



# Drawing improves memory in patients with hippocampal damage

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## Abstract

The hippocampus plays a critical role in the formation of declarative memories, and hippocampal damage leads to significant impairments in new memory formation. Drawing can serve as a form of multi-modal encoding that improves declarative memory performance relative to other multimodal encoding strategies such as writing. We examined whether, and to what extent, patients with hippocampal damage could benefit from the mnemonic strategy of drawing. Three patients with focal hippocampal damage, and one patient with both hippocampal and cortical lesions, in addition to 22 age-, sex-, and education-matched controls, were shown a list of words one at a time during encoding and instructed to either draw a picture or repeatedly write each word for 40 s. Following a brief filled delay, free recall and recognition memory for words from both encoding trial types were assessed. Controls showed enhanced recall and recognition memory for words drawn versus those that were written, an effect that was even more pronounced in patients with focal hippocampal damage. By contrast, the patient with both hippocampal and cortical lesions showed no drawing-mediated boost in either recall or recognition memory. These findings demonstrate that drawing is an effective encoding strategy, likely accruing from the engagement of extra-hippocampal processes including the integration of cortical-based motor, visual, and semantic processing, enabling more elaborative encoding.

**Keywords** Drawing effect · Hippocampus · Memory · Encoding · Cortical plasticity

## Introduction

The use of drawing as an encoding technique that creates contextually rich representations and increases memory performance has recently been highlighted (Fernandes et al., 2018). In a series of studies, Wammes et al. (2016,

2019) showed that compared to writing, drawing target words improves both free recall and recognition memory performance, indicating its beneficial effects at encoding. Furthermore, encoding-related drawing benefits are greater than semantic elaborative encoding of the to-be-remembered words, and were robustly demonstrated in different contexts and study designs (Wammes et al., 2016, 2018).

Wammes et al. (2019) suggest that drawing may be particularly effective as it integrates visual, motor, and semantic components of studied material, as well as elaborative strategies. Engaging multiple distinct cognitive processes or sensory modalities during encoding is purported to be key in improving both the quality and quantity of memory. For example, semantic elaboration or deep encoding is known to provide significant benefits to memory ( Craik & Lockhart, 1972). Generating to-be-remembered information can also enhance encoding relative to simply reading (Slamecka & Graf, 1978). The picture-superiority effect (Paivio et al., 1968; Paivio 1971) is attributed to ‘dual-coding’: pictures can be represented in terms of visual features and also verbal labels (Paivio et al., 1968), whereas words are represented primarily using only verbal codes. Overt

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production, in which materials (i.e., words) are read aloud during encoding, also improves retention relative to words read silently (MacLeod et al., 2010). Similarly, enactment (Engelkamp & Zimmer, 1997), when one performs a bodily action that depicts the meaning of a to-be-remembered target word, benefits subsequent memory relative to simply reading it. The act of drawing, as a means to encode a new target word, amalgamates each of these encoding strategies to create more distinct memory representations, which may reduce output interference between similar representations (Wammes et al., 2016). Output interference refers to the phenomenon in which the retrieval of specific information from memory is disrupted or impaired due to the presence of similar or competing information in memory; it has been demonstrated in the recall of word lists. However, when to-be-remembered information is drawn instead of written, output interference diminishes (Wammes et al., 2016). This finding has been attributed to the advantage that drawn information creates a distinct representation, as well as the fact that output interference can prevent the recall of written words at a later time (Wammes et al., 2016).

The mnemonic benefits conferred by drawing have recently been documented in both healthy older adult populations (Meade et al., 2018) and individuals with probable dementia (Meade et al., 2020). Areas in the brain that are often affected in those experiencing memory disorders include the frontal and medial temporal lobes (MTLs), and specifically the hippocampus and entorhinal cortex in the MTLs (Clark & Maguire, 2016; Eichenbaum, 2004; Gomez-Isla et al., 1996), while primary visual cortices and the ventral visual pathway are typically less affected (Arndt et al., 1996). Given this, one interpretation for why patients with memory disorders have been shown to benefit from studying pictures compared to words is that the former engages intact areas of the brain to represent visual perceptual features of to-be-remembered information (Ally et al., 2009), allowing for better retention of studied items.

Damage to the hippocampus can lead to profound impairments in the encoding, maintenance, and retrieval of newly learned information (Aggleton & Brown, 1999; Rosenbaum et al., 2012; Squire, 1992; Squire & Zola, 1996). The hippocampus is critically involved in the formation of memories by binding together distinct memory elements from separate inputs and enabling the relation between various scenes or events (Cohen & Eichenbaum, 1995; Cohen et al., 1999). This relational property of hippocampal memories might explain the disproportionate preservation of single-item recognition memory compared with free recall in patients with damage restricted to the hippocampal formation (e.g., Aggleton et al., 2005; Mayes et al., 2002; Vann et al., 2009; Waidergoren et al., 2012). Indeed, it has been argued that while the hippocampus is required for supporting recall, single-item recognition can be supported by extra-hippocampal medial temporal cortices

(Aggleton & Brown 1999; Eichenbaum et al. 2007). We therefore tested memory using both free recall and recognition in the present study.

One important function of the hippocampus in memory is that it protects memories from interference as representations of context-dependent memories undergo pattern separation depending on their overlapping components (Rolls & Kesner, 2006; Rolls, 2013; Yassa & Stark, 2011). The hippocampus allows for pattern separation, thus enhancing memory specificity by protecting from interference from similar events with overlapping features (Favila et al., 2016; Koolschijn et al., 2019). Interference resolution can be performed either by hippocampal pattern separation or by cortical inhibition of overlapping representations (Nee et al., 2007). It is possible that drawing may promote cortical learning even when hippocampal input is minimal, by making the information more distinct (Hebscher et al., 2019), and thus minimizing the impact of cortical inhibition on overlapping representation in learning (Hebscher et al., 2019; Wing et al., 2022).

The drawing effect has yet to be examined in patients with hippocampal lesions. Gesturing, a somewhat analogous active encoding strategy, has been shown to benefit such patients (Hilverman et al., 2018). This effect was attributed to the engagement of brain regions outside of the hippocampus (e.g., striatum), which may support encoding by calling on semantic knowledge or motor skills (Hilverman et al., 2018). As drawing is also believed to engage non-hippocampally mediated processes and representations, such as motoric and visuo-spatial, hippocampal patients may benefit from drawing-based memory-encoding strategies.

The goal of this study was to determine whether patients with hippocampal lesions and memory impairment may benefit from the mnemonic effects of drawing. Based on the evidence that non-hippocampally mediated, multi-process and multi-modal encoding approaches enhance memory performance, we predict that patients with hippocampal dysfunction will benefit from the mnemonic effects of drawing and display enhanced recall and recognition performance for words drawn compared to written during encoding. If this hypothesis is supported, the findings would suggest that multi-modal encoding requires less hippocampal involvement to support successful encoding. We examined this possibility by contrasting memory performance in hippocampally lesioned patients, and with a patient with both hippocampal and neocortical damage.

## Materials and methods

### Participants

This case-controlled study design involved participation from four patients with hippocampal lesions, one patient

with additional cortical lesions, along with a sample of 22 age-, sex-, and education-matched controls. Eight controls were tested during the COVID-19 pandemic and therefore completed testing remotely through video-conference. Controls were matched to the patients on age ( $\pm 5$  years), years of education ( $\pm 2$  years) and sex. Eight males were matched to the male patients and 14 females were matched to the female patient (Table 1), all recruited from the Baycrest Research Participant Database at the Rotman Research Institute at Baycrest Hospital. All participants signed informed consent forms prior to participating in the study and were compensated with a \$15 Amazon e-Gift card for their participation.

Patients' neuropsychological assessments had all been conducted within the previous 2 years, except DA whose neuropsychological data were 5 years old and, in all cases, testing was conducted well into the chronic stage of their injury (see Fig. 1 and text below). Consistent with a diagnosis of anterograde amnesia, all patients had clinically significant deficits on measures of delayed memory but were within normal limits on measures of general intellectual ability, attention, and executive functioning. Performance on measures of immediate memory was more variable (see Fig. 1 and text below). Patients all had significant hippocampal damage (Table 2) but differed in terms of the extent of damage to other cortical structures in the medial temporal lobe (MTL) and temporal pole (Table 2; see details of individual patients below).

Patient GP is a 53-year-old right-handed male with 13 years of education who suffered bilateral hippocampal anoxic damage following cardiac arrest due to a pulmonary embolism in 2019. GP managed to call 911 and firefighters who arrived at his apartment, witnessed his collapsed, and performed CPR. He has not been previously reported, and Fig. 2 shows a sample image of his hippocampal volume reduction. Volumetric analysis of his hippocampi (See Stamenova et al., 2018 for details) revealed a decrease of about 40% bilaterally, as well as a decrease of about 30% in volume of the entorhinal cortex bilaterally, while the perirhinal and anterior temporal cortices were normal in volume (Table 2). Clinical MRI also demonstrated small punctate foci of increased T2/FLAIR

signal with faint associated restricted diffusion involving the left anterior thalamus suggestive of acute or subacute small vessel infarction. Clinical neuropsychological assessment demonstrated significant immediate and delayed memory impairment in both the verbal and the visual domains, but relatively preserved executive and attentional functioning as well as overall IQ (Fig. 1).

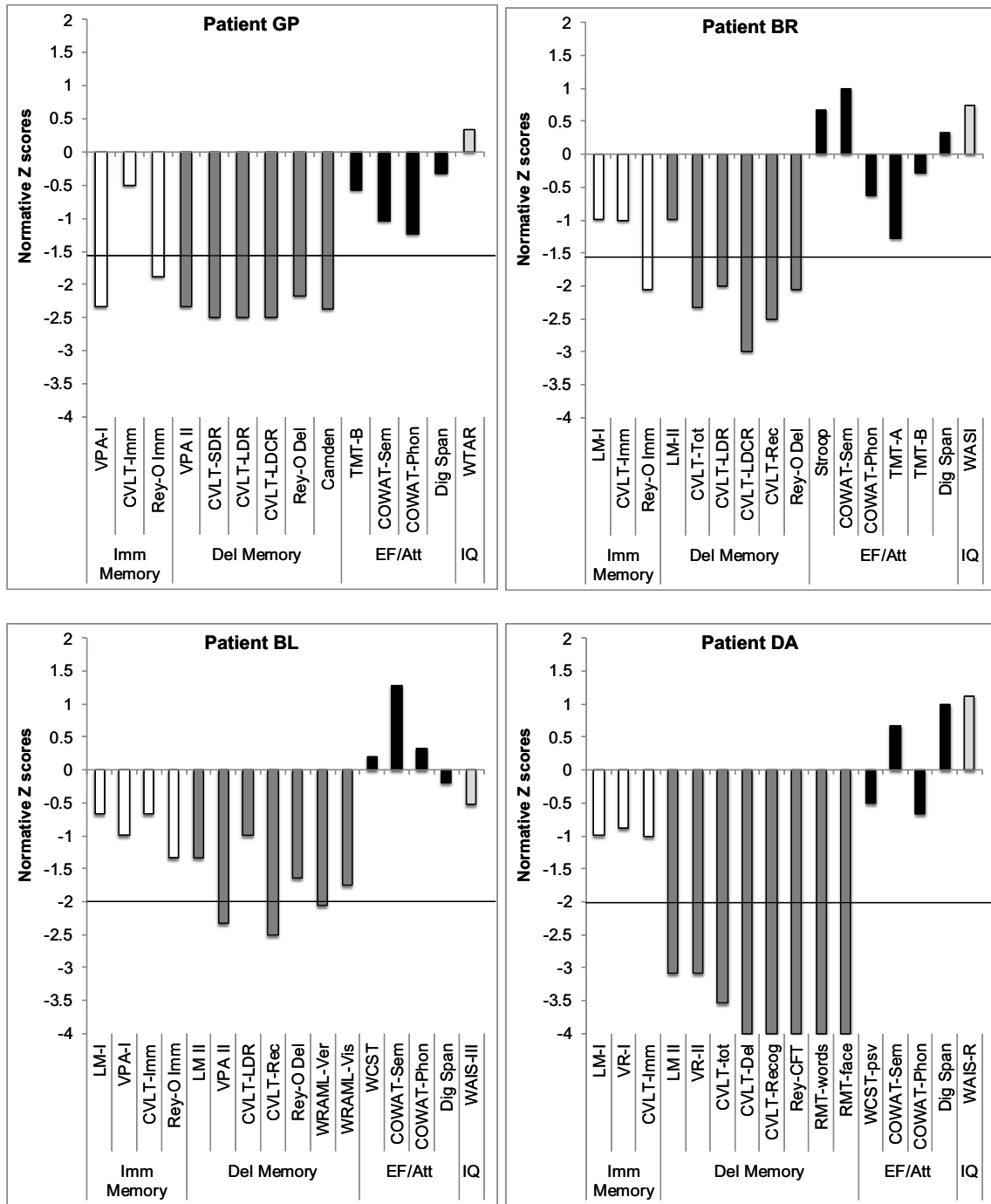
Patient BR is 40-year-old right-handed female with 16 years of education. At the age of 18 years, BR suffered from anoxia due to a meperidine overdose, which resulted in bilateral hippocampal damage. She has not been previously reported in detail (but see Marlatte et al., 2023) and Fig. 2 shows a sample image of her hippocampal volume reduction. Specifically, reduced hippocampal volume was seen at approximately 23% on the left and 45% on the right hippocampus, which appeared to be preferentially driven by loss of volume to the CA1 field (Table 2). In addition, clinical MRIs demonstrated small globus pallidus lesions and possible cerebellum degeneration. BR was able to complete an undergraduate degree with significant support after the onset of her memory disorder. Clinical neuropsychological assessment demonstrated significant anterograde memory impairment, more pronounced after a delay, but intact executive and attentional functioning as well as normal IQ (Fig. 1).

Patient BL is a 61-year-old right-handed male with 13 years of education whose anatomical and neuropsychological profiles have been extensively described in the past (Baker et al., 2016; Mitchnik et al., 2022). BL was diagnosed with anoxic brain injury following an electrical injury and cardiac arrest. This incident resulted in bilateral ischemic lesions in the hippocampus, particularly affecting the dentate gyrus, and a portion of the CA3, while the CA1 subfield and surrounding entorhinal and perirhinal cortices were relatively spared. Furthermore, volumetric analysis of BL's hippocampus and surrounding MTL cortices displayed decreased size of the dentate gyrus (approximately 50% smaller), while the CA1 subfield was 8% larger (Baker et al., 2016). BL's immediate memory functioning is within the low-average range, while his delayed memory functioning is mostly within the borderline to impaired range (Fig. 1).

Patient DA is a 59-year-old right-handed male with 17 years of education. In 1993, DA contracted herpes encephalitis, which resulted in bilateral hippocampal lesions and cortical damage. In the MTL, DA's lesions, which have been described in detail by Rosenbaum et al. (2008) and Ryan et al. (2013), include complete damage to the right hippocampus and parahippocampal gyrus (including perirhinal, entorhinal, and parahippocampal cortices) and the right anterior temporal lobe. On the left, more than two-thirds of his hippocampus is damaged, as well as most of the left perirhinal and parahippocampal cortices (Table 2). Outside of the MTL, volume loss was found in the ventral frontal cortex, anterior cingulate cortex, anterior and

**Table 1** Demographic information for patients and controls (standard deviation in brackets)

	Age, y	Gender	Education, y
Patient GP	53	Male	13
Patient BR	40	Female	16
Patient BL	61	Male	13
Patient DA	59	Male	17
Controls Female/Male	41.36 (3.29)/ 56.62 (4.59)	14/8	15.71 (1.06)/ 17.13 (1.24)



**Fig. 1** Patients’ performance on clinical neuropsychological tests. *Note:* Neuropsychological test scores are noted in normative Z scores. Abbreviations: Verbal Paired Associates (VPA), California Verbal Learning Test (CVLT), Rey-Osterrieth Complex Figure Task (Rey-O), Logical Memory I & II (LM) from the Wechsler Memory Scale, Controlled Oral Word Association Test (COWAT), Trail Making Test (TMT), Wide Range Assessment of Memory and Learn-

ing (WRAML), Wisconsin Card Sorting Test (WCST), Recognition Memory Test (RMT), Verbal Recall (VR), Wechsler Test of Adult Reading (WTAR), Digit Span (Dig Span), Wechsler Abbreviated Scale of Intelligence (WASI), the Wechsler Adult Intelligence Scale (WAIS), Immediate Memory (Imm Memory), Delayed Memory (Del Memory), Executive Function/Attention (EF/Att), Intelligence Quotient (IQ)

posterior temporal cortex and occipital cortex, as well as small lesions in the right posterior thalamus (Ryan et al., 2013). Despite the pervasive neurological damage, DA’s

neuropsychological functioning is relatively preserved, with normal levels of IQ, executive, and attentional functioning and even immediate memory (Fig. 1). He suffers severe

**Table 2** Volumes of hippocampus, medial temporal lobes cortices, and temporal poles of patients as percentage of matched controls' volumes

	Hippocampal	Hippocampal subfields	Perirhinal cortex	Entorhinal cortex	Temporal pole
BL <sup>1</sup>	--	50% CA23/DG 108% CA1	98% left 107% right	97% left 107% right	--
BR <sup>2</sup>	77% left 56% right	91% CA23/DG 57% CA1	130% left 122% right	84% left 108% right	91% left 112% right
DA <sup>3</sup>	26% left 4% right	--	0% left 0% right	25% left 0% right	115% left 17% right
GP	60% left 59% right	--	103% left 101% right	66% left 72% right	93% left 104% right

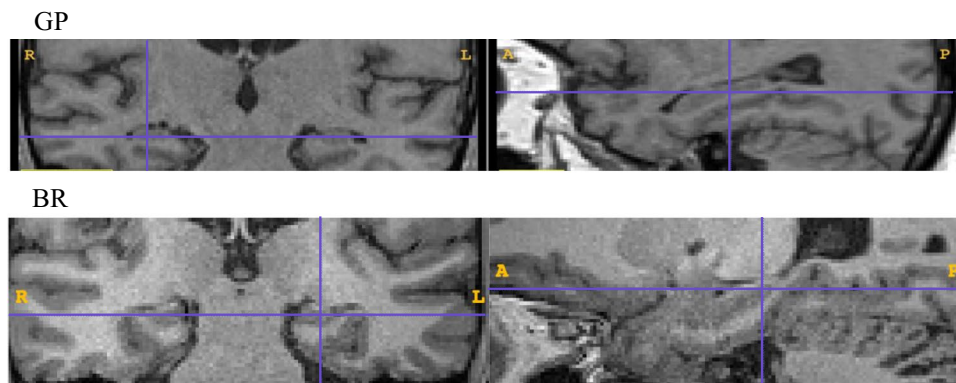
Brain region percentages are derived by comparing a patient's subregion volume to the average of their control group, which can be greater than 100% if their subregion is larger than their controls

CA: Cornu Ammonis, DG: dentate gyrus

<sup>1</sup>As reported in Baker et al., 2016

<sup>2</sup>As reported in Marlatte et al., 2023

<sup>3</sup>As reported in Rosenbaum et al., 2008; Ryan et al., 2013



**Fig. 2** Coronal and sagittal images of the hippocampi of patients GP and BR. *Note:* The cursor marks the location of coronal section through the body of the right hippocampus of GP and the left hippocampus of BR

anterograde amnesia as measured by standard neuropsychological tests and as evident in his daily functioning.

## Materials

**Target items** An 80-item word list was created from a subset of those used by Wammes et al. (2016). These words had been previously validated for ease of drawing (e.g., 'pants' vs. 'bacteria'). This reduced the amount of time required for participants to generate each drawing without necessitating excessive visual details. Word length ranged between three and 11 letters ( $M = 5.56$ ,  $SD = 1.79$ ), and words had one to four syllables ( $M = 1.63$ ,  $SD = 0.72$ ). Fifteen words were randomly assigned to the 'draw' condition, and 15 to the 'write' condition. The two lists did not differ on characteristics such as word length, number of syllables, concreteness, or imageability (see Table 3 and Appendix Table 6). The remaining 50 words were used as lures in the recognition testing component of the task.

**Filler task** Stimuli for this task consisted of simple arithmetic questions. Each consisted of numbers that ranged from 1 to 20. Half of the equations were true (e.g.,  $4 + 5 = 9$ ), while half were false (e.g.,  $2 + 11 = 15$ ).

## Procedure

Testing began prior to the COVID-19 pandemic; thus, in-person testing involved stimulus presentation to participants using PsychoPy3.0.6 (Peirce et al., 2019) on a 15-in. MacBook Pro. Instructions were both presented on the MacBook screen and read aloud by the researcher. The eight controls who were tested remotely were sent a Zoom link by the experimenter, and testing was completed via video conferencing. Prior to the testing session, participants were sent a standardized notebook to use during the task and were asked to complete the session in a quiet room to ensure controlled encoding settings. The notebook was made up of  $8.5 \times 11$ -in. sheets of unlined, blank white paper. Participants were reminded to have the notebook they were sent readily

**Table 3** Word characteristics for the two conditions

	Condition	Mean	SD	t
Length	Draw	5.60	2.13	$t = -0.32$ $P = 0.75$
	Write	5.87	2.38	
Syllable	Draw	1.67	0.90	$t = 0.24$ $P = 0.82$
	Write	1.60	0.63	
Concreteness <sup>1</sup>	Draw	597.50	23.09	$t = -1.16$ $P = 0.26$
	Write	609.58	27.87	
Imageability <sup>1</sup>	Draw	590.08	34.06	$t = -0.21$ $P = 0.83$
	Write	592.67	24.88	

<sup>1</sup>Concreteness and imageability are derived from the MRC Psycholinguistic Database (Wilson et al., 1988) for 12/15 of the words in each condition for which data were available. Ratings for both on the MRC range from 100 to 700 with means of 438 (SD = 120) and 450 (SD = 108). As expected the words used here were highly concrete and imageable

available, to leave their phone in another room, and to use headphones during the experiment (to avoid any interfering noise). The experimenter shared their computer screen when launching the experiment using PsychoPy3.0.6 (Pierce et al., 2019), and used a second screen to view the participant during the task. Other than these differences, and the change to the recognition procedure noted below, all other procedures were the same for participants tested in person and controls tested remotely.

### Encoding

Participants were informed that they would be presented with a list of words on the screen, with a prompt to either write down or draw the word that they see, with prompts randomized (within-subject). There was no mention to participants that their memory for these words would later be assessed, i.e., that this was a period of incidental encoding. Words were randomized once as described above, and all participants received the same list of words to accommodate comparisons of single patients to case-matched controls. On each trial, a ‘DRAW’ or ‘WRITE’ prompt was displayed on a computer screen for 1 s, followed by a 500-ms fixation point, before the target word was displayed on the screen for 40 s. If the prompt was to draw, participants were instructed to draw a picture of the target word for 40 s, using any extra time to add visual details to their drawing. If the prompt was to write, they were instructed to repeatedly write the target word for 40 s on the page. After 40 s elapsed, the experimenter asked the participant to turn the page in their notebook for the next trial. By turning the page over, it was facing down, and they did not see their productions again (ensuring no review of their drawings or words). The experimenter pressed the spacebar on their computer to initiate each trial. Prior to starting the task, participants

completed two demonstration trials (one with a ‘DRAW’ prompt, and one with a ‘WRITE’ prompt) to ensure that they understood the task instructions and procedure before beginning the task.

### Intervening filler task

Following encoding, a short filler task was administered to ensure that any deliberate rehearsal during the post-encoding period was avoided (McGhee et al., 2020). Participants were told they would next be shown some simple equations in the center of the screen, which had the words ‘TRUE’ and ‘FALSE’ beneath the equations on the left and right side of the screen, respectively. Each equation was displayed on the screen until the participant’s response was recorded. A 500-ms inter-stimulus blank screen followed each equation, and the task lasted for 2 min.

### Free recall

Following the filler task, participants were told that earlier in the experiment, they saw a variety of words on their screen and either drew or wrote them down. They were instructed to try and recall aloud as many of the words as possible, regardless of whether they had drawn them or written them down. The experimenter recorded each of the words by writing them down as the participant recalled them. Once the participant indicated that they could no longer recall any more words from the list, or was silent for 30 s, the experimenter probed them to determine whether they had any other words to report before moving on to the next portion of the experiment.

### Recognition

Following the free-recall segment, participants were given a recognition memory task, which consisted of 80 words in total, comprised of the 30 target words they had encoded, and 50 new words. Participants were told that they would be presented with a list of words one at a time, and that some of these words were ones they had previously either drawn or written down (targets) and that some of the words were new (lures). Participants who were tested in person were instructed to indicate whether they had seen the word during encoding, regardless of whether it was drawn or written, using the left and right arrow keys on the MacBook. If they believed they had seen the displayed word during encoding, they were instructed to press the left arrow key for ‘YES’. If they believed that the displayed word was not seen during encoding, they were instructed to press the right arrow key for ‘NO’. Similar to the presentation of the filler task, on the left and right side of the screen beneath the presented words were prompts for ‘YES’ and ‘NO’. Participants tested

remotely were instructed to say “yes” aloud if they had seen the word and “no” if they thought the word was new. The experimenter clicked the left arrow key if the participant said yes, and the right arrow key if the participant said no. The words were presented in a random order. There was no time limit to the recognition memory task, and the experiment automatically ended once the responses to all 80 words had been recorded.

## Analysis

To compare patient performance to that of the control group, we implemented methods developed by Crawford and colleagues (Crawford & Howell, 1998; Crawford & Gatherwaite, 2002, 2007; Crawford et al., 2010) for single case studies. This statistical methodology uses a modified t-test to compare the difference between patients and matched control sample performance on either single or multiple measures. We used the publicly available software accessible from: <https://homepages.abdn.ac.uk/j.crawford/pages/dept/psychom.htm>. We used the revised t-test for comparing a single case with a matched control group implemented in `Singlims_ES.exe`. Briefly, this test treats the control sample’s mean and SD as sample statistics and not as population based on a formula that uses the t-distribution (with  $n-1$  degrees of freedom).

To assess the size of the drawing effect in patients compared to controls, we created a drawing effect score for each participant that reflects the drawing advantage as a function of the total words recalled or recognized. This was calculated subtracting the number of written words from the number of drawn words and dividing by the total words correctly recalled or recognized  $(D-W)/(D+W)$ . A positive score reflects better memory for drawn words than written words, 0 means equal memory and a negative score reflects better memory for written words. Individual patients’ drawing effect was compared to their matched controls’ drawing effect (male patients to male controls; female patient to female controls) using a Bayesian test developed by Crawford and Garthwaite (2007) implemented in `SingleBayes.exe`. The analysis begins with a non-informative prior distribution, and combines it with the data through an iterative resampling procedure (100,000 iterations) to obtain a posterior distribution on which inference and estimates are based. This yields a Bayesian point estimate of the abnormality of the case’s score, which reflects an estimate of the percentage of the control population that would obtain a score lower than the patient’s and also provides an interval estimate of this probability.

These analyses were applied both to the free-recall data and the recognition data. An additional measure of  $d'$  ( $d$ -prime) was used to test recognition sensitivity.  $D'$  was calculated by taking the difference between the  $Z$ -transformed hit rate and the  $Z$ -transformed false alarm rate using the formula  $d' = Z(\text{hit rate}) - Z(\text{false alarm rate})$ . Correction for

extreme cases was applied using the log-linear rule (Hautus, 1995). Finally, to analyze the impact of the drawing effect on memory performance in recall and recognition we used paired-sample t-tests to compare performance within the control group. Note that participants tested in-person did not differ from those tested remotely on free recall ( $t(20) = 0.046$ ;  $p = 0.96$ ) or on  $d'$  recognition sensitivity ( $t(20) = -0.1$ ;  $P = 0.92$ ). Nor were there any differences in the size of the drawing effect for either recall ( $t(20) = -1.17$ ;  $P = 0.25$ ) or recognition ( $t(20) = 1.12$ ;  $P = 0.28$ ).

## Results

Participants’ drawing quality varied greatly, as might be expected, but there was no apparent difference between the quality of patients’ drawings and controls. One patient drew very elaborate drawings showing a lot of talent, whereas another drew objects that were sometimes difficult to identify. The quality of drawing did not appear to matter much for memory performance. For example, the drawings of ‘cow’ and ‘frog’ of the latter patient were barely discernible, yet during free recall, having said ‘cow’, the patient said “there was another animal, without a tail... frog!” Patients also demonstrated an awareness of the drawing effect in their own recall performance, making comments such as: “I can’t remember the ones I wrote”, and another who asked “I wrote some down too, right?”.

### Free recall

#### Group analysis

Patients as a group recalled numerically more words that had been drawn compared to written at encoding ( $M = 4$ ,  $SD = 2.27$ , range: 0–6 words). There was a floor effect in recall in patients, who all recalled 0 words that were written at encoding. The control group recalled a significantly larger number of words that had been drawn ( $M = 9.2272$ ,  $SD = 2.4675$ , range: 5–15) relative to written at encoding ( $M = 3.8181$ ,  $SD = 1.6800$ , range: 1–6),  $t(21) = 8.4989$ ,  $p < .00001$ ,  $d = 2.5625$ .

#### Individual patient performance analyses

Next, we compared the Recall performance of each patient to the performance of their healthy matched control group (see Table 4). Patient BR recalled five of the drawn words, which was marginally lower than her matched controls, and none of the written words, which was significantly worse than her matched controls. Interestingly, despite the marginally lower performance for the drawn words, Bayesian inferential analysis showed a significantly greater

benefit from drawing, with over 99% of the control population expected to show a drawing effect that is smaller than BR's (Table 4; Fig. 5).

Patients GP and BL recalled six and five of the 15 drawn words, respectively, which did not significantly differ from the control sample's performance. By contrast, neither of these patients recalled any of the written words; this also was not significantly different from controls, though their performance on recall for written words may reflect a floor effect and the difference was marginal ( $p = 0.1$ ). We next analyzed the difference in the size of the drawing effect between GP and BL and their controls using Bayesian inferential methods. These analyses showed significantly greater benefits from the drawing effect for both GP and BL, with over 98% of the control population expected to show a drawing effect that is smaller than the patients' (Table 4; Fig. 5).

Patient DA is the one patient who did not display the drawing effect. In fact, DA did not recall any drawn or written words, which was significantly different from controls for the former, and marginally so for the latter. This lack of advantage for drawn words was reflected in a significantly different drawing effect, such that fewer than 2% of the control population were expected to show no advantage for drawn words, as happened with DA (Table 4; Fig. 5).

In sum, patients BR, BL, and GP all freely recalled only drawn words, did not significantly differ from controls on the number of drawn words recalled, and showed a significantly larger drawing effect than their respective controls.

By contrast, patient DA did not recall any words and thus showed no drawing effect.

## Recognition

### Group analysis

As a group, the patients correctly recognized a higher number of words drawn at encoding ( $M = 11.75$ ,  $SD = 3.30$ ) than words written at encoding ( $M = 6.5$ ,  $SD = 3.32$ ), with some endorsement of lure items ( $M = 5.25$ ,  $SD = 9.84$ ). The control group also correctly recognized significantly more drawn ( $M = 14.64$ ,  $SD = 0.79$ ) than written words ( $M = 10.45$ ,  $SD = 3.45$ ),  $t(21) = 5.55$ ,  $p = 0.0001$ ,  $d = 1.67$ , while also demonstrating a low endorsement rate for the number of lure items ( $M = 1.32$ ,  $SD = 2.44$ ). There is a notable ceiling effect in the control participants' recognition of drawn words Fig. 3.

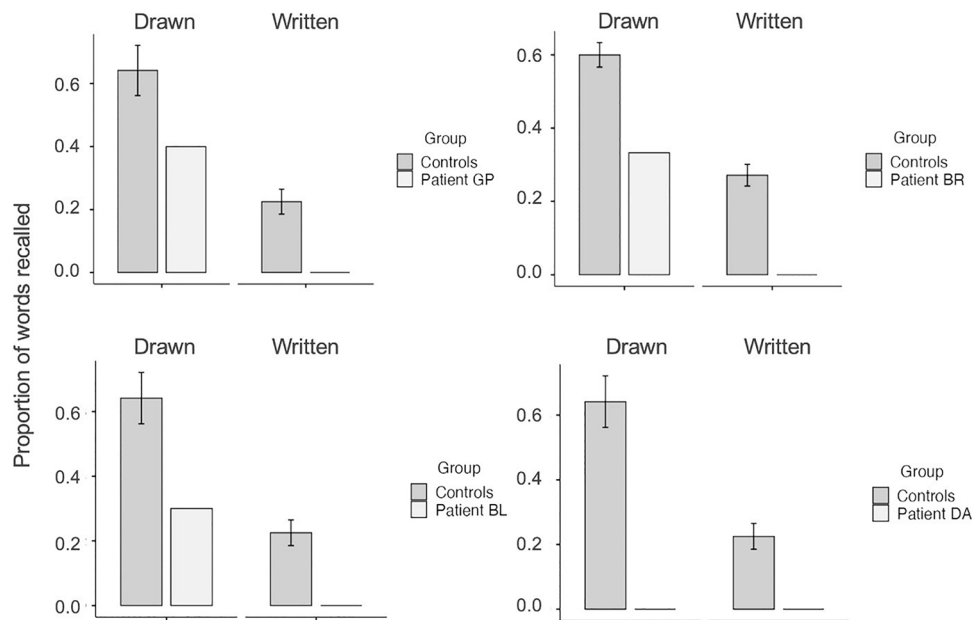
### Individual patient performance analyses

Next, we compared the recognition performance of each patient to the performance of their healthy matched control group. We assessed recognition memory by using the d-prime ( $d'$ ) statistic as a measure of sensitivity for recognition accuracy scores. Specifically, we calculated  $d'$  for the total hit rate, regardless of condition, and false alarm rate to ensure that both groups of participants recognized

**Table 4** Individual patient analyses on free-recall performance

	Number of drawn words	Patients vs. controls for drawn words	Effect size (plus 95% CI)	Number of written words	Patients vs. controls for written words	Effect size (plus 95% CI)	Size of drawing effect: Bayesian point estimate and prob. (2-tailed)	Effect size Z-CC [95% credible interval]
Patient GP	6	T = 1.01, P = 0.35	-1.07 (-1.94 to -0.17)	0	T = -1.89, P = 0.10	-2.0 (-3.22 to -0.75)	98.39% $P_{(\text{Bayesian})} = 0.03$	2.83 [1.21 to 4.43]
Patient BR	5	t = -2.05, p = 0.06	-2.123 (-3.08 to -1.15)	0	t = -2.33, <b>p = 0.04</b>	-2.42 (-3.46 to -1.35)	99.43% $P_{(\text{Bayesian})} = 0.01$	3.05 [1.77 to 4.31]
Patient BL	5	t = -1.29, p = 0.24	-1.37 (-2.33 to -0.36)	0	t = -1.89, p = 0.10	-2.00 (-3.22 to -0.75)	98.39% $P_{(\text{Bayesian})} = 0.03$	2.83 [1.21 to 4.43]
Patient DA	0	t = -2.67, <b>p = 0.03</b>	-2.85 (-4.45 to -1.22)	0	t = 1.89, p = 0.10	-2.00 (-3.22 to -0.75)	1.86% $P_{(\text{Bayesian})} = 0.04$	-2.72 (-4.26 to -1.15)
Controls (M)	9.63 (3.38)			3.38 (1.69)				
Controls (F)	9 (1.88)			4.07 (1.69)				

Patients GP, BL, and DA were compared to the matched healthy controls (Male), while patient BR was compared to the matched healthy controls (Female). Significant values at two-tailed probabilities are bolded



**Fig. 3** Individualized plots for each patient displaying their free-recall performance compared to matched controls

the encoded words above the chance level. This analysis revealed that both control groups were close to ceiling on overall recognition sensitivity with average  $d'$  scores  $> 3$ . Patients BL and BR also had very high  $d'$  scores (just under 3), which did not significantly differ from their matched controls. Patient GP had a high  $d'$  of 2, which also did not significantly differ from his matched controls on overall recognition sensitivity, although in his case the difference was marginal, reflecting mostly lower hit rate. By contrast patient DA's  $d'$  reflected negligible recognition sensitivity, significantly lower than that of the controls, suggesting poor ability to differentiate words previously seen from novel words (see Table 5).

We next sought to determine whether recognition performance of the patients for drawn compared to written words was different from those of their controls. Patients BR and BL did not significantly differ from their controls on recognition of either drawn or written words. By contrast, GP showed lower hit rates for both drawn and written words compared to the control group. In the context of his low false alarm rates, leading to a relatively high  $d'$ , this reflects a significantly degraded ability to identify old words as old, rather than identifying new words as old. By contrast, patient DA had significantly impaired recognition of drawn but not written words; however, in the context of his  $d'$ , this likely reflects his overall low sensitivity and his uniform endorsement as 'old' words from all categories (see Fig. 4; Table 5).

Patients BR and BL, who did not differ from controls on recognition of written or drawn words, also did not differ from their controls in terms of size of their drawing effect, as might be expected. Interestingly, patient GP

was impaired on both conditions. Yet, he demonstrated an enhanced drawing effect, similar to the findings with all three patients on the results from the recall test. Finally, patient DA did not significantly differ on the size of their drawing effect, although this result is difficult to interpret in light of his overall floor performance (Table 5; Fig. 5).

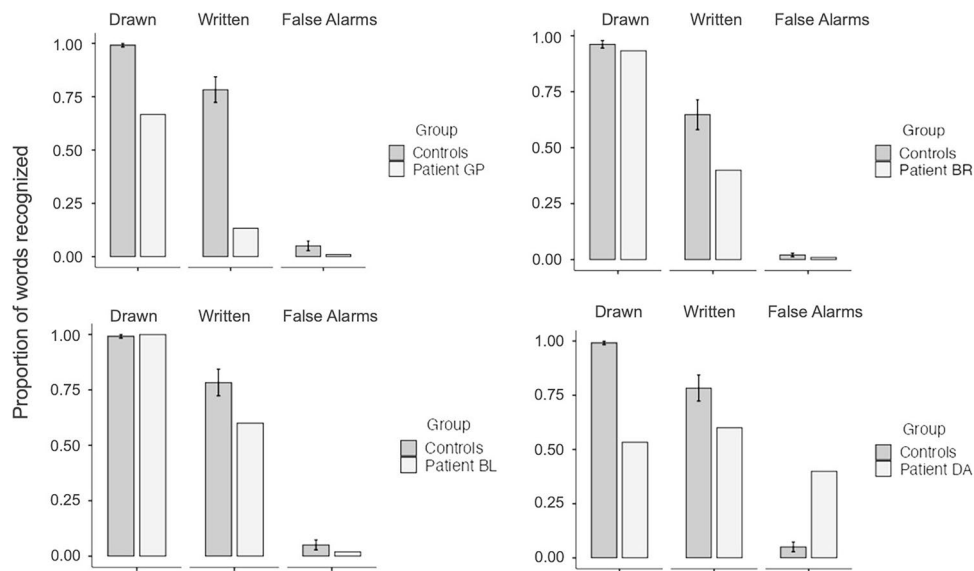
## Discussion

We investigated whether the drawing effect is present in patients with different extents of medial temporal lobe damage and memory impairments. Broadly, patients with focal hippocampal damage (GP, BR, and BL) and their matched healthy control groups showed better recall and recognition memory for words that were drawn compared with words that were written. Moreover, these patients demonstrated an enhanced drawing effect compared to controls, most notably on tests of free recall where such patients typically show the greatest impairment. In contrast, patient DA with more extensive hippocampal and additional extensive cortical lesions did not show the drawing effect on either recall or recognition, showing essentially no memory for words regardless of how they were encoded. These findings demonstrate that drawing can be an effective encoding strategy to improve memory in those with focal hippocampal damage, though intact cortical representations and possibly some residual hippocampal tissue are necessary for the drawing effect.

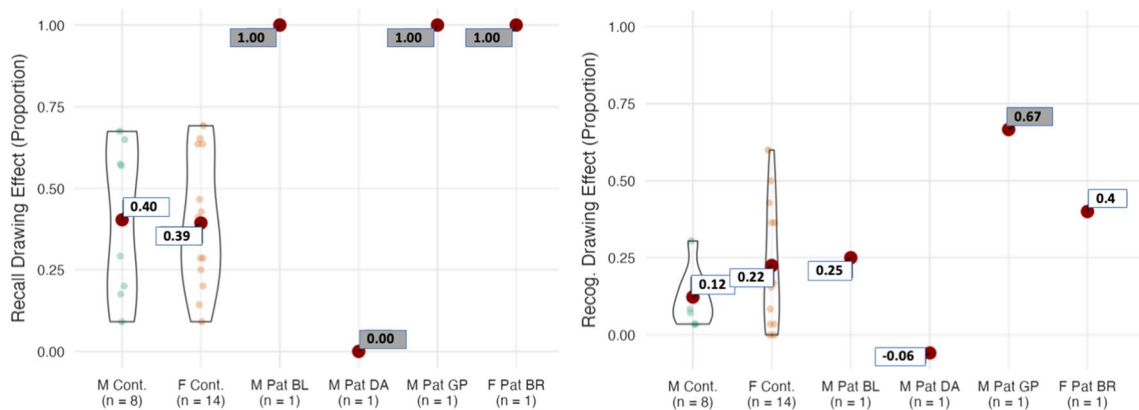
**Table 5** Individual patient analyses on recognition performance

<i>d'</i>	Patients vs. controls <i>d'</i> difference	Effect size (plus 95% CI)	Number of drawn words	Patients vs. controls drawn words	Effect size (plus 95% CI)	Number of written words	Patients vs. controls written words	Effect size (plus 95% CI)	Size of drawing effect: Bayesian point estimate and prob. (2-tailed)	Effect size Z-CC [95% credible interval]
Patient GP	$t = -1.68, p = 0.14$	-1.79 (-2.91 to -0.62)	10	$t = -13.00, p = \mathbf{0.0001}$	-13.79 (-20.89 to 6.74)	2	$t = -3.61, p = \mathbf{0.009}$	-3.82 (-5.89 to -1.74)	99.88% $P_{(Bayesian)} = 0.002$	4.91 [2.30 to 7.51]
Patient BR	$t = -0.57, p = 0.58$	-0.59 (-1.15 to -0.01)	14	$t = -0.44, p = 0.67$	-0.46 (-1.00 to 0.10)	6	$t = -0.96, p = 0.36$	-0.99 (-1.62 to -0.33)	78.68% $P_{(Bayesian)} = 0.43$	0.85 [0.22 to 1.45]
Patient BL	$t = -0.52, p = 0.62$	-0.55 (-1.28 to 0.22)	15	$t = 0.33, p = 0.75$	0.35 (-0.37 to 1.06)	9	$t = -1.02, p = 0.34$	-1.08 (-1.94 to -0.17)	83.11% $P_{(Bayesian)} = 0.34$	1.09 [0.18 to 1.96]
Patient DA	$t = -4.03, p = \mathbf{0.005}$	-4.27 (-6.55 to -1.97)	8	$t = -18.34, p = \mathbf{0.0001}$	-19.45 (-29.44 to -9.53)	9	$t = -1.02, p = 0.34$	-1.08 (-1.94 to -0.17)	7.38% $P_{(Bayesian)} = 0.14$	-1.73 (-2.83 to -0.58)
Controls (M)	3.11 (0.63)		14.88 (0.35)			11.75 (2.55)				
Controls (F)	3.01 (0.71)		14.43 (0.94)			9.71 (3.75)				

Patients GP, BL, and DA were compared to the matched healthy controls (Male), while patient BR was compared to the matched healthy controls (Female). Significant values at two-tailed probabilities are bolded



**Fig. 4** Individualized plots for each patient displaying their recognition performance compared to matched controls



**Fig. 5** Size of the drawing effect for recall and for recognition. *Note:* Proportion drawing effect reflects the difference between remembered drawn words and remembered written words divided by the total words remembered:  $(D-W)/(D+W)$ . DA’s 0 Drawing effect for Recall

reflects the fact that he could not recall any word at all. Shaded scores denote a significant Bayesian point estimate difference between patient and their matched controls. Cont.= Controls; F = Female; M = Male; Pat = Patient

**Recall and recognition** Healthy controls and patients with focal hippocampal damage showed the drawing effect for recall and for recognition. Interestingly, however, patients demonstrated an enhanced drawing effect in free recall but not in recognition memory performance. All three focal hippocampal lesion patients failed to recall any written words, but did recall approximately a third of the drawn words. By contrast, the recognition performance of BL and BR was equivalent to that of the controls for both written and drawn words, also reflecting an equivalent drawing effect. Disproportionate preservation of recognition memory is consistent with previous studies showing impaired recall and relatively preserved recognition in patients with focal hippocampal

dysfunction (e.g., Aggleton et al., 2005; Mayes et al., 2002; Vann et al., 2009; Waidergoren et al., 2012; for reviews, see Aggleton & Brown, 1999; Eichenbaum et al., 2007). Unlike BL and BR, patient GP had impaired recognition for both drawn and written words, and was also the only patient showing an enhanced drawing effect for recognition, recognizing five times as many drawn than written words.

One interpretation of patterns of preserved recognition but impaired recall following hippocampal damage is in terms of recollection and familiarity processes (Gardiner, 2001; Tulving, 1983). Recollection entails remembering both the occurrence of the item itself and its associated contextual information, whereas familiarity entails item

memory devoid of contextual memory. By this view, free and cued recall require hippocampally dependent recollection processes because the item itself is not presented as a cue, whereas recognition can be supported by either recollection or familiarity, where the latter can be supported by extra-hippocampal cortices (Aggleton & Brown, 1999; Eichenbaum et al., 2007). Thus, our pattern of results in which drawing rescues even recall performance in patients, suggests that the drawing effect reflects enhanced memory recollection in patients with focal hippocampal damage. This could either reflect drawing's support of extra-hippocampal recollective processes or its enhancement of residual hippocampal function. This does not negate the possibility that during recognition the drawing effect additionally reflects enhanced item familiarity, and future studies could explore its process-specificity.

**Distinct representations** Enhanced recollection in hippocampal patients suggests that extra-hippocampal structures can rapidly form novel declarative associative memory with minimal or no hippocampal support. Extra-hippocampal cortical representations are highly susceptible to interference from overlapping representations (Norman & O'Reilly, 2003; O'Reilly & Norman, 2002). However, it has recently been suggested that non-overlapping associations (Merhav et al., 2014) or partially overlapping multimodal information can be rapidly integrated into neocortical representations with little or no hippocampal contributions (Antony et al., 2017; Gilboa & Marlatte, 2017; Gilboa & Moscovitch, 2021; Hebscher et al., 2019; Moscovitch & Gilboa, 2021; Pöhlchen & Schönauer, 2020). Richer, more extensive representations of stimuli reduce the interference that is typically generated by high feature overlap (Wing et al., 2022) and is conducive to rapid cortical learning (Zaiser et al., 2022a,b).

Drawing is a rich, elaborative encoding process that facilitates the integration of verbal memory traces with multisensory information at encoding (Wammes et al., 2016), leading to enriched memory representations (Wammes et al., 2019). We believe that at least three separate factors contribute to memory enhancement: (i) Semantic elaboration supporting a deep level of processing ( Craik & Lockhart, 1972); (ii) gesture-based learning and memory enactment due to activating motor systems during the act of drawing (Engelkamp & Zimmer, 1989; Guttentag & Hunt, 1988); and (iii) dual-coding capitalizing on visual aspects of the picture-superiority effect as pictures are depicted both visually and verbally (Paivio et al., 1968; Paivio, 1991). We discuss these three elements in more detail in the following sections, relating them to recent models of rapid cortical integration of declarative memories. These different components produce an integrated memory trace comprised of diverse contextual features generated during the initial drawing-based encoding (Wammes et al., 2018). The creation of representations

with a diversity of features allows for greater distinctiveness, which ultimately protects memory from interference (Craik & Rose, 2012; Wing et al., 2022) and produces a stable, differentiated, uniquely specified trace that is more readily retrieved (Carr et al., 2015).

Translating a word into a visual image entails semantic elaboration as conceptual information is accessed in order to generate a mental image of the concept (Patterson et al., 2007; Ralph et al., 2017). Semantic elaboration enhances mental representations and enriches the encoding process (Amlein et al., 2019), improving subsequent memory strength (Amlein et al., 2019; Craik, 2002; Lockhart & Craik, 1990). Previous research typically found little memory benefit for deep conceptual processing in hippocampal amnesia (e.g., Yonelinas et al., 1998). However, encoding in these studies was limited to the verbal modality in contrast to the multimodality drawing strategy employed here. The semantic elaboration demands imposed during drawing may have further engaged multimodal representations (e.g., translation from verbal to visual to motoric) and contributed to the patients' enhanced memory for words that were drawn at encoding. This was exemplified by a patient's self-cueing during free recall: "there was another animal, without a tail... frog!"

Motoric demands of drawing may also contribute to the rich multimodal representation that drives the drawing effect. Previous research has shown that the act of gesturing can enhance a memory trace both in healthy controls (Iani & Bucciarelli, 2017) and in hippocampal patients (Hilverman et al., 2018). The mnemonic advantage associated with gesturing has been attributed to the activation of extra-hippocampal neural structures that typically mediate non-declarative memory processes (Hilverman et al., 2018). Drawing requires greater deliberate and more complex motor engagement than writing, as well as motor imagery of the object. Consistent with this idea, the benefits of employing the motor modality during memory encoding are reduced when the motor action is unrelated to the task (Iani & Bucciarelli, 2017; Meade et al., 2019). Traditional memory models consider motor systems to be non-declarative memory systems (Squire, 1992; Squire & Zola, 1996). In the current task, however, they appear to engage in a declarative memory task, suggesting that neural systems cannot be strictly assigned to particular types of memory representations. Instead, multimodal representations, including motor ones, can indeed contribute to rapid neural changes in extra-hippocampal structures that are sufficient to support declarative memory (Hebscher et al., 2019).

Finally, elaborative encoding through drawing may benefit from the engagement of visual pathways including primary visual cortices and the ventral visual pathway, consistent with the evidence of a mnemonic benefit associated with studying pictures versus word stimuli in patients with hippocampal

damage (Ally, 2012; Barbeau et al., 2005). According to dual code theory (Paivio, 1971), verbal (symbolic) information and visual (analogue) information exist as separate codes and either or both can be drawn upon when retrieving information, increasing the likelihood of successful retrieval. Alternatively, according to common code theory (Prinz, 1990), a common similarity-based perception-action code exists such that actions are coded in terms of their perceivable outcomes. This is more consistent with the model of rapid multimodal encoding (Wammes et al., 2019) leading to rapid formation of cortical memory traces (Hebscher et al., 2019).

Our results demonstrate that the drawing effect likely requires little or no hippocampal input to emerge, but does not unequivocally assess the extra-hippocampal structures that support the effect. Patient DA's failure to benefit from drawing may provide clues as to what cortical structures are necessary. In addition to the hippocampus, DA suffered disproportionate right hemisphere volume loss including ventral frontal, anterior cingulate, anterior and posterior temporal, and some occipital cortex damage (Ryan et al., 2013). This partially aligns with an imaging study that reported object drawing-related activity could be decoded from occipital and inferotemporal cortices, but not the hippocampus and MTL cortex (Fan et al., 2020). Note that this study focused on training how to draw a very small set of visually presented objects, suggesting these posterior cortical regions engage in the transformation of perceptual to action representations (Fan et al., 2020). In a self-generated verbal-to-visual object drawing plan as required in the present study (Fernandes et al., 2018; Wammes et al., 2019), more anterior cortical regions are likely engaged as well. Based on these findings, we propose that the act of drawing creates a strong memory trace by engaging a rich, multimodal elaborative encoding that combines visual, motor, and semantic components. These elements are each associated with cortical regions that may be functionally independent from the hippocampus or may require only minimal hippocampal contribution as cortical memory stabilization processes are accelerated (Hebscher et al., 2019). We therefore propose that drawing supports word learning by specifically engaging in non-hippocampally mediated memory processes.

## Conclusion

This study provides early evidence that patients with focal hippocampal damage can benefit from the drawing effect. Our findings extend previous research demonstrating the drawing effect in individuals with probable dementia (Meade et al., 2020) by demonstrating disproportionate benefits during free

recall and by suggesting that this advantage may be abolished if brain damage extends to cortical regions. Looking forward, drawing may offer an inexpensive, feasible approach to enhance the encoding of day-to-day events and/or important information. Indeed, a recent study has shown that reminiscing by drawing rather than writing in a personal diary enhances accuracy and quality of later recollections (Tran et al., 2022). The potential of this approach was highlighted in a comment offered by one patient who, on noticing their enhanced memory of the drawn, compared to written, words said: *"they should publish that for people with brain injuries so they could use it as a tool. I'm going to tell my husband that!"*

## Appendix

**Table 6** Words used in the Drawing and Writing conditions:

Word	Condition	Length	Syllables	Concrete-ness	Image-ability
Wagon	Draw	5	2		
Sweater	Draw	7	2	569	560
Pumpkin	Draw	7	2	556	556
Frog	Draw	4	1	619	617
Flute	Draw	5	1	587	581
Giraffe	Draw	7	2		
Skirt	Draw	5	1	614	573
Hammer	Draw	6	2	605	518
Caterpillar	Draw	11	4	586	626
Kite	Draw	4	1	592	624
Cow	Draw	3	1	621	632
Axe	Draw	3	1	623	597
Corn	Draw	4	1	576	601
Pineapple	Draw	8	3		
Sheep	Draw	5	1	622	596
Ear	Write	3	1	640	597
Screw-driver	Write	12	3		
Pear	Write	4	1	634	590
Ladder	Write	6	2		
Rabbit	Write	6	2	635	611
Ruler	Write	5	2	555	543
Strawberry	Write	10	2	610	631
Blouse	Write	6	1	640	595
Guitar	Write	6	2		
Harp	Write	4	1	591	621
Glove	Write	5	1	607	596
Toaster	Write	7	2	579	580
Jacket	Write	6	2	635	611
Coat	Write	4	1	601	572
Doll	Write	4	1	588	565

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**Data availability** Data are available from the authors upon request

## Declarations

**Conflicts of interest/Competing interests** No conflicts of interest were reported by the authors.

**Ethics approval** Approval was obtained from the Research Ethics Board at the Rotman Research Institute at Baycrest Hospital. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

**Consent to participate** Informed consent was obtained from all individual participants included in the study.

**Consent for publication** All participants signed informed consent regarding publishing their data from this study.

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