have been associated with superior semantic memory as indexed by overall performance in fragment completion. An ANOVA revealed no difference between handedness groups in total number of fragments completed ($F < 1$).

EXPERIMENT 2

Experiment 1 replicated the findings of Christman et al. (2003), in that presumed greater interhemispheric interaction (as indexed by individuals engaging in bilateral eye movements in the former study and by mixed-handedness in the present experiment) resulted in superior episodic but not implicit memory for laboratory stimuli. Experiment 2 was designed to determine whether these findings would generalize to real-world, autobiographical memories, thus replicating the results of Christman et al.'s (2003) Experiment 2.

Method

Participants. Fifty-seven undergraduate psychology students (43 women and 14 men) participated in this experiment for course extra credit (the data for an additional 13 participants were dropped because of failures to follow instructions). Individuals scoring $+85$ and above on the EHI were considered strongly right-handed, and those scoring between -85 and $+85$ were considered mixed-handed. As in the previous experiment, this cutoff point was chosen because it represented the median EHI value in the sample. Only one individual scored below -85. Because there is evidence that the strongly left-handed differ from both the strongly right- and the mixed-handed, and thus may constitute their own group (e.g., Barnett & Corballis, 2002; Burnett, Lane, & Dratt, 1982; Christman, 1993; Ponton, 1987; Porac, 1993), this individual was eliminated from further analysis. These criteria resulted in 29 MH and 28 SRH participants.

Materials and Procedure. The 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 a participant's normal routine, and it was specified that the events could be mundane (e.g., stubbing one's toe) or highly significant (e.g., attending a funeral). The participants were asked to record the length of time elapsing between the occurrence of an event and its recording in the journal and to record events as soon as possible after they occurred. The participants also recorded the duration of the events themselves. Journals were handed in 7 days after the start of journal keeping. The participants were not informed that they would be tested for their memories of the journal entries.

Approximately 1 week after journal completion, the participants were tested for their memory for the journal events. They were instructed to recall the gist, in one or two sentences, of as many items from their journals as they could. The participants wrote down responses, with no time limit for task completion. The responses were scored by two judges as to whether or not they reflected an accurate recall of journal entries; judges were blind to the handedness of the participants. Only items on which both judges agreed were considered to be accurate.

Results and Discussion

For journal recall, correctly recalled journal entries were hits and recalled events that were not from the journal were false alarms. See Table 1 for means and standard errors of the mean as a function of handedness. Preliminary analyses of both the hit and false alarm variables indicated no main effect of nor any interactions involving sex, so subsequent ANOVAs were performed on numbers of hits and false alarms as dependent variables and handedness (strong right versus mixed) as a between-subjects variable.

Analyses of the number of hits yielded a main effect of handedness [$F(1,55) = 4.69$, $MS_e = 2.97$, $p < .035$], with mixed-handers having more hits ($M = 6.2$) than did strong right-handers ($M = 5.2$). Analyses of the false alarm data yielded a marginally significant effect of handedness [$F(1,55) = 3.44$, $MS_e = 1.02$, $p < .069$], with mixed-handers having fewer false alarms ($M = 0.2$) than did strong right-handers ($M = 0.7$). To assess overall accuracy in this paradigm, we once again used the corrected scores suggested by Graf and Mandler (1984); in the present paradigm, the maximum possible score would be a 10. The corrected scores yielded a main effect of handedness [$F(1,55) = 7.19$, $MS_e = 4.60$, $p < .010$], with mixed-handers having higher corrected accuracy scores ($M = 5.9$) than did strong right-handers ($M = 4.6$).

To analyze strength of handedness as a continuous variable, correlations were also computed between the absolute value of the EHI score and the dependent variables. Significant negative correlations were obtained between strength of handedness and both number of hits ($r = -.285$, $p < .050$) and corrected score ($r = -.331$, $p < .022$), reflecting an association between stronger degrees of handedness and poorer memory performance. A similar, albeit nonsignificant, positive correlation was found for number of false alarms ($r = .241$, $p < .099$), reflecting a nominal association between stronger degrees of handedness and increased likelihood of false alarms.

Post hoc analyses of handedness effects on the average recorded duration of events recorded in the log book and on the recorded time between a given event occurring and that event being recorded in the log book revealed no effect of handedness for both comparisons (Fs < 1, $N = 55$; 2 participants did not record the event duration or the amount of time elapsing between an event occurring and the recording of the event).

The results of Experiment 2 replicate findings of increased interhemispheric interaction being associated with superior episodic memory. Christman et al. (2003) demonstrated increased recollection for real-world experiences in individuals who underwent an experience that was proposed to increase interhemispheric communication in comparison with individuals who did not undergo such an experience. In the present study, personal handedness was used to infer levels of hemispheric interaction, with the result that mixed-handed individuals displayed the same type of superior recollection as those individuals who have previously been suggested to have increased interhemispheric interaction.

GENERAL DISCUSSION

The present set of experiments replicates and extends previous findings of an association between interhemispheric interaction and episodic memory ability. In the previous studies, interhemispheric interaction was assessed via bilateral presentation of stimuli (Christman & Propper, 2001), comparison of individuals with versus without familial left-handedness (Christman & Propper, 2001), or the use of bilateral eye movements (Christman et al., 2003). The present study used individual differences in personal handedness to infer differences in hemispheric communication. The results showed that the mixed-handed, those individuals who are thought to have increased corpus callosum–mediated hemispheric interaction, demonstrated superior recall of both laboratory-based and real-world autobiographical episodic memories relative to strongly right-handed individuals.

These behavioral findings are consistent with brain imaging results indicating that episodic and nonexplicit memory are associated with bihemispheric and unihemispheric activity, respectively (Cabeza & Nyberg, 2000). The results from the present study further serve to demonstrate the validity and utility of using handedness variables as markers for variations in the magnitude of interhemispheric interaction and for individual differences in episodic memory ability. At the very least, the present results suggest that handedness variables be controlled for in tests of cognition, particularly those involving a memory component. As they now stand, current models of episodic memory do not include parameters corresponding to interhemispheric interaction or handedness-mediated individual differences; the present results indicate that incorporating such factors could prove informative.

A possible explanation for the association between episodic memory and increased hemispheric interaction demonstrated by behavioral and brain imaging studies is that hemispheric interaction allows for the comparison of hemisphere-specific information necessary for accurate recall. For example, there is evidence that the presentation of a stimulus results in a sensory trace within the cortex (Fabiani, Stadler, & Wessels, 2000), and research has suggested that some increases in left hemisphere activity during veridical, as compared with false, recognition reflect the retrieval of sensory information encoded during stimulus presentation (Schacter et al., 1996). Likewise, increased right hemisphere activity during an episodic task has been suggested to reflect response set maintenance or postretrieval verification (Schacter, Buckner, Koutstaal, Dale, & Rosen, 1997). To the extent that the right hemisphere response set is able to be integrated with the left hemisphere sensory trace and that accurate recall relies on a comparison of hemisphere-specific information, increased interaction between the hemispheres could result in increased recall ability.

A more general and speculative conceptual account of the present findings can be found in analogy with hemispheric differences in figure–ground processing. Cronin-Golomb (1986) reported that although both hemispheres were proficient at processing the figure, there was a right hemisphere advantage in processing the background. This finding is reminiscent of other reports indicating a general right hemisphere advantage in processing the context in which stimuli are presented (e.g., Ornstein, 1997). In applying these findings to the topic of the role of interhemispheric interaction in episodic, but not implicit, memory, we start with Tulving's (1985, 1986) original idea that episodic memories are simply semantic memories with additional information about the time and/or place in which that information was originally encoded.

In this sense, the specific content of a memory (e.g., "I saw the word *apricot*.") corresponds to the figure, whereas the spatiotemporal information (e.g., "I saw that word 30 min ago while sitting in this room.") corresponds to the background. Thus, when a task does not require retrieval of the spatiotemporal context in which a stimulus is encoded, as in implicit memory during the fragment completion task, interhemispheric interaction is not necessary, and no handedness differences are observed. Only when the content of the memory needs to be explicitly matched with the context of encoding is interhemispheric interaction necessary, and handedness differences subsequently emerge. This framework, in essence, suggests that the mixed-handed advantage in episodic memory may reflect a more general mixed-handed advantage in metacognitive ability to access source memory (e.g., Shimamura, 2002). This idea is admittedly speculative, but it receives support from recent papers indicating a mixed-handed advantage in metacognitive processing (Niebauer, 2004; Niebauer & Garvey, 2004).

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