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The contributions of spatial context and imagery to the recollection of single words

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Abstract

A number of theories of hippocampal function have placed spatial context at the center of richly recollected memories, but the subjective and objective ways that spatial context underlies the recollection of single words has been largely overlooked and underexplained. In this study, we conducted three experiments to investigate the involvement of spatial context in the recollection of single words. In all three experiments, participants encoded single words with varying features such as location and color. The subjective experience of recollection was measured using remember/know judgments and participant self-report of the types of information they recollected about the words. Objectively, recollection was measured using source memory judgments for both spatial and non-spatial features associated with the words. Our results provide evidence that spatial context frequently accompanies the recollection of single, isolated words, reviving discussions on the role of the hippocampus in spatial and detailed recollection.

KEYWORDS

imagery, recollection, source memory, spatial context, word memory

1 | INTRODUCTION

Recollection, which entails the recall of detailed and associative information about past experiences, is considered the purview of the hippocampus (Eichenbaum, Yonelinas, & Ranganath, 2007; Moscovitch, Cabeza, Winocur, & Nadel, 2016; Staresina & Davachi, 2008; but see Squire et al., 2010, for a more nuanced view). The processes underlying recollection have been suggested to support not only memory, but our ability to engage in other hippocampally-mediated cognitive processes such as future-thinking, imagination, and spatial navigation (Hassabis, Kumaran, & Maguire, 2007; Moscovitch et al., 2016; Schacter et al., 2012; Spiers & Maguire, 2006). The nature of the processes underlying recollection have been researched and debated for decades. Lynn Nadel has been involved in the generation of two major theories of hippocampal function and recollection: Cognitive Map Theory (CMT) (O'Keefe & Nadel, 1978), and Multiple Trace Theory (MTT) (Nadel & Moscovitch, 1997). Allocentric spatial representations are at the heart of CMT and detailed episodic memory is at the heart of MTT. CMT proposes that memories for past events are embedded within spatial representations generated by the hippocampus, while memories lacking spatial structure or context are not hippocampally-mediated (Nadel, 2008). MTT posits that the hippocampus is responsible for the vivid recollection of details from past events. Over time, the representation of detailed episodic memories remain dependent on the hippocampus, while semantic memories come to rely solely on the neocortex (Moscovitch, Nadel, Winocur, Gilboa, & Rosenbaum, 2006; Nadel, Samsonovich, Ryan, & Moscovitch, 2000; see Robin & Moscovitch, 2017 and Sekeres et al., 2018, for the most recent iteration of MTT).

At the level of events, CMT and MTT can be reconciled in that events are thought to unfold in a spatial framework. In everyday life, all events that we experience take place in some form of spatial context. Thus, detailed recollective representations, reliant on the hippocampus, may be based on an underlying spatial representation. Consistent with this view, Scene Construction (SC) theory posits that the hippocampus is responsible for the construction of spatially coherent scenes, which act as a scaffold upon which the details of events are built (Hassabis & Maguire, 2007, 2009; Maguire, Intraub, &

Mullally, 2016; Spiers & Maguire, 2006). Supporting this view, Robin and colleagues (Robin, Wynn, & Moscovitch, 2016) found that imagined events with a spatial context specified at study were better remembered than those without. Most interestingly, even when no spatial context was specified, participants tended to spontaneously generate a spatial context at encoding and retrieve it at recall. These results suggest that spatial context is a fundamental component of event memory (Robin, 2018), consistent with both CMT and MTT. Questions remain, however, regarding whether CMT and MTT can explain other kinds of memory which do not, at first glance, seem to involve spatial context.

CMT, and to some extent, MTT have been unable to account for the recollection of items that do not, on the surface, involve the re-experiencing of spatial information, such as verbal memory. For the most part, more complex forms of verbal memory, like memory for word-pair associations (Cameron & Hockley, 2000) and narratives (Furman, Dorfman, Hasson, Davachi, & Dudai, 2007) are understood to be hippocampally-mediated and may involve spatial representations (Clark, Kim, & Maguire, 2018). The nature of recollection memory for single words, however, is less clear. Following Tolman (1948), O'Keefe and Nadel (1978) proposed that verbal memory may not depend on the allocentric spatial information of a cognitive map, but rather on a conceptual map. More recent elaborations of this idea have suggested that memoranda lacking spatial elements may rely on relational networks which can be organized along conceptual dimensions based on a spatial framework but without overtly spatial features (Bellmund, Gärdenfors, Moser, & Doeller, 2018; Collin, Milivojevic, & Doeller, 2017; Constantinescu, O'Reilly, & Behrens, 2016; Eichenbaum & Cohen, 2014; Eichenbaum, Dudchenko, Wood, Shapiro, & Tanila, 1999; Milivojevic & Doeller, 2013). These views might predict that single word recollection can be achieved without the need for overt spatial representations, while a more strongly spatial view would predict that even the recollection of single words, thought to be free of context or relations, would involve spatial representations.

The ancient mnemonic technique of Method of Loci involves linking simple memoranda such as words or images to spatial representations in order to improve memory (Bouffard, Stokes, Kramer, & Ekstrom, 2017; Roediger, 1980; Rolls, 2017; Yates, 1966). Maguire and Mullally (2013) have proposed that scene imagery may play a role in memory for single words, similar to a spontaneous form of method of loci. Global spatial context, such as a classroom or testing room (see Smith & Vela, 2001 for a review), and non-global spatial contexts, such as screen position (Murnane & Phelps, 1993, 1994, 1995) have been implicated in improved recognition memory for words when preserved between study and test. Uncapher et al. (2006) also manipulated the non-global context of single words and tested participants on both spatial and non-spatial aspects of context. They found that source memory for the word's position was better than for the word's color, again providing evidence for a spatial element to single word memory.

Imagery is also known to feature prominently in word memory. Early work suggested a role for imagery in memory for concrete nouns when rate of presentation is slow enough to allow these processes to be implemented. Slower rates of presentation allow for the verbal representation to evoke an imagery-based representation, typically of the item the word denotes, resulting in improved memory performance (Paivio, 1991; Paivio & Csapo, 1969; Paivio & Csapo, 1973). Confirming findings in patients with unilateral temporal lobectomy (Jones-Gotman & Milner, 1978), a more recent study using word pairs of high or low imageability found that hippocampal activation was higher for highly imageable word pairs (Caplan & Madan, 2016). A main effect of word imageability on recall accuracy in this study also suggested that imagery-based processes were influencing hippocampal function; it is possible that similar effects would be at play for single words. A verbal paired-associates task using scene words, object words, or abstract words found that hippocampal activation for scene and object words was similar and more prominent in participants who favored imagery use (Clark et al., 2018). Together, these studies support that mental imagery is a common aspect of the recollective experience of words, but it is unknown to what extent these forms of imagery involve spatial representations. It is vital to ascertain how prominently space figures in the recollection of single words that seem to have no ostensible allocentric spatial component, just as it did for events when no spatial context was provided at study (Robin et al., 2016).

In the present study, our goal was to explore the contents of recollection for single words, in order to determine the frequency of spatial representations underlying the recollective experience. Recollection is often measured using one of the following two methods: the remember/know procedure, which relies on subjective reports from participants to describe the type of memory they are experiencing, or measures of source memory, thought to accompany the richer experience of recollection but not familiarity. In this study, we designed a novel paradigm to capture both of these subjective and objective measures of recollection and probe them for their content. In this paradigm, participants encoded words presented one at a time. Words appeared in varying locations on a computer screen, and with different color or shape information, to provide spatial and non-spatial forms of source information. Color and shape information were selected for the present studies as previous work has indicated that they are rooted in mental imagery (Marks, 1999; Nanay, 2015). At test, recollection of each word was assessed using a subjective remember/know procedure (Gardiner, Ramponi, & Richardson-Klavehn, 2002; Tulving, 1985a, 1985b; Yonelinas, 2002). If participants remembered the word, we probed recollection further, asking participants to report which types of information informed their memory decision. Next, spatial and non-spatial source information was tested, for a more objective measure of recollection. We predicted that if memory for single words is based on recollective processes, remembering these items will frequently be subjectively associated with additional detailed information such as visual imagery or spatial information, and associated with measures of spatial or non-spatial source memory. This study will provide insight both into the contents of recollection of single words, as well as how imagery and spatial representations support such recollections. These data, in turn, will speak to the broader question of whether spatial memory is a component of hippocampally-mediated memory, such as recollection and source memory.

2 | METHODS

2.1 | Experiment 1

2.1.1 | Participants

We recruited undergraduate students from the University of Toronto introductory psychology subject pool and Facebook community. Forty-three participants took part in Experiment 1 (26 women, 13 men). Three participants were excluded because they had participated in other versions of the experiment. All participants provided informed consent and all procedures were in accordance with the University of Toronto Office of Research Ethics. Participants were compensated monetarily or with course credit.

Participants were fluent in English with normal or corrected-to-normal hearing and vision (mean age = 21.48 years, range = 18–29 years; mean years of education completed = 15 years, range = 13–20 years). Inclusion criteria were: no history of psychiatric disorders, no history of a learning disorder, and no history of neurological disorders.

2.1.2 | Stimuli and Materials

Word stimuli

We used 72 word stimuli in this experiment. These stimuli were all nouns, acquired from the Toronto Noun Pool (mean word frequency = 6.7, mean imagery rating = 6.3) (Friendly, Franklin, Hoffman, & Rubin, 1982). Thirty-two words were presented during the encoding session. During the retrieval session, these 32 words were presented alongside 32 new words. The order of the words was randomized for each participant, and encoding and lure word lists were counterbalanced between participants. The remaining eight words were used during practice. All stimuli were presented on a computer equipped with E-prime software. Instructions were given on a separate computer in the same room using Microsoft PowerPoint.

2.1.3 | Procedure

Prior to beginning the experiment, participants were given instructions for the encoding session. They were told to pay attention to the words that would appear on the screen and then completed a practice session. Participants were given the opportunity to ask questions. The experimenter left the room while they completed the encoding session, after which there was a 5-minute delay. The experimenter then returned to give instructions for the retrieval session, during which participants were taught to distinguish between re-experienced, known and new words. Re-experiencing a word was described as an ability to remember associated details from the first time they had seen the word in the experiment. Knowing a word was described as having a sense of familiarity for the word which could be either weak or strong, with no associated details about the first time they had seen the word in the experiment. A new word was described as a word that they did not remember seeing in the encoding session. The retrieval instructions also included detailed descriptions of the different categories participants might remember about the words (self, location, imagery, sensation, emotion, other, or more than one; see below for more information). Participants completed a practice for the retrieval session with the experimenter, and then completed the retrieval session on their own.

Encoding session

The participant attended to the words on the screen, which were presented one at a time. Four words were presented as practice and 32 words were presented during the actual session. The words were presented for 2.5 s each, followed by a 1 s fixation cross before the next trial (Figure 1a).

On each trial, participants were presented with two kinds of source information: location and color. We operationalized location or spatial context as quadrant location and divided the screen into four quadrants, based on black lines bisecting the screen vertically and horizontally. Words were presented centrally in one of the four spatial

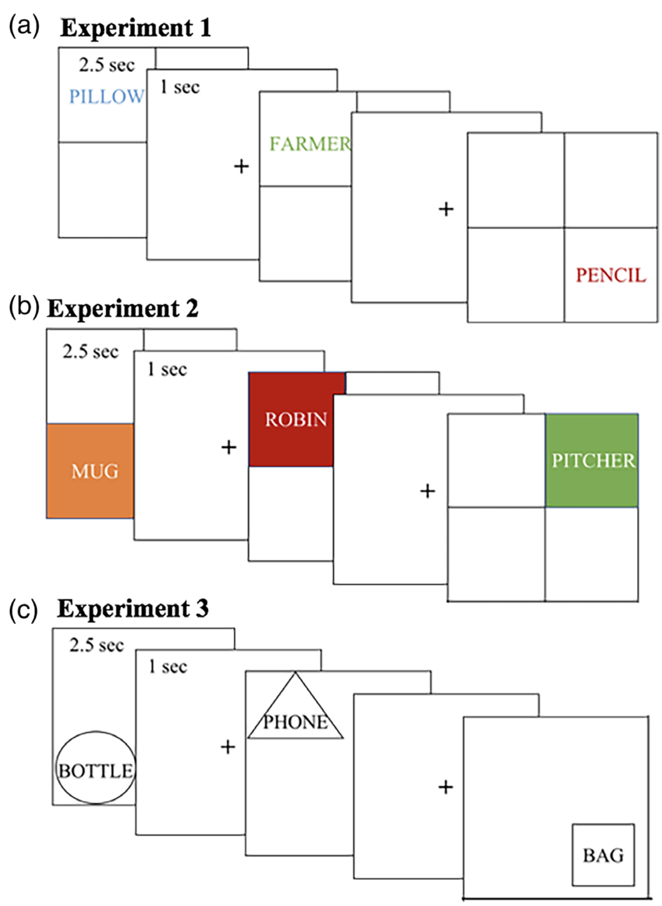

FIGURE 1 Encoding session for (a) Experiment 1: participants viewed colored words in one of four quadrants, (b) Experiment 2: participants viewed words in one of four colored quadrants, and (c) Experiment 3: participants viewed words in shapes in one of four quadrants

quadrants on the computer screen: top-left, top-right, bottom-left, or bottom-right. In order to encourage implicit encoding of color during reading, word text was displayed in one of four color options: blue, orange, green, or red. Word location and color were randomly selected for each trial, counterbalancing across the four options for each.

Delay

After finishing the encoding session, participants waited for 5 min before calling the experimenter. They were instructed to sit quietly for these 5 min, without using their phones or engaging in other material (e.g., reading or taking notes).

Retrieval session

Eight words were presented as practice, with four having appeared during the previous practice session. During practice, the experimenter provided detailed instructions and feedback to the participant and assessed the participant's level of understanding of the experiment with questions such as: “Why did you choose that option?”; “What kind of thought are you having about the word?” Sixty-four words were presented during retrieval, with 32 being words the participant had seen during encoding and 32 being new words. Retrieval trials were self-paced, with no time limit.

On each trial, participants were presented with a word on the screen and asked to select one of three options. If they did not remember seeing the word before, they indicated that it was new by pressing “N” on the keyboard. If they remembered seeing the word, but did not recall any associated details about it (for example: they had a feeling they had seen the word “fish”), they indicated that the word was known by pressing “K” on the keyboard. Lastly, if they remembered seeing a word and could recall additional details about it (for example: they remembered thinking of a fishing trip the first time they saw the word “fish”), they indicated that the word was re-experienced by pressing “R” on the keyboard. Next, participants rated how confident they were in their judgment that the word was new or old. They used a scale from 1 to 5 (low confidence to high confidence) and the corresponding keyboard numbers.

If participants indicated that the word was old (a response of known or re-experienced), they were asked two source questions. They first indicated in which quadrant the word was located. Then, they indicated the word's color. For both source questions, they could indicate that they did not know by pressing the 0 key.

We then asked them to indicate whether they had a specific thought about the word, using the “Y” key to indicate yes and the “N” key to indicate no. If participants responded that the word was associated with a specific thought, they were directed to answer an additional question about what they pictured from a list of predetermined thought categories. These categories were derived from the results of a number of pilot studies in which participants freely recalled their memories for the words. In order to ensure both clarity and consistency, and to address directly our question about the content of memories for single words, we provided separate, definable categories. The options for specific thought categories included thoughts related to: (a) self (if participants were present in what they remembering or if it was occurring from their own perspective); (b) location (if the memory was of a location or place, imagined [extra-experimental] or related to the testing room or source quadrant location); (c) imagery (if there was any other mental image imagined or relating to the testing room or source imagery); (d) sensation (if they remembered a particular sound/smell/taste/sensation); (e) emotion (if they remembered a particular emotion or feeling); (f) other (if something came to mind that didn't fit in any of the previous categories); (g) more than one of the above; or (h) none of the above. If participants selected (g) for more than one of the above, they were permitted to report multiple categories.

2.2 | Experiment 2

In this experiment, instead of presenting the font in different colors, we chose to present the word as white but against a background of color that covered the entire quadrant in which the word was presented. We chose to do this based on the findings of Experiment 1, in which performance on source memory for word color was worse than source memory for quadrant location. Thus, we attempted to match the difficulty of both types of source by equating the salience of color with space.

2.2.1 | Participants

Forty-two participants took part in Experiment 2 (35 women, 7 men; mean age = 20.48 years, range = 18–25 years; mean years of education completed = 14.24 years, range = 12–18 years). All recruitment, compensation, and consent procedures were identical to Experiment 1. Inclusion criteria were identical to Experiment 1. One participant reported no recollected responses, and another did not comply with task instructions, so were excluded from analyses.

2.2.2 | Stimuli and materials

All stimuli and materials were identical to Experiment 1, with one exception. For source information, word color remained white while the background of the quadrant in which the word appeared was completely filled with 1 of 4 color options: blue, orange, green, or red. Quadrant color was randomly determined for each trial, counterbalancing across the four options.

2.2.3 | Procedure

All procedures were identical to Experiment 1 (see Figure 1b and Figure 2), except that participants were asked to report quadrant color instead of word color if they indicated that the word was old. Additionally, if participants chose (b) location or (c) imagery, a subsequent question asked which category best described the location or spatial context, or the mental image, that they were picturing. Their options, which correspond to the keys they used to select them, were: (a) details about the testing room (i.e., picturing the testing room or an

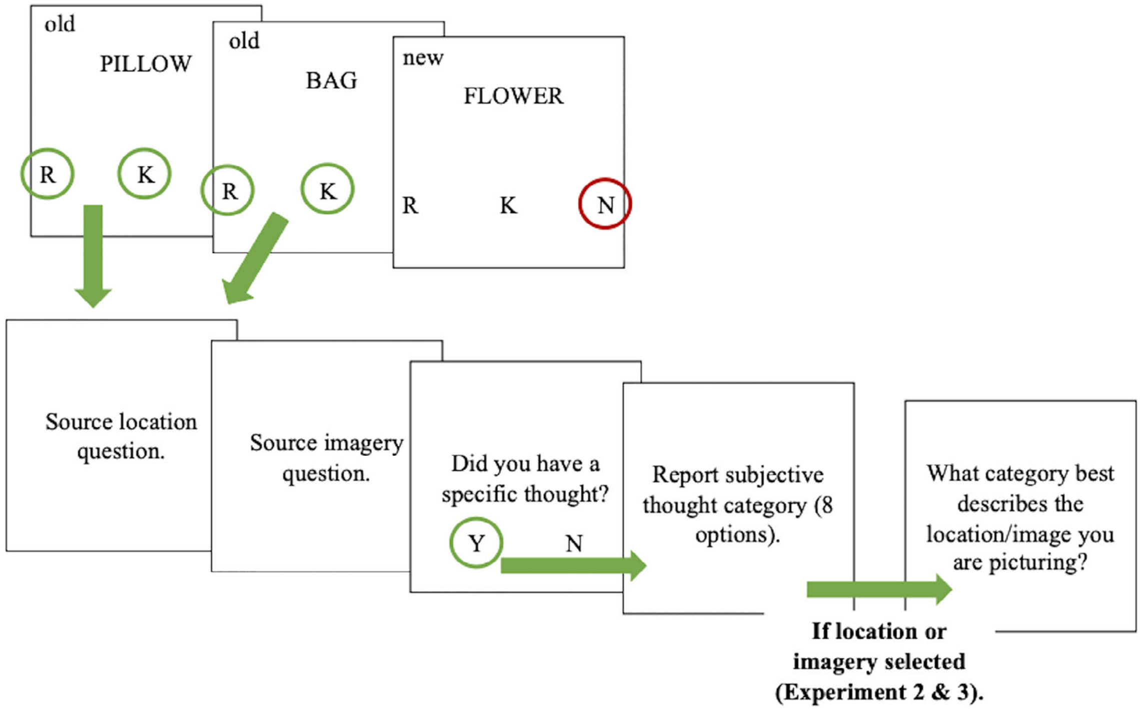

FIGURE 2 Retrieval session for Experiments 1, 2, and 3. Participants provided a remember/know/new judgment on each word, before responding to the source memory questions and, if reporting a specific thought, indicating which categories they were remembering

object in the testing room); (b) details about the setting of the imagined object (i.e., an imagined location or an imagined object); (c) details about source information (i.e., quadrant location or quadrant color); or (d) other details.

2.3 | Experiment 3

In this experiment, instead of varying the color of the word, we varied the shape surrounding the word to compare the influence of shape with that of location in source memory for words. This procedure was adopted to determine whether our findings for color in Experiments 1 and 2 extended to other types of non-spatial information, such as shape.

2.3.1 | Participants

Thirty-nine participants took part in Experiment 3 (27 women, 12 men; mean age = 19.82 years, range = 18–29 years; mean years of education completed = 13.79 years, range = 12–19 years). All recruitment, compensation, and consent procedures were identical to Experiment 1 and 2. Inclusion criteria were identical to Experiment 1 and 2. One participant was excluded due to participating in multiple versions of the experiment. One participant reported no familiar responses so was removed from the source memory ANOVA.

2.3.2 | Stimuli and materials

All stimuli and materials were identical to those in Experiment 2, with one exception. Word color remained black and quadrant color was white, while the word could be presented inside 1 of 4 shapes which occupied the quadrant: circle, square, triangle, or hexagon. Shape was randomly determined for each trial, counterbalancing across the four options.

2.3.3 | Procedure

All procedures were identical to Experiment 2 (see Figure 1c and Figure 2), except that participants were asked to report shape instead of quadrant color if they indicated that the word was old.

3 | RESULTS

3.1 | Results: Experiment 1

3.1.1 | Memory performance

Verbal memory performance was quantified using signal detection theory. A d-prime score for each participant was calculated to quantify their ability to detect old words, while accounting for possible response biases (Wixted, 2007). As a d-prime of zero indicates no use of memory, a one-sample *t*-test was conducted to compare the d-prime scores to zero. We found that the d-prime scores differed

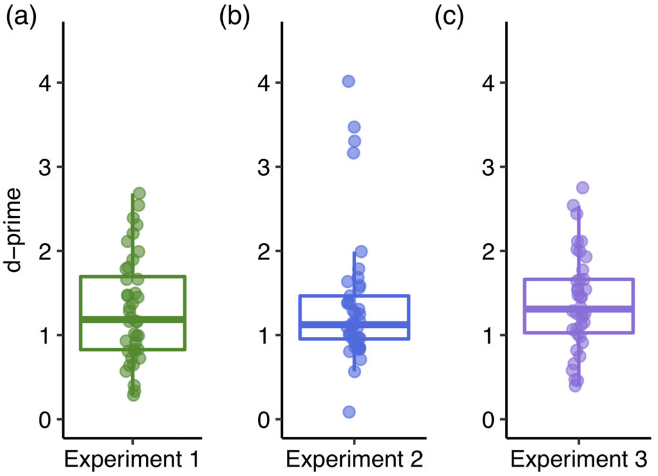

FIGURE 3 Boxplots and individual d-prime scores of word memory performance in (a) Experiment 1, (b) Experiment 2, and (c) Experiment 3

significantly from zero ($t[39] = 13.18$, $p < .001$, 95%CI: 1.10–1.50) (Figure 3a). Participants were able to remember the words in this task reliably.

3.1.2 | Subjective recollection

As expected, participants had a higher instance of reporting specific thoughts when they indicated they were recollecting a word (M = 96.5% of trials, *SD* = 6.8%) than when they reported it as familiar (M = 23.9% of trials, *SD* = 24.5%; $t[39] = 17.43$, $p < .001$, 95%CI: 0.64–0.81). When words were recollected with specific thoughts, participants reported the highest rates of experiencing both imagery- (M = 75.7% of trials, *SD* = 21.5%) and location-related (M = 56.9% of trials, *SD* = 25.7%) information (Figure 4a). The rate of choosing imagery was higher than that of choosing location ($t[39] = 4.17$, $p < .001$, 95%CI: 0.10–0.28). Of the new words presented during retrieval, an average of 5.08 new words (15.9%) were classified as recollections.

We used a mixed effects model with a dependent variable of word accuracy, fixed effects of each recollection category and random effects of subject and word to investigate how the presence of the recollection categories related to verbal memory performance. This model showed that only location ($\beta = .79$, $p = .004$) and imagery ($\beta = .95$, $p < .001$) were related significantly to accurate memory for the words (Figure 5a). For both location and imagery, experiencing these types of representations was more likely to accompany accurate word memory.

3.1.3 | Objective recollection (source memory)

To assess the effect of recognition response (recollection versus familiarity) and source type (word location versus word color) on source memory performance, a 2 × 2 repeated measures ANOVA was conducted (Figure 6a). There were significant main effects of

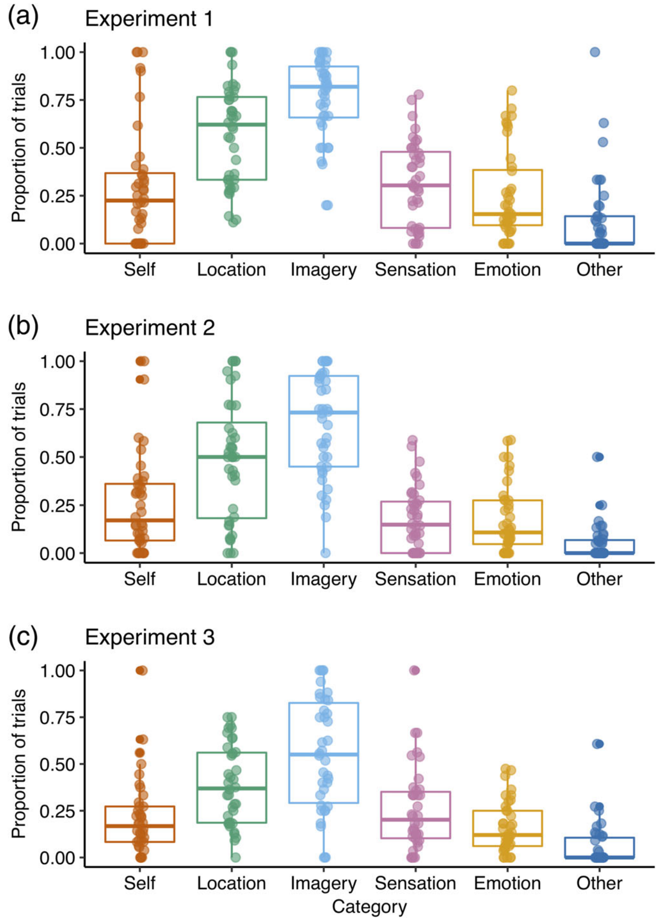

FIGURE 4 Boxplots and individual data points showing the rate of reporting each category when a word was recollected for (a) Experiment 1, (b) Experiment 2, and (c) Experiment 3. Imagery, followed by location, were the most frequently reported categories in all three experiments

recognition response ($F[1,39] = 40.90$, $p < .0010$, $\eta_G^2 = 0.22$) and of source type ($F[1,39] = 7.30$, $p = .01$, $\eta_G^2 = 0.05$), and a significant interaction between recognition response and source type ($F[1,39] = 27.57$, $p < .001$, $\eta_G^2 = 0.05$). Post-hoc comparisons revealed that source memory differed for recollected words, with higher accuracy for word location than word color ($t[39] = 4.08$, $p < .001$, 95% CI: 0.09–0.27), but there was no difference in source accuracy for familiar words ($t[39] = 0.04$, $p = .97$). During recollection, source memory is more accurate for the location of the word than for its color or shape.

Additionally, we computed the probability of getting each type of source memory correct depending on whether the other type of source memory was correct or incorrect. We then conducted a 2 × 2 ANOVA with factors of feature (color or location) and accuracy for the judgment on the other feature (correct or incorrect), and found that the probability of making a correct source judgment was higher if the other feature was also correct ($F[1,30] = 19.61$, $p < .001$, $\eta_G^2 = 0.19$). Thus, source accuracy for location and color were not independent of one another. Location source memory, however, was superior.

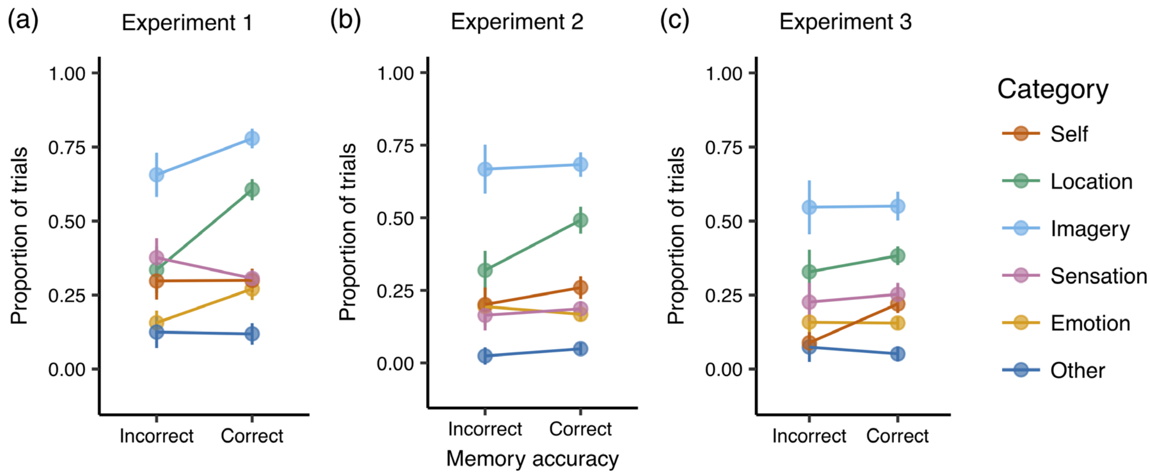

FIGURE 5 The rate of reporting each category, divided by whether the word was accurately remembered or not in (a) Experiment 1, (b) Experiment 2, and (c) Experiment 3. Location and imagery were related to memory accuracy in Experiment 1, location was related to memory accuracy in Experiment 2, and self was related to memory accuracy in Experiment 3, despite being reported less frequently than imagery or location

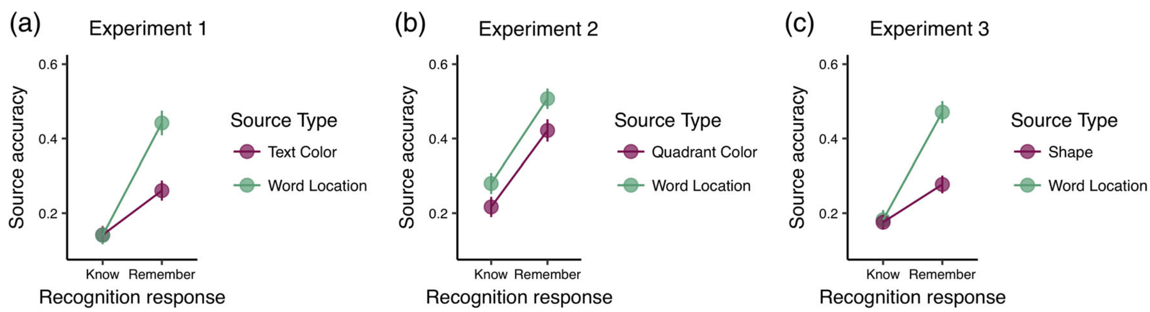

FIGURE 6 Source memory accuracy for remember and know responses in (a) Experiment 1, (b) Experiment 2, and (c) Experiment 3. Word location refers to the quadrant that the word was displayed in for all three experiments. In Experiment 1, the color of the word varied, in Experiment 2, the color of the entire quadrant varied, and in Experiment 3 the shape surrounding the word varied. In all three experiments, source memory for word location was significantly better than the other type of source memory for recollected words

3.2 | Interim discussion: Experiment 1

Experiment 1 demonstrated that recollection of single words is often accompanied by detailed visual imagery and spatial information. When participants identified a word as recollected, they tended to report experiencing location- and imagery-related representations. Imagery was reported more often than location, but both were related to correct memory for the words. The subjective and objective measures of recollection were qualitatively different, however, with participants demonstrating more accurate source memory for the location of the word, than for its color, the latter of which is more closely related to imagery. However, it is important to note that the two forms of source information were not independent of one another, suggesting that a relational or integrated memory was formed that included both types of information.

The possibility remains that source information for color in Experiment 1 was more difficult for participants to remember because only the letters of the word were colored, a subtler manipulation than changing word location. As quadrant information occupied a larger area of the screen than color information in Experiment 1. Thus, our finding in Experiment 1 could be due to task difficulty or the saliency of information presented. In order to equate both the difficulty of the location and imagery source questions and to make the imagery information more salient, in Experiment 2 the background color of the quadrant in which the word appeared was manipulated rather than the color of the word text. The results of Experiment 1 also spurred us to include an additional question in subsequent versions. Given that both location and imagery-related source information were manipulated in Experiment 2 and that location and imagery were the two most reported categories, we wanted to assess whether performance on the source memory task was related to the subjective experience of recollecting color or quadrant, or if participants were subjectively experiencing something else.

3.3 | Results: Experiment 2

3.3.1 | Memory performance

We found that participants were reliably able to remember the words in Experiment 2, with d-prime scores significantly above zero ($t[40] = 10.98$, $p < .001$, 95%CI: 1.11–1.61) (Figure 3b).

3.3.2 | Subjective recollection

In Experiment 2, participants also reported more specific thoughts when they indicated they were recollecting a word (M = 91.6% of trials, *SD* = 15.1%) than when they reported it as familiar (M = 19.4% of trials, *SD* = 21.3%; $t[39] = 15.88$, $p < .001$, 95%CI:0.63–0.81). As in Experiment 1, when words were recollected with specific thoughts, participants reported the highest rates of experiencing both imagery- (M = 67.4% of trials, *SD* = 27.5%) and location-related (M = 48.6% of trials, *SD* = 31.5%) information (Figure 4b), and the rate of choosing imagery was higher than the rate of choosing location ($t[39] = 2.77$, $p = .0086$, 95%CI: 0.05–0.33). Of the new words presented during retrieval, an average of 4.14 new words (12.9%) were classified as recollections.

When reporting location, participants indicated that they were predominantly experiencing memories related to imagined (extra-experimental) locations (M = 57.7% of trials, *SD* = 37.3%) than to source location (M = 31.4% of trials, *SD* = 36.9%), the testing room (M = 8.7% of trials, *SD* = 21%), and other (M = 2.2% of trials, *SD* = 6.7%). Similarly, when reporting imagery, participants indicated a high frequency of memories related to imagined objects (M = 69.2% of trials, *SD* = 31.7%), with lower frequencies reported for source color (M = 19.5%, *SD* = 30.7%), objects in the testing room (M = 2.4% of trials, *SD* = 6.7%), and other (M = 8.9% of trials, *SD* = 17.3%).

A mixed effects model investigating how the presence of the recollection categories related to verbal memory performance showed that, as in Experiment 1, location ($\beta = .64$, $p = .024$) was related to accurate memory for the words (Figure 5b), but in this experiment, imagery was not significantly related to word accuracy ($\beta = .47$, $p = .12$), despite being more frequently reported than location.

3.3.3 | Objective recollection (source memory)

We used a repeated-measures ANOVA to assess the effect of recognition response (recollection versus familiarity) and source type (word location versus quadrant color) on source memory performance (see Figure 6b). We found a main effect of recognition response ($F[1,39] = 37.60$, $p < .001$, $\eta_G^2 = 0.20$) and a main effect of source type ($F[1,39] = 6.76$, $p = .01$, $\eta_G^2 = 0.01$), demonstrating better source memory for recollected words and better source memory for word location compared to quadrant color. The interaction between recognition response and source type was not significant, ($F[1,39] = 0.19$, $p = .66$).

A 2 x 2 ANOVA with factors of feature (color or location) and accuracy for the judgment on the other feature (correct or incorrect), and found that the probability of making a correct source judgment was higher if the other feature was also correct ($F[1,35] = 11.73$, $p = .0016$, $\eta_G^2 = 0.11$). Consistent with Experiment 1, source accuracy for location and color were not independent of one another, although location source memory was superior.

3.4 | Interim discussion: Experiment 2

Experiment 2 replicated our findings from Experiment 1: participants subjectively reported imagery- and location-related information when they recollected words, with imagery information being more prevalent. The location and imagery information was mostly self-generated, imagined (extra-experimental) content, rather than details of the testing environment. In this experiment, only location information was related to accurate word memory. Source memory for word location remained higher than for color information when words were recollected, despite color now occupying the entire quadrant. Participants appear to recollect location-related source information although they more often explicitly report the presence of imagery. As in Experiment 1, the two types of source memory were not independent of one another suggesting that often an integrated, relational memory was formed that included both components.

Our failure to find an interaction between source accuracy (on quadrant and color) and response type (recollected and familiar) could be due to our manipulation of color in this version. Occupying an entire quadrant with color possibly enhanced the spatial nature of the color component, which in turn made the task easier and improved source accuracy for both familiar and recollected items. Another interpretation is that the increased saliency of the color information may have increased its contribution to recollection in this version of the experiment. We interpret the effect of better location memory than color memory for familiar words with caution, since both of these were close to chance (25%). It is possible that source memory for color in Experiments 1 and 2 was more challenging to remember than other kinds of information related to imagery. In order to address this possibility, in Experiment 3, instead of color, we varied the type of shape surrounding the word, in order to provide a different form of non-spatial information for the source memory test.

3.5 | Results: Experiment 3

3.5.1 | Memory performance

Participants were reliably able to remember the words in Experiment 3, with d-prime scores significantly above zero ($t[37] = 14.76$, $p < .001$, 95%CI: 1.19–1.58) (Figure 3c).

3.5.2 | Subjective recollection

As in Experiments 1 and 2, participants reported more specific thoughts when they indicated they were recollecting a word (M = 89.8% of trials, *SD* = 11.2%) than when they reported it as familiar (M = 32.0% of trials, *SD* = 26.1%; $t[37] = 13.25$, $p < .001$, 95%CI:

0.49–0.67). Also consistent with results from Experiments 1 and 2, when words were recollected with specific thoughts, participants reported highest rates of experiencing both imagery- (M = 55.0% of trials, *SD* = 30.5%) and location-related (M = 38.8% of trials, *SD* = 21.5%) information (Figure 4c), and the rate of choosing imagery was higher than the rate of choosing location (t[37] = 3.16, p = .003, 95%CI: 0.06–0.27). Of the new words presented during retrieval, an average of 3.40 new words (10.6%) were classified as recollections.

When reporting location, participants indicated that they were predominantly experiencing memories related to imagined (extra-experimental) locations (M = 57.3% of trials, *SD* = 39.0%) than to source location (M = 32.7% of trials, *SD* = 40.1%), the testing room (M = 6.1% of trials, *SD* = 12.6%), and other (M = 3.9% of trials, *SD* = 10.4%). Similarly, when reporting imagery, participants indicated a high frequency of memories related to imagined objects (M = 69.2% of trials, *SD* = 30.7%), with lower frequencies reported for source shape (M = 15.5%, *SD* = 26.3%), objects in the testing room (M = 1.9% of trials, *SD* = 9.5%), and other (M = 13.4% of trials, *SD* = 24.0%).

A mixed effects model investigating how the presence of the recollection categories related to verbal memory performance demonstrated that, surprisingly, neither location (β = .18, p = .61), nor imagery (β = .60, p = .12) were significantly related to word accuracy. Information relating to the self was significantly related to memory for words (β = 1.02, p = .037) in this experiment, despite being reported less frequently than location or imagery (Figure 5c).

3.5.3 | Objective recollection (source memory)

We used a repeated measures ANOVA to assess the effect of recognition response (recollection versus familiarity) and source type (word location versus word shape) on source memory performance (see Figure 6c). We found a main effect of recognition response (F[1,36] = 42.45, p < .001, η_G^2 = 0.18) and a main effect of source type (F[1,36] = 12.95, p = .001, η_G^2 = 0.001). The interaction between recognition response and source type was significant (F[1,36] = 17.22, p < .001, η_G^2 = 0.002). As in Experiment 1, post-hoc comparisons revealed that source memory differed for recollected words, with higher accuracy for word location than word shape (t[37] = 4.98, p < .001, 95%CI: 0.11–0.27), but there was no difference in source accuracy for familiar words (t[36] = 0.23, p = .82).

A 2×2 ANOVA with factors of feature (color or location) and accuracy for the judgment on the other feature (correct or incorrect), and found that the probability of making a correct source judgment was higher if the other feature was also correct (F[1,36] = 5.19, p = .031, η_G^2 = 0.07). Consistent with Experiments 1 and 2, source accuracy for location and shape were not independent of one another and location source memory remained superior.

3.6 | Interim discussion: Experiment 3

In Experiment 3, we found that participants still reported imagery and location for recollected words more frequently than for other attributes. Again, these tended to represent imagined (extra-experimental) content in both cases. Although self-related information was reported relatively rarely, consistent with Experiments 1 and 2, in Experiment 3 it was found to be related to verbal memory accuracy. Imagery and location were reported much more frequently than self-related information but were not found to be related to verbal memory accuracy. This result was somewhat surprising and could indicate that participants employed different strategies in Experiment 3. Memoranda related to self may be more deeply encoded, resulting in better memory (Craik & Tulving, 1975; Carson, Murphy, Moscovitch, & Rosenbaum, 2016), such as we observe in the present study. Without further insight into the types of self-related thoughts and how participants were using this information, we cannot determine why this category was more related to memory success in this experiment. Nonetheless, our findings for source memory remained consistent with those of Experiments 1 and 2, despite testing participants on shape information rather than color information. Source memory for the word's location was better than source memory for the shape surrounding the word, consistent with the view that spatial context is implicated in memory for single words. However, as in Experiments 1 and 2, shape and location source were not independent, once again suggesting an integration of both memory elements.

4 | GENERAL DISCUSSION

There has been a great deal of research on the relationship of recollection to the hippocampus, but little, if any, on the subjective and objective ways that spatial context underlies the recollection of single words. In this study, we conducted three experiments to test the prediction that spatial context, hypothesized to be mediated by the hippocampus, accompanies recollection, even for single, isolated words. Participants' subjective experience of recollecting studied words was measured using the R/K paradigm and self-report of the types of information used to inform their memory judgments. In addition, we measured recollection more objectively, by having participants make source memory judgments for both spatial and non-spatial features related to the studied words. Overall, the predicted results were obtained: for the subjective measures, we found that recollection of single words entails rich accompanying spatial content on about 50% of the trials across three experiments with only imagery yielding a higher average. On our objective measures, recollection was consistently accompanied by higher performance on the source location judgment than for other source types, while source performance on familiar trials did not differ or differed little.

It is not surprising that imagery was subjectively elicited more often than location during recollection for three reasons. Firstly, location itself depends on having images of a particular place; in accordance with this, participants often classified their recollections along both imagery- and location-based dimensions. Secondly, each trial presented participants with a concrete word, which often elicited an image of its referent. Lastly, different types of imagery may have contributed to recollection, which all fell under the imagery category in the present study. Thus, the category of imagery may be too broad, encompassing not only visual images of the objects denoted by the words themselves, but also other images associated with the words, including location. A recent study of word-pair memory suggested that even pairs of object words may evoke scene imagery in memory (Clark et al., 2018); thus, it is possible that the images associated with single word memories may also include aspects of spatial context that failed to meet participants' criterion for reporting location. Despite imagery being the most frequent category reported across our three experiments, however, it was not consistently related to memory accuracy for the words. The presence of imagery was only related to memory success in Experiment 1. Future studies probing the types of imagery in more detail may be able to further elucidate what forms of imagery contribute to successful memory formation. Using stimuli less evocative of imagery, such as abstract words, may also help to more fully characterize how imagery relates to recollection when it is less directly related to the studied words.

In contrast to imagery, subjective reports of location information were related to word memory in Experiments 1 and 2, implying that spatial context proved beneficial to accurate recollection. It is unclear why the presence of location information was not related to word memory in Experiment 3, however. The failure to find this effect may be due to the fact that, for Experiment 3, subjective reports of location were lower than in Experiments 1 and 2. We instead found that thoughts relating to the self were most related to recollection in Experiment 3. Based on these mixed findings, we think that this study offers partial support for the idea that mental representations of spatial context benefit memory for single words.

It is important, in this regard, to consider the results of our source memory task, which was included to provide a more objective measure of recollection. Here our study revealed better location memory for recollected words in all three experiments, surpassing word color, quadrant color, and shape. This pattern did not hold for words reported as familiar, where memory performance was low for all source modalities, and was only found to differ between source types in Experiment 2. The results of our source memory study are telling: they suggest that objective, imagery-related information, such as the color of the word and the shape surrounding it, are not as closely linked to word memory as location on the screen during recollection. It is noteworthy that when words were classified as familiar, as opposed to recollected, there was little or no difference between source memory accuracy for imagery and location information. Taken together, the subjective and objective measures of spatial context confirm a role for spatial information in the recollection of single words.

Nonetheless, we found that the two types of source memory were not independent of one another, suggesting that they form an integrated representation. Support for this idea comes from Uncapher et al. (2006), where they also find dependency between two forms of source memory, and from work by Horner and Burgess (2013), where dependency was found between individual elements of an event. Thus, it seems that the hippocampus is involved not only in binding together the constituents of more complex experiences into a single memory representation, as with the person-location-object event triads used by Horner and Burgess (2013), but also in establishing more simplistic associations between imagery and location, as in Uncapher et al. (2006) and, we hypothesize, the present study.

Across all three experiments, we further replicated the findings of Uncapher et al. (2006) in that memory for location surpassed memory for the color of the word. We extend these results in two ways. First, we find that this pattern is maintained when compared to other kinds of imagery-based information, such as the quadrant color or surrounding shape. Second, we show that this effect pertains only to recollected words, not those judged as merely familiar, a distinction that was not previously noted. Taken together, our replication of these findings alongside our results on the subjective and objective memory tasks suggest that memory for words, or any stimulus or event for that matter, consists of an integrated memory representation. This representation includes both the information that is presented objectively as well as other information that is invoked subjectively at encoding and subsequently retrieved. The extent of this integration, given that the content of subjective recollection overwhelmingly consists of extra-experimental content, remains unknown. Of the subjective information reported, location and imagery seem to be the most significant in our study—however, in an experiment on the self-reference effect or on emotion, the category of self and emotion respectively may increase in prominence. Whether spatial representations continue to be crucial components of such memories remains to be seen.

The importance of spatial information for memory has been emphasized by a number of theories of hippocampal functioning, including CMT (Nadel et al., 2000), SC (Maguire & Mullally, 2013) and the binding-in-context model (BIC; Diana, Yonelinas, & Ranganath, 2007). Although a number of studies before ours have shown that simplified memoranda, like single words, can automatically generate detailed representations in memory, what is novel about our findings is that a substantial proportion of such complex representations have a spatial component. The results of our study are thus consistent with CMT, SC, and BIC, and with our previous findings on event memory, which together suggest that spatial context is a crucial element of episodic memory and is spontaneously evoked even when unprompted (Robin, 2018; Robin et al., 2016; Rubin, Deffler, & Umanath, 2019; Rubin & Umanath, 2015). Although the original conception of CMT referred to allocentric spatial representations, recent research has suggested that the human equivalent of allocentric place cells in rodents may be analogous to spatial view cells in primates (Rolls and Wirth, 2018; Ekstrom, 2015). Thus, perceived or even imagined spatial information such as the location of a word on the screen or imagined spatial context may be consistent with CMT and dependent on hippocampal mechanisms.

It is common now to interpret CMT as encompassing more than space, reflecting some of Tolman's (1948) original thoughts on the topic which were picked up by O'Keefe and Nadel (1978). The results of the present study illustrate that there are many components that contribute to recollection. We highlight, however, the link between spatial information and recollection by demonstrating that spatial information frequently features even in ostensibly non-spatial tasks. Our study and findings, therefore, are both a throwback to a time when space was considered a defining feature of CMT and hippocampal function as well as a nod to newer, broader conceptualizations of CMT. Mindful of recent developments on conceptual cognitive maps (Bellmund et al., 2018; Collin et al., 2017; Constantinescu et al., 2016; Eichenbaum & Cohen, 2014), and of the perils of drawing correspondences between brain function and behavior, we do not want to suggest that the hippocampus is exclusively concerned with space. Instead, we think our findings revive a number of interesting questions about the relation of space to episodic memory and recollection, about the relation of CMT to MTT, and of both to hippocampal function.

For starters, not all recollections of single words are accompanied by spatial representations. Our findings raise the interesting possibility that the hippocampus is implicated primarily in recollection of single words only if they are accompanied by spatial representations; recollection for words accompanied only by other representations such as imagery, self, emotion, and other categories may be mediated by extra-hippocampal structures. Even though Nadel (Nadel, 1991; O'Keefe & Nadel, 1978) and others (Clark et al., 2018; Maguire et al., 2016; Maguire & Mullally, 2013) have mounted a spirited defense of an explicitly spatial hypothesis of hippocampal function, there have been many studies that argue against this strong conclusion (Barnett, O'Neil, Watson, & Lee, 2014; Duff, Kurczek, Rubin, Cohen, & Tranel, 2013; Eichenbaum et al., 1999; Eichenbaum & Cohen, 2014; Hsieh & Ranganath, 2015; Konkel & Cohen, 2009; Moscovitch, 2008; Tavares et al., 2015). Until we test this strong hypothesis directly, for example, by seeing if hippocampal activation predicts subsequent memory only for words encoded and retrieved with a spatial component, we are willing to accept the lesser claim that space often plays a significant role even for memories of items, such as single words, that ostensibly do not have a spatial component.

This more modest claim allows us to relate CMT to MTT which focuses on the role of the hippocampus in retention and retrieval of rich perceptual details that enable individuals to re-experience events even from the remote past. Our view, based on behavioral and neuroimaging studies, is that space provides a scaffold on which perceptually-rich details of past events are built (Bird & Burgess, 2008; Burgess, Becker, King, & O'Keefe, 2001; Clark et al., 2019; Hassabis, Kumaran, Vann, & Maguire, 2007; Hassabis & Maguire, 2007; Robin, 2018; Robin et al., 2016; Robin, Buchsbaum, & Moscovitch, 2018; Rubin, Deffler, & Umanath, 2019; Rubin & Umanath, 2015). What the current study suggests is that similar mechanisms are at play in memory for single words—perhaps not always, but far more often than one would have predicted based on the fact that words are encoded as single, non-associative items. Thus, theories of hippocampal functioning such as CMT and MTT which posit a special role for the hippocampus in detailed and spatial representations in memory can accommodate memory for stimuli like single words given that their subjective recollection is associated predominantly with rich imagery- and location-related information. Furthermore, our finding that source memory for location and imagery are not independent suggest that a highly relational memory representation is formed, indicative of the perceptual re-experiencing associated with recollection. Based on these theories and our findings, we would predict that in cases of rich recollection for single words accompanied by spatial information, the hippocampus would be involved in supporting such memories.

A limitation of the present study design is that our subjective recollection measures relied on participant introspection and self-report to classify the contents of memory. Based on these reports, imagery was the most frequently reported category during recollection, despite poorer performance on source memory for color and shape. It is possible that participants tend to report imagery the most due to expectations that memory is imagery-based or because this category is most easily noted in subjective reports. Despite our instructions, participants may have also classified some forms of spatial information as imagery. As we found in Experiment 2 and 3, there was variation in the types of imagery and spatial information recollected across trials, though in both cases imagined content was the most frequent. Thus, the types of imagery evoked on a given trial may differentially contribute to recollection success. For example, memory may benefit only from images related to the words and not from images that are unrelated. In contrast, it is possible that even unrelated spatial context information may boost memory for words by providing a spatial background for the word, resulting in a richer associative memory. Whether our findings indicate a true difference in subjective and objective memory or simply participant expectations and awareness is unclear.

Another limitation is that subjective reports of recollection were indicated from a list of predetermined categories. Despite designing our instructions to target the non-spatial aspects of these categories, a number of them may contain fundamentally spatial elements. For example, self could be associated with a number of significant locations tied to one's self-concept. The inherently spatial nature of some of our categories notwithstanding, it is still noteworthy that location is explicitly reported to such a high degree. If spatial information is also included, but not reported, on some trials when the participants report imagery or self, it only reinforces our claim that spatial information frequently features as part of recollection. Thus, our results represent the frequency at which participants are *aware* of a spatial component of recollection, which may underestimate the latent spatial features of other types of recollective experiences.

Additionally, participants always viewed the source memory questions for location and imagery prior to reporting which categories they recollected about the word. This procedure may have influenced them to report location and imagery more than they would have otherwise. After observing this tendency in Experiment 1, we added a question in Experiments 2 and 3 to address whether first answering the source question resulted in explicit recollection of the source information. The results of this additional question revealed that when participants selected location and imagery as thought, they overwhelmingly indicated recollections involving imagined, extra-experimental locations or objects, respectively, rather than information about source location or imagery. This observation suggests that participants were not biased toward picking location and imagery due to the task design.

We cannot completely rule out that the source memory task, in which location and imagery were manipulated, influenced the subjective reports in some way. It is clear, however, that our objective and subjective measures of recollection were at least somewhat independent, with participants explicitly reporting their memories for imagined locations and objects more often than memories for quadrant or imagery source information. Further work is needed to explore how experimentally manipulated measures of recollection, such as source memory, interact with self-generated elements of recollection including imagery and imagined spatial context.

We also note that, across all three experiments, there are substantially more female, than male, participants. There is some evidence to suggest that women show better performance on verbal memory tasks than men (Herlitz & Rehnman, 2014), but this is likely to be an effect that fluctuates across the menstrual cycle (Rosenberg & Park, 2002). Performance on visuospatial tasks has also been found to differ according to sex, with women showing a disadvantage compared to men (Herlitz & Rehnman, 2014), but this effect is inconsistent across the literature investigating sex differences in spatial tasks (Rosenberg & Park, 2002). Furthermore, studies taking menstrual cycle phase into account find that performance on visuospatial tasks also varies as a function of estradiol level (Hausmann, Slabbekoorn, Van Goozen, Cohen-Kettenis, & Guntiirkun, 2000; Postma, Winkel, Tuiten, & Van Honk, 1999). Thus, as menstrual cycle phase is assumed to vary randomly across participants, any effects on verbal or spatial memory that could be expected as a function of a predominantly female sample is not expected to influence our results significantly. Nonetheless, it would be worthwhile to investigate the effects of sex or gender in our tasks more systematically.

The present study set out to investigate spatial contributions to the objective and subjective recollection of single words. Although objective and subjective recollection were found to be different from each other, a common thread emphasizing the involvement of spatial information is evident—whether in the form of source memory for the location of a word or reported location-related memories accompanying recollection. Imagery also was found to frequently play a role in recollection, though source memory for imagery-related content was worse than for location. Our findings indicate that although it may be possible to remember a single word without a spatial component, single words are often recollected with spatial elements that can go unnoticed in other studies. As such they support a reconciliation between the allocentric spatial representations of CMT and the detailed episodic memories of MTT, as envisioned by Nadel (1991, 2000), and supported by others (Diana et al., 2007; Maguire & Mullally, 2013; Robin, 2018). Indeed, we can safely say that without the work of Nadel and his collaborators, it is unlikely that a study on the role of spatial context on memory for single words would ever have been undertaken, and the finding on the ubiquity of space in memory would have gone unreported, and perhaps undetected.

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DATA AVAILABILITY STATEMENT

The data and materials from this study are available from the corresponding author upon request.

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