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The effect of bilateral eye movements on hypermnesia

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ABSTRACT

The effect of eye movement (bilateral/horizontal, vertical and central) on episodic memory was tested across a series of recall trials. Recall was measured in terms of correctly recalled items, item gain and item loss. It was found that bilateral eye movements enhanced the number of items correctly recalled; participants in the bilateral condition also displayed a significantly higher number of item gain (reminiscence) across the three trials. Participants in the vertical and central (no eye movement) conditions displayed no significant increase in the retrieval of episodic memories (or item gain) across trials. It was concluded that interhemispheric interaction plays a key role in episodic memory performance, whereby the greater the interaction, the more enhanced the memory performance.

KEYWORDS:	**EPISODIC MEMORY**	**HYPERMNESIA**	**HANDEDNESS**	**INTERHEMISPHERIC INTERACTION**

Introduction

In the last decade especially, there has been renewed interest in the effects of the interaction of the cerebral hemispheres upon memory processes. Although hemispheric interaction has proven to be strongly implicated in tests of some types of memory, this is not always the case. For example, there is very little verification of an associated link between hemispheric interaction and semantic memory; however, most of the research within this area supports the assumption that interaction directly influences episodic memory. Episodic memory refers to "a neurocognitive system... that enables human beings to remember past experiences" (Tulving, 2002, p.1) involving the retrieval of specific details (such as time and place), and there is continuously new evidence that indicates that the retrieval of episodic memories in fact depends on the interaction between the left and the right cerebral hemispheres (Christman, Propper & Brown, 2006).

In many previous studies, interhemispheric interaction has been induced by bilateral (horizontal) eye movements, relative to control conditions – vertical eye movements, central fixation and/or no eye movements. Christman, Garvey, Propper & Phaneuf (2003) found that engaging participants in thirty seconds of bilateral saccadic eye movements before testing selectively enhanced retrieval of episodic memory for both laboratory and everyday events, but vertical and smooth pursuit eye movements did not. Other research (Parker & Dagnall, 2007; Parker, Relph & Dagnall, 2008; Parker, Buckley & Dagnall, 2009) has also shown a significant effect of bilateral eye movements upon particular types of memory, such as contextual, associative and recognition memory, as well as a reduction in false memories and misinformation effects.

The apparent cause of such phenomena, in which bilateral eye movements are thought to improve episodic memory performance, can be explained as follows. It has been hypothesised that eye movements to the left or right field of vision "reflect activation of the cerebral hemisphere contralateral to the direction of gaze" (Ehrlichman & Weinberger, 1978, p.1080). Furthermore, saccadic eye movements are thought to generate more cortical activity (especially in the frontal lobes) than smooth pursuit eye movements (O'Driscoll, Strakowski, Alpert, Matthysse, Rauch, Levy & Holzman, 1998), and when performed repetitively, bilateral eye movements are presumed to activate both cerebral hemispheres simultaneously (Christman *et al*, 2003).

A theory which attempts to further explain these suppositions, saccadic induced retrieval enhancement (SIRE), was first introduced by Christman *et al* (2003), and was based on three central assumptions: firstly, that saccadic bilateral eye movements equalise activations of each hemisphere; secondly, that this equalisation allows for the hemispheres to work together more efficiently; and finally, that the cooperation between the hemispheres aids retrieval, because retrieval is a process that, to some extent, depends on hemispheric interaction. Although these suppositions seem to fit well with previous speculations into the mechanisms behind retrieval enhancement, Lyle & Martin (2010) determined that Christman *et al*'s (2003) attempts are limited in that each of their assumptions relies on the processes of "equalisation of activation levels" and "interhemispheric interaction" for which they have not provided a specified definition; additionally, these assumptions can also be questioned on the basis that there is very little evidence to show that the relationships between bilateral eye movements, equalisation of interhemispheric activation, enhanced interhemispheric interaction and superior episodic retrieval are in fact directly causal relationships. However, it should also be acknowledged that all subsequent researchers (including Lyle, Logan & Roediger, 2008) have favoured the interhemispheric interaction hypothesis notably in consideration of the cause of SIRE, despite its limitations, as there is abundant correlational data that suggests a positive association between the degree on interhemispheric interaction and episodic retrieval (Lyle & Martin, 2010).

Consistent with the current framework, Zaidel (1995) presented a review of memory processes in split-brain patients who have had their corpus callosum – the major pathway in the brain that allows interhemispheric interaction to occur – bisected (this is usually done in order to alleviate epilepsy). Split-brain patients have shown marked impairments in everyday memory tasks, such as details of current events, memory for time (e.g. appointments) and for space (e.g. parked car locations), as well as impairments in laboratory memory tasks, such as paired associate learning and memory for story passages, all of which are generally consistent with processes requiring episodic memory (Christman *et al*, 2006). Additionally, Zaidel (1995) reported that memory for such things as cooking recipes, categorical knowledge and historical events, which are consistent with semantic memories, were unaffected in split-brain patients. This provides further suggestion of the idea that semantic memory processes do not require interhemispheric interaction, but rather that they occur intrahemispherically, yet episodic memory is dependent upon the communication between the two hemispheres, and operates through interhemispheric interaction.

Lyle & Martin (2010) observed the effects of saccadic eye movements on simple letter-matching tasks that were performed under conditions that either required interhemispheric interaction (whereby participants were to identify matching uppercase and lowercase letters across opposite visual fields), or did not (here, matching letters were consistently presented within the same visual field). In a similar study, the results showed that split-brain patients are able to detect letter matches under conditions resembling those of within- but not across-hemisphere trials (Eviatar & Zaidel, 1994), supporting a greater role for interhemispheric interaction in the latter than the former (Lyle & Martin, 2010).

Further support for the interhemispheric interaction hypothesis arises from research into the effects of handedness on the retrieval of memories. Theoretically, handedness is assumed to have a similar effect upon memory as do saccadic bilateral eye movements; that is, handedness is theorised to induce superior retrieval of episodic memories, and is related to the interaction between the left and right cerebral hemispheres (Parker & Dagnall, 2010). The level of performance on some tests of memory is suspected to be dependent on the degree of handedness within individuals, i.e. whether individuals are “strongly” right lateralised in their handedness behaviour or not (Lyle, McCabe & Roediger, 2008). Previous research has found that strongly right (SR)-handed individuals perform less well on tests of episodic memory than individuals that are not strongly right (nSR)-handed (Propper, Christman & Phaneuf, 2005). Logically, in explaining these conclusions in terms of the interhemispheric interaction hypothesis, the findings can be based on two assumptions: firstly, that the degree of handedness affects the degree of hemispheric interaction in the brain, and secondly, that this interaction is somewhat related to the enhancement of memory retrieval (Lyle, McCabe *et al*, 2008). As with eye movements, whereby a particular directional gaze activates the contralateral hemisphere, hand preference is associated with the activation of the opposite cerebral hemisphere (Volkmann, Schnitzler, Witte & Freund, 1998). For example, a right-handed individual will be left hemisphere dominant for manual skills, and vice versa. This may also suggest that mixed-handed individuals are expected to perform better on tests of episodic memory due to the simultaneous activation of both cerebral hemispheres, and hence an increase in interhemispheric interaction.

Furthermore, researchers have been able to clarify these postulations in terms of neuroanatomical structures; the corpus callosum has been found to be smaller in SR individuals in relation to nSR individuals in many studies (Witelson, 1985; Habib *et al*, 1991; Cowell, Kertesz & Denenberg, 1993), thus perhaps allowing for a greater amount of interaction, and Cowell *et al* (1993) concluded that consistency of right-handed preference directly correlates with the size of the corpus callosum. However, there have also been a number of other studies that found an insignificant difference, or no difference at all, between handedness and the size of the corpus callosum (Kertesz, Polk, Howell & Black, 1987; Jäncke & Steinmetz, 2003).

One of the first models that attempted to explain the above theories and findings, especially those of SIRE and of handedness differences, was the hemispheric encoding and retrieval asymmetry model (HERA) model (Tulving, Kapur, Craik, Moscovitch & Houle, 1994), an idea which lies at the focus of active discussion surrounding the recent results of positron emission tomography (PET) and other neuroimaging studies. The term episodic memory is associated with the “activation” of prefrontal neural systems in the brain (Brewer et al, 1998). There is activation especially in the anterior half of both of the cerebral hemispheres, which is an evidently imperative area in the processes of memory encoding and retrieval (Babiloni, Babiloni, Carducci, Cappa, Cincotti, del Percio, Miniussi, Moretti, Pasqualetti, Rossi, Sosta & Rossini, 2004). Although semantic memories are more unilaterally localised (Christman & Propper, 2001), Tulving *et al* (1994) proposed that the left and right hemispheres (LH and RH), particularly the frontal lobes, are involved in episodic memory encoding and retrieval. Furthermore, it was suggested that the left prefrontal cortex was responsible for both encoding and retrieval processes; however, episodic encoding is more implicated in the LH, whereas episodic retrieval is more implicated in the RH (Tulving *et al*, 1994). Thus, episodic memories appear to be related to interhemispheric interaction, compared to semantic memories, which are believed to be associated with intrahemispheric interaction.

As mentioned above, the HERA model of interhemispheric interaction provides a logical explanation for differences in individual variables, such as handedness. Accordingly, it is highly possible that nSR individuals, especially mixed-handed individuals, perform better on tests of episodic memory than SR individuals due to the fact that ambidextrous individuals will not have a dominant hemisphere, but rather will use both equally, encouraging hemispheric interaction. In consideration of the HERA model as a rationalisation of the interhemispheric interaction account, it can also elucidate an answer as to why then, that left handed individuals also perform better than right handed individuals. As the theory claims that the LH is particularly important during encoding processes, and the RH is primarily implicated in retrieval processes, it follows that left handed individuals (with a dominant RH) should be able to retrieve more items on tests of episodic memory.

As well as the effects of handedness and eye movements upon episodic memory, the current study also focuses on the phenomena of memory enhancement over repeated tests - hypermnesia. A typical finding is that over a series of testing, participants may experience an increase in recall, i.e. may remember new items that were not remembered in the prior recall attempts (e.g. Tulving, 1967). However, although hypermnesia depends on reminiscence, repeated recall attempts also often include omissions from previously recalled information, and "for hypermnesia to be observed, the reminiscence of new information must also exceed forgetting" (La Rooy, Pipe & Murray, 2005, p.236). Many psychologists believe that repeated testing is most beneficial for recall as it requires individuals to retrieve information effortfully from memory, and the act of taking tests in succession may be a mechanism to permit memories to consolidate or reconsolidate (Dudai, 2006). In support of this proposition, Wheeler & Roediger (2006) presented results from a study which advocated that the number of recall tests given immediately after learning greatly enhanced recall performance on a similar test a week later, and it appeared that the act of taking more successive tests essentially halted the forgetting process and strengthened learned memories.

In their investigation of hypermnesia in children, La Rooy *et al* (2005) found that increased recall of new items only occurred when the participants were assessed immediately (through interviews directly after the event) and 24 hours later, but hypermnesia was not found when the children were interviewed 6 months after the event. These results suggest that repeated testing may result in enhanced recall only in relatively short-term conditions. Numerous studies into the underlying causes of hypermnesia have investigated possibilities such as increasing strength of imaginal traces during the retention interval of processing, and increased retrieval practice from prior tests (Roediger & Payne, 1982), though the reasons for hypermnesia are not yet clear. Results from a study by Erdelyi & Becker (1974) showed that repeated tests of words, without visual imagery, did not lead to improved recall across multiple trials, but repeated tests of pictures did, suggesting that imaginal traces play an important role in learning and memory. Accordingly, it has also been implied that hypermnesic effects are most noticeable relative to the "depth" of processing, which could explain the results of Erdelyi, Buschke & Finkelstein's (1977) experiment, which demonstrated that hypermnesia is more effective in picture rather than word (less deep processing) trials. Nevertheless, it was concluded that the effects of hypermnesia are not limited to only picture conditions, and further determined that subjects performed better in the Socratic condition (deepest cognitive processing, whereby participants were required to memorise personally generated solutions to riddles) than those in both the pictures and words condition (Erdelyi *et al*, 1977).

The present study was conducted with the aim of reconfirming the results and providing conclusions in accordance with previous research. Here, two key areas of cognition have been combined in the hope of providing greater understanding of the mechanisms underlying episodic memory processes. Although it has been abundantly suggested that interhemispheric interaction has a significant effect on the retrieval of episodic memories, very little research so far has investigated the effects of hypermnesia. It is hypothesised that this experiment will determine a significant association between bilateral eye movements and enhanced episodic memory over a series of repeated tests (hypermnesia); it is expected that participants in the bilateral condition will display significantly higher recall levels over the three trials, than those in the vertical and central conditions. Also, the degree of handedness for each participant was scored, and it was expected that nSR-handed individuals would display significantly higher recall levels than SR-handed individuals.

Participants were assessed on the number of items they correctly recalled, along with the number of new items (reminiscence; item gain) they recalled, and forgotten items (item loss) over three trials. Item gain refers to the number of new items recalled (in Recall 2 and Recall 3) that were not recalled in the previous trial(s), whereas item loss refers to the number of items forgotten (in Recall 2 and Recall 3), that were correctly recalled in the previous trial(s). Roediger & Payne (1982) claimed that “the conditions that most easily elicit the phenomena are those in which people are given a long series of pictures to recall” (p.66), and similar results were discovered by Erdelyi & Stein (1981). A series of 58 pictures were used as stimuli in the present study and participants were then tested three times, interspersed with two periods of eye movements; prior to the first test, a distracter task was presented in order to reduce recency effects.

Method

Participants

30 individuals, both students (of multiple universities) and non-students, participated in the study and their results were analysed. The mean age of the participants was 24.73 years and 53.33% were female. Handedness was assessed using the Edinburgh Handedness Inventory (EHI; Oldfield, 1971) which operates on a scale ranging from -100 (for consistently left-handed) to 100 (for consistently right-handed). The median of handedness scores for participants in this study was 87.50.

Design

The experiment had two independent variables, the first of which consisted of three levels: horizontal eye movement vs. vertical eye movement vs. no eye movement; the second independent variable was level of handedness (mixed-handedness vs. right-handedness). The dependent variable was the number of items recalled over three subsequent trials. The design was a 3 (eye movement condition: horizontal eye movement vs. vertical eye movement vs. no eye movement; between) x 3 (recall trial: recall 1 vs. recall 2 vs. recall 3; within) mixed factorial. Further ANOVAs were carried out for item gain – a 2 (gain 1 vs. gain 2; within) x 3 (eye movement condition; between) mixed factorial; and item loss – a 2 (loss 1 vs. loss 2; within) x 3 (eye movement condition; between) mixed factorial.

Apparatus & Materials

Before taking part in the study, participants read through an instruction sheet, which gave a brief overview of the procedure and explained that they had the right to withdraw from the experiment at any time. Participants were also presented with an experiment booklet, which contained: the handedness inventory, measuring the degree of handedness of each participant on a scale of -100 to 100; a distracter task, which required participants to name as many towns and cities in the UK as possible; and a recall sheet for each of the three trials. A slideshow made up of a total of 58 pictures was used as the stimuli. A computer programme was used in order to induce eye movements. The programme consisted of a small black circle on a white background, which flashed from side to side (horizontal condition), up and down (vertical condition) and in a fixed spot in the centre of the screen (central condition).

Procedure

All participants were tested individually. They were each given a briefing sheet, which notified them that their memory would be tested, and an experiment booklet (they were informed by the experimenter of when to turn the page). They were asked to complete the first page of the booklet, i.e., their age and gender, followed by watching the picture slideshow on a computer screen. The pictures were shown for 4 seconds each, with a blank slide in between each image shown for 2 seconds. Participants were then asked to complete a distracter task (although they were not made aware that this task was irrelevant to the main study), which required them to list as many towns and cities within the UK as possible within 5 minutes. Following this, they were given 5 minutes to list as many of the images from the slideshow as they could. This was succeeded by a trial of eye movements (bilateral, vertical or fixed) for 30 seconds. Again, participants were asked to recall as many of the original images as possible within a 5 minute time period, and this was followed by another eye movement trial. For each participant, the second eye movement trial was the same as the first, e.g. if the participant was in the bilateral eye movement condition, they would have experienced the bilateral eye movements on both trials. Finally, they were asked to complete a third recall of the images they saw in the slideshow for a further 5 minutes.

Results

Scoring

Participants' recall scores were the number of correctly recalled items (excluding any invented/falsely recalled items). Item gain scores were calculated by recording the number of new items recalled between the first and second trials (Gain 1), and between the second and third trials (Gain 2); similarly, item loss scores were calculated by recording the number of items that were forgotten between the first and second trials (Loss 1) and between the second and third trials (Loss 2).

Handedness[1] was scored on a scale of -100 to 100, with -100 referring to a consistently left-handed individual and 100 to a consistently right-handed individual.

Overall Recall

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[1] Handedness was eventually not assessed due to too few participants tested (eye movement conditions could not be further subdivided into SR- and nSR-handed individuals).

A 3 (Recall Trial: Recall 1 vs. Recall 2 vs. Recall 3; within) × 3 (Eye Movement: Central vs. Vertical vs. Bilateral; independent) mixed ANOVA was performed on the number of correct items recalled by participants (see Table 1).

Table 1
Mean and Standard Deviation for Correct Items Recalled across Eye Movement Conditions and Recall Trials

	Eye Movement Condition							
	Central		Vertical		Bilateral		Overall	
	M	SD	M	SD	M	SD		
	(*n = 10*)		(*n = 10*)		(*n = 10*)		M	SD
Recall Trial								
Recall 1	18.80	2.94	21.10	6.77	19.90	6.15	19.93	5.44
Recall 2	19.40	2.01	21.20	6.55	20.70	6.00	20.43	5.13
Recall 3	19.00	2.06	20.80	6.11	22.40	6.24	20.73	5.19
Overall	19.07	2.34	21.03	6.48	21.00	6.13	20.37	5.25

Considering that Mauchley's Test of Sphericity was significant, it was concluded that sphericity was not assumed; therefore, Greenhouse-Geisser values were employed in the analysis.

There was no main effect of Recall Trial, $F(1.65, 54) = 2.19$, $p > .05$, or of Eye Movement, $F(2, 27) = 0.47$, $p > .05$. However, a significant Recall Trial x Eye Movement interaction was observed, $F(4, 54) = 2.86$, $p < 0.05$. The interaction was explored using simple main effects analysis. Follow-up one-way ANOVAs were performed on each Eye Movement condition, assessing change across recall trials.

A significant main effect of Recall Trial was found for the bilateral eye movement condition only, $F(1.19,4) = 6.46$, $p < 0.05$. The difference between Recall Trials was examined using within subjects (paired) t-tests. These revealed there to be a significant increase in the recall of correct items between Recall 2 ($M = 20.70$, $SD = 6.00$) and Recall 3 (M = 22.40, SD = 6.24), $t(9) = -2.94$, $p = .008$ (one-tailed), Cohen's $d = 0.29$. No difference was observed between Recall 1 and Recall 2, $t(9) = -1.56$, $p > .05$.

No main effect in the vertical condition, $F(2,18) = 0.18$, $p > 0.05$, or in the central condition, $F(2,18) = 0.55$, $p > 0.05$.

Item Gain and Item Loss

A series of 2 (Item Gain: Gain 1 vs. Gain 2 / Item Loss: Loss 1 vs. Loss 2; within) × 3 (Eye Movement: Bilateral vs. Vertical vs. Central; between) ANOVAs were performed on the number or items gained and items lost over three recall trials (see Table 2).

Table 2
Mean and Standard Deviation Values for the Number of Items Gained and Lost Between Trials

	Eye Movement Condition							
	Central (n = 10)		Vertical (n = 10)		Bilateral (n = 10)		Overall	
	M	SD	M	SD	M	SD	M	SD
Trial								
Item Gain								
Gain 1	1.70	1.64	1.50	1.43	1.40	1.43	1.53	1.46
Gain 2	0.60	0.70	0.30	0.68	2.30	1.50	1.07	1.34
Overall	1.15	1.17	0.90	1.10	1.85	1.47	1.30	1.40
Item Loss								
Loss 1	1.20	1.40	1.10	1.10	0.60	0.70	0.97	1.10
Loss 2	0.80	1.03	1.20	1.32	0.60	0.70	0.87	1.04
Overall	1.00	1.22	1.15	1.21	0.60	0.70	0.92	1.07

Item Gain

There was no main effect of Item Gain, $F(1,27) = 2.62$, $p > .05$, or of Eye Movement, $F(2,27) = 2.34$, $p > .05$. However, a significant Item Gain x Eye Movement interaction was observed, $F(2,27) = 5.62$, $p < .01$. The interaction was explored using simple main effects analysis. The difference between Item Gain 1 and Item Gain 2 was examined using paired t-tests for each Eye Movement condition. These displayed that there was a significant increase from Gain 1 ($M = 1.40$, $SD = 1.43$) to Gain 2 ($M = 2.30$, $SD = 1.50$) in the bilateral eye movement condition, $t(9) = -2.59$, $p = .015$ (one-tailed).

There was a significant decrease from Gain 1 ($M = 1.50$, $SD = 1.43$) to Gain 2 ($M = .30$, $SD = .68$) in the vertical condition, $t(9) = 2.09$, $p = .033$ (one-tailed), and from Gain 1 ($M = 1.70$, $SD = 1.64$) to Gain 2 ($M = .60$, $SD = .70$) the central eye movement condition, $t(9) = 2.01$, $p = .038$ (one-tailed).

Item Loss

No main effects of Item Loss, $F(1,27) = .11$, $p > .05$, or for Eye Movement, $F(2,27) = 1.63$, $p > 0.05$. There was no significant Item Loss x Eye Movement inteaction, $F(2,27) = .27$, $p > .05$.

Discussion

Present Study Results and Previous Research

In the current study, the effects of saccadic eye movements on episodic memory performance, across a series of trials, was investigated. Although, there were no main effects of Recall Trial, or of Eye Movement, there was a significant interaction between these two variables. In the bilateral condition, which required completion of three picture recall trials, each separated by a 30-second period of horizontal eye movements, participants exhibited significantly increased recall across three trials. This finding supports the hypothesis that there is a significant association between bilateral eye movements and improved episodic memory retrieval performance. Additionally, as expected, there was no significant increase in recall across trials in the vertical and central eye movement conditions.

The significant effect of bilateral eye movements is in accordance with the results by Christman *et al* (2003), who also found that both vertical and central eye movements had no significant effect on the number of items correctly recalled. Given that saccadic eye movements generate a higher level of cortical activity than smooth pursuit eye movements (O'Driscoll *et al*, 1998), and that only horizontal eye movements induce the activation of contralateral hemispheres (Ehrlichman & Weinberger, 1978; Christman et al, 2003), the increase in episodic memory in the current study may have been due to the simultaneous, or even rapidly alternating, activation of both hemispheres (and therefore an increase in interhemispheric interaction), provoked by repetitive bilateral horizontal saccades. Although not a significant effect, participants in the vertical condition correctly recalled a higher number of items than those in the central condition (i.e. no eye movement), suggesting that any instance of eye movement may activate the cerebral hemispheres and therefore, increase the interaction between them. Taking into account that vertical and central eye movements did not produce a significant increase in episodic memory retrieval, it is possible to dismiss the idea that the improved memory effects demonstrated here was a result of non-specific enhanced oculomotor activity (Christman *et al*, 2003).

Moreover, in order to determine whether a hypermnesic effect occurred, it was necessary to acknowledge the number of items gained and lost between one trial and the next, as although participants may be able to recall many new items, it is imperative that previously recalled items were not forgotten. The results showed that there was a significant interaction between Item Gain and Eye Movement; however, a significant increase in Item Gain across trials was only identified in the bilateral condition. As the participants completed all recall trials immediately after (within 30 minutes) of memorising the picture stimuli in the present study, the significant increase in the number of items gained across the three trials is in compliance with the results of La Rooy *et al* (2005), who found that participants only demonstrated hypermnesic effects when assessed instantly (i.e. within 24 hours of the event stimuli). Although in the long-term experiment (up to 6 months), La Rooy *et al* (2005) observed that the amount of reminiscence was significantly smaller than that obtained in the shorter term experiment (up to 24 hours), they reported that participants still elicited new information after long delays, which allows for the conclusion that reminiscence is a reliable phenomenon in recall of past events over both short and long delays. Similary, Wheeler & Roediger (1992) emphasised the importance of the interval between successive tests as the critical factor, claiming that the interval must be short, on the order of minutes, for performance on successive non-cued tests to be significantly enhanced.

A detailed interpretation of hypermnesia was introduced by Raaijmakers & Shiffrin (1980), and was named the Search of Associative Memory (SAM) model. Within this model, it is assumed that retrieval of information from long term memory is a cue-dependent process (Tulving, 1974), whereby probe cues are 'assembled in short term memory, and these probe cues guide the sampling of items from long term memory' (Payne, Hembrooke & Anastasi, 1993, p.58). Such cues could be, for example, general contextual cues from the testing environment, other list items, and (if applicable) category labels from categorised lists. The SAM model operates on two supposed processes: incrementing and alternate retrieval routes. The former refers to the strengthening of the retrieved items, and of the association between the item and the cues present in short term memory when the item is recovered; the latter refers to the 'notion that that items not recovered when a given set of retrieval cues is present in short-term memory may be recovered later if at least one of the cues in the set changes' (Payne *et al*, 1993, p.58). Raaijmakers & Shiffrin (1980) claim that the largest hypermnesic effect occurs when both of these processes are operational, the smallest effect occurs when only one is active, and when neither of these process are operational, no increase in recall across a series of tests is observed. As all three of the trials in the present study took place in exactly the same environment as the participants viewed the stimuli, the SAM model provides an appropriate explanation for the underlying mechanisms of hypermnesia.

In consideration of extra research into hypermnesic effects, tests into cued recall and recognition (rather than free recall) may be valuable, as there are very few studies that have investigated hypermnesia in these types, and mixed results have so far been obtained (Erdelyi & Stein, 1981; Otani & Hodge, 1981; Payne & Roediger, 1987; Payne *et al*, 1993). Additional studies should aim to clarify the distinction between hypermnesia in free recall, and in cued recall/recognition.

The current results, on the other hand, revealed that there was no main effect for Item Loss, nor was there a significant interaction between Item Loss and Eye Movement. From this, it can be concluded that there were clear hypermnesic effects shown by participants in the bilateral condition, providing additional evidence in support of the hypothesis.

The paired t-tests performed on the bilateral condition revealed that there was a significant increase in the number of items recalled correctly between Recall 2 and Recall 3; however, there was no difference between Recall 1 and Recall 2. This result may generally be unexpected, due to the fact that as more trials are completed, and subsequently more new items are remembered, there are decreasingly fewer new items remaining that are available for recall with each trial. Thus, it would be anticipated that more new items would be recalled between Recall 1 and Recall 2 than between Recall 2 and Recall 3. A further expansion of this (which would also be especially beneficial in analysing item loss and item gain) may be to develop an alternative method of calculating the variation in scores; for example, noting the proportion of remaining items that the participant correctly identified for each trial, rather than the raw number of new items recalled, may provide a more representative analysis.

Overall, the results are in accordance with research concerned with theories that express the importance of interhemispheric interaction in complex memory processes, especially in memory retrieval. For example, in comparing the general finding – that participants in the bilateral condition exhibited greater levels of item recall – with the assumptions of SIRE – that bilateral eye movements equalise hemispheric activation, which allows for a more efficient interaction, and therefore acts as an aid towards any process that is dependent on interhemispheric interaction (Christman *et al*, 2003) – it may be suggested that this model provides a valid and coherent explanation of the processes that have produced these results. It follows that, if this account was to be true, it can be assumed that the retrieval of episodic memories is somewhat reliant on efficient interhemispheric interaction (Christman & Propper, 2001). This description would be applicable as a clarification of the processes underlying the phenomena of episodic memory enhancement. Considering that research into the difficulties that split-brain patients experience on tests of episodic memory (Christman *et al*, 2006) has shown that these individuals are unaffected on memory tasks requiring semantic knowledge, this provides further support for the assumption that semantic memory is heavily dependent on interhemispheric interaction.

The results of the present study also supply general support for the HERA model of interhemispheric interaction (Tulving *et al*, 1994). However, as the HERA model promotes that episodic encoding is implicated more in the left hemisphere, and episodic retrieval in the right, minor adjustments could be made to the current methodology in the hope of enhancing the results further. It could be proposed that, rather than all participants only experiencing two 30-second sessions of eye movements, it may be worth having half of the participants experiencing three 30-second sessions; the first of which could take place prior to the picture stimuli, and the following two sessions would take place at the times demonstrated in the current study (i.e. after Recall 1 and after Recall 2). The benefits of this modification may be that, in reference to the HERA model, engaging in bilateral eye movements before the stimuli are presented may allow for a more enhanced encoding process, whereas in the present study, it would appear logical that only the retrieval process is being affected by engaging in eye movement. Also, through extended repetition, this adjustment may eventually provide a more efficient interaction between the encoding and retrieval processes in the succeeding recall trials. Conversely, adding extra tasks to the procedure would make the experiment even more time consuming than it already is.

The results of the present study have important practical implications for the mechanisms underlying eye movement processes and the retrieval of episodic memories. Eye movement desensitisation and reprocessing (EMDR; Shapiro, 1989), which is often considered a controversial therapy technique, is a treatment method currently used for post-traumatic stress disorder (PTSD) (Christman *et al*, 2003). Sufferers of PTSD often have serious difficulty in the voluntary retrieval of the traumatic memory; the procedure of EMDR treatment involves alternating left-right eye movements (as in the current study), which aims to make the memories more readily accessible and assist patients in recovering them. This type of treatment assumes that bilateral eye movements increase interhemispheric interaction, and thus supposes the enhanced retrieval of memories due to this interaction.

Kitayama, Brummer, Hertz, Quinn, Kim & Bremner (2007) reported that the posterior midbody was of a smaller ratio to the total size of the corpus callosa in PTSD compared to healthy individuals, which suggests that PTSD may be characterised by a dysfunction in hemispheric interaction. Therefore, the use of bilateral eye movements is expected to induce interhemispheric interaction and enhance retrieval of memories via an otherwise limited process. However, the success of EMDR treatment so far is dubious, as ‘many of the experimental and clinical protocols used in EMDR research and therapy appear to use smooth pursuit, and not saccadic, eye movements’ (Christman & Propper, 2008). Of course, this creates a problem in being able to determine the underlying mechanisms of EMDR treatment at this point, and further research is required to distinguish between the results of EMDR using both saccadic and smooth pursuit eye movements.

Further Limitations/Improvements

Two main methodological issues have been identified. Firstly, as with many experiments, it is difficult to determine how reliable this type of testing is within the given settings. It was stated by Roediger, Agarwal, Kang & Marsh (2010) that learning is, more often than not, self-regulated, e.g. the learner decides what to study, how long to study for, and the kinds of methods to use whilst studying, etc. All of these factors are structured around the learner’s personal goals, beliefs and time constraints. In the present study, although participants were assessed in their natural settings, they were under pressure to remember as much of the stimuli as possible within a short period of time, which may have had an effect on the results that they produced. In addition to this, all participants will have had varying strategies for learning and memorising material, some of which may have been restricted by the constraints of the current experiment.

Secondly, it may be of interest in future experiments to include corrective/positive feedback in between recall trials, which may be expected to aid the retention of the target information. Roediger *et al* (2010) assert that ‘although most evidence suggests that tests require effortful retrieval yield the most memorial benefits, it should be noted that this depends upon successful retrieval on the initial test (or the delivery of feedback)’ (p.19), supposing that if participants informed of which items they have correctly recalled, they are more likely to retain that material and recall it on subsequent trials. They also conclude that ‘for the testing effect to manifest itself fully, feedback must be provided if initial test performance is low’ (p.20), claiming that low scorers will benefit more from corrective feedback, and are therefore more likely to experience a hypermnesic effect.

Conclusion

The conclusions drawn from the present study have provided further support for the expected association between bilateral eye movements, enhanced episodic memory retrieval and hypermnesia. It was demonstrated that the increase in memory retrieval was limited to bilateral eye movements only, and that hypermnesic effects were apparent only in the bilateral condition. Using interhemispheric interaction theories (such as SIRE and the HERA model), it was predicted which conditions would, and which would not, show the interaction effect. If future research also provides results in support of the theory, eye movements may further emerge as a methodologically convenient aid that gives rise to the investigation of how interhemispheric interaction can so greatly affect memory retrieval.

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