On the relationship between trait autobiographical episodic memory and spatial navigation

Carina L. Fan^{1,2} · Hervé Abdi³ · Brian Levine^{1,2,4}

Accepted: 29 August 2020 / Published online: 13 October 2020
© The Psychonomic Society, Inc. 2020

Abstract

Influential research has focused on identifying the common neural and behavioural substrates underlying episodic memory (the re-experiencing of specific details from past experiences) and spatial cognition, with some theories proposing that these are supported by the same mechanisms. However, the similarities and differences between these two forms of memory in humans require further specification. We used an individual-differences approach based on self-reported survey data collected in a large online study ($n = 7,487$), focusing on autobiographical episodic memory and spatial navigation and their relationship to object and spatial imagery abilities. Multivariate analyses replicated prior findings that autobiographical episodic memory abilities dissociated from spatial navigational abilities. Considering imagery, episodic autobiographical memory overlapped with imagery of objects, whereas spatial navigation overlapped with a tendency to focus on spatial schematics and manipulation. These results suggest that trait episodic autobiographical memory and spatial navigation correspond to distinct mental processes.

Keywords Autobiographical memory · Episodic memory · Navigation · Visual imagery · Individual differences

Introduction

An influential body of animal and human research has investigated the overlapping neural and behavioural substrates of episodic memory (i.e., the recall and re-experiencing of details from past events with a specific spatiotemporal context; Tulving, 1972, 2002) and spatial cognition. This work began with Tolman's (1948) conceptualization of a cognitive map, used in spatial navigation and in guiding cognitive behaviour more broadly. Theoretical and experimental work in this field

has proliferated in the past decade, particularly in trying to reconcile the role of the hippocampus in both memory and spatial cognition (Buzsáki & Moser, 2013; Collin, Milivojevic, & Doeller, 2017; Ekstrom & Ranganath, 2018; Schiller et al., 2015). These studies seek to provide an integrative framework for how the hippocampus's critical roles in both spatial and episodic memory can be explained using the same fundamental processes.

Cognitive map theory posits that the brain builds a unified representation of the spatial environment in order to navigate, and that this process is also used to support memory and guide future action in other cognitive domains (e.g., Behrens et al., 2018; Ekstrom & Ranganath, 2018; Schiller et al., 2015). This work mostly stemmed from rodent research, especially from the discovery of place cells in the rodent hippocampus (O'Keefe & Nadel, 1978). These cells are active when a rodent revisits a particular spatial location, and researchers have extended these findings to other mammals (e.g., Poulter, Hartley, & Lever, 2018), including monkeys (e.g., Rolls & Wirth, 2018) and humans (e.g., Bellmund, Gärdenfors, Moser, & Doeller, 2018). With respect to human episodic memory, cognitive map theory proposes that we form a map-like representation of memories in time and space, and that the processes supporting navigation through physical space also support navigation through our episodic memories (Epstein, Patai, Julian, & Spiers, 2017). An implication of this

Electronic supplementary material The online version of this article (<https://doi.org/10.3758/s13421-020-01093-7>) contains supplementary material, which is available to authorized users.

✉ Carina L. Fan
carina.fan@mail.utoronto.ca

✉ Brian Levine
blevine@research.baycrest.org

¹ Department of Psychology, University of Toronto, Toronto, Ontario, Canada

² Rotman Research Institute, Baycrest, Ontario, Canada

³ School of Behavioral and Brain Sciences, The University of Texas at Dallas, Dallas, TX, USA

⁴ Department of Medicine (Neurology), University of Toronto, Toronto, Ontario, Canada

view might be that strong navigation abilities correspond to better episodic memory. While little research exists to address this possibility, some evidence suggests that this is not the case (Berntsen, Hoyle, & Rubin, 2019; Clark et al., 2019).

A related stream of research has investigated the overlap between spatial processing and episodic memory by focusing on scene construction (Hassabis & Maguire, 2007; Rubin & Umanath, 2015). Unlike the foundational studies on cognitive map theory, scene construction and related theories have focused on human episodic memory, particularly autobiographical episodic memory, or memory for specific episodes from one's life (as opposed to episodic memory for laboratory stimuli), and the use of visual processes to construct detailed recollections. According to scene construction theory, an image of the spatial context or location serves as a scaffold for elaboration with additional details. It follows that individuals who are able to form strong and vivid mental images of scenes should have a corresponding benefit in recollecting past autobiographical episodes (Conway, 2005; Greenberg & Knowlton, 2014).

These two influential bodies of research emphasize different aspects of spatial memory: map-like spatial representations versus memory for contexts and scenes. Studying individual differences in these abilities can provide a theoretical framework in which to understand the relative contributions of different aspects of spatial processing to memory retrieval (Underwood, 1975), but there has been relatively little research on the relationship between spatial and episodic autobiographical memory abilities across individuals (for an exception, see Clark et al., 2019). In the present report, we use an individual-differences approach among healthy adults to evaluate the relationships between spatial cognition and episodic autobiographical memory. We sought to assess these relationships at the trait level using self-reported capacities for episodic autobiographical memory and spatial navigation in naturalistic contexts.

Trait-based, individual-differences measures of memory provide an important distinction and complement to both performance- and laboratory-based measures. First, there is a distinction between trait- and performance-based measures of autobiographical memory. Trait-level autobiographical memory abilities reflect general tendencies in how individuals recall memories (Palombo, Sheldon, & Levine, 2018; Sheldon, Farb, Palombo, & Levine, 2016); this is in contrast to performance-based measures of autobiographical memory that involve the recall and description of a select few, often well-rehearsed, events (e.g., Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). As such, individuals with low trait-level autobiographical episodic memory abilities may tend not to retrieve details when recalling memories in everyday life yet still may generate many seemingly episodic details when recalling a particular event during an autobiographical memory task (Palombo, Alain, Söderlund, Khuu, & Levine,

2015), because the memory selected for the task was one of the few that did incorporate some episodic re-experiencing for the individual, or because the memory was well rehearsed and the individual “knows” the details without re-experiencing them, or some combination of the two. This could account for the relative lack of association between trait and performance measures of autobiographical memory (Clark & Maguire, 2020; Palombo, Williams, Abdi, & Levine, 2013), although when a sample is carefully selected to cover a broad range of trait mnemonic abilities, then an association between trait- and performance-based measures does emerge (Armson, Diamond, Levesque, Ryan, & Levine, 2020).

Second, there is a distinction between measures of autobiographical episodic memory, which involve the rich recollection of personal past episodes, and traditional laboratory-based episodic memory measures, which often involve the recollection of lists of simple stimuli such as words or pictures (Gilboa, 2004; McDermott, Szpunar, & Christ, 2009). Furthermore, there is inter-individual variability in baseline naturalistic memory abilities that many studies fail to consider and integrate when examining cognitive processes by relying on group differences (Goodhew & Edwards, 2019). Thus, our approach to assessing the relationship between naturalistic episodic autobiographical memory and spatial cognition abilities from an individual-differences perspective provides a novel framework in which to address the question of their relationship.

This study builds upon earlier research using the Survey of Autobiographical Memory (SAM; Palombo et al., 2013), an instrument that we developed to measure self-reported episodic autobiographical, semantic, spatial, and future thinking abilities. In a sample of 598 university students, our data-driven analyses demonstrated that episodic autobiographical memory and navigation abilities as measured by the SAM were orthogonal – an effect that was unexpected given the above-described body of research on memory and navigation. In the present study, our first aim was to replicate this finding in separate samples. Our second aim was to examine how individual differences in visual imagery – particularly object imagery (imagery for specific object features such as shape and colour) and spatial imagery (imagery for spatial relationships and transformations) as measured by the Object-Spatial Imagery Questionnaire (OSIQ; Blajenkova, Kozhevnikov, & Motes, 2006) – contribute differentially to episodic memory and spatial navigation abilities. Individuals scoring high on the object subscale of the OSIQ can form detailed mental images of scene components, and according to scene construction theory, these individuals should have strong episodic autobiographical memory abilities. On the other hand, individuals scoring high on the spatial subscale of the OSIQ can easily form schematic representations such as blueprints of environments, and according to cognitive map theory, these individuals should have strong episodic autobiographical memory abilities.

Methods

Participants

Participants were drawn from responses to an online survey that we created as a platform for research participation in response to media reports on our work on severely deficient autobiographical memory (SDAM; Palombo et al., 2015). The present study includes records collected from April 2015 to October 2019, after which recruitment declined and additional records did not substantively add to our dataset. While not random, given its large number of respondents this sample nonetheless provides information concerning the dimensional structure of episodic memory and spatial navigation abilities and their relationship to visual imagery. Extensive cleaning of the dataset was conducted to assess the cognitive and neurological health of this sample. To evaluate the generalizability of our results, we replicated key findings from this sample in two separate previously collected datasets (see [Online Supplemental Materials](#) [OSM]). Participants who completed this short study as well as a longer follow-up online study were compensated with a \$10 gift card. We did not specify an a priori target sample size; rather, we left our online survey open and aimed to collect as many responses as possible.

Exclusions Of the 18,189 survey responses recorded, 3,241 responses were blank in the fields of interest (i.e., only had data such as location coordinates, but not for our questionnaires), indicating either non-human responses or human respondents looking for compensation without actually completing the questionnaires, and were thus removed from the dataset. For multiple survey responses listed with the same email address, only the first response was kept (260 emails were associated with two or more responses). In addition, responses were removed if they were completed in an implausibly short length of time (i.e., less than 3 min, $n = 992$). Participants with fewer than 9 years or greater than 26 years of education were excluded ($n = 656$), as were participants under the age of 18 years ($n = 3$).

We included two “catch” questions as part of the online survey to ensure participants were paying attention and were human (rather than “bots”), in which participants were asked to select a specific point on a Likert scale (e.g., “For this question, please select ‘Totally agree.’”). We also included a text catch in which participants had to answer “What is 3 plus seven” in a text box. Responses that failed one or more of the catch questions were excluded from analyses ($n = 4,055$).

After these preliminary cleaning steps, participants who endorsed a history of major neurological conditions were excluded from the dataset (head injury with loss of consciousness >15 min, $n = 465$; stroke, $n = 35$; dementia, $n = 20$; epilepsy, $n = 155$; brain surgery, $n = 50$; cancer, $n = 156$; psychotic disorder requiring hospitalization, $n = 147$; learning

disorder, $n = 637$; alcohol/drug abuse, $n = 777$), as were participants who reported a significant decline in cognition over the past few years that affects everyday function ($n = 502$). Furthermore, participants who scored 20 or higher on the Patient Health Questionnaire depression module (PHQ9; Kroenke, Spitzer, & Williams, 2001), indicating severe depression, were excluded ($n = 532$). All participants who met these exclusionary criteria but otherwise provided valid data were nonetheless compensated for their participation, reducing the likelihood of under-reporting health conditions in order to receive compensation.

After all exclusions, our sample comprised 7,487 adults aged 18–85 years ($M = 40.00$, $SD = 14.23$). On average, the sample had 16.92 years of education ($SD = 3.15$), and included 4,954 females, 2,451 males, and 82 individuals who indicated “Prefer not to answer” with respect to gender.

Measures

Our complete online survey materials can be found on the Open Science Framework (OSF) at <https://doi.org/10.17605/OSF.IO/JD4Q8>. The survey took 10–15 min to complete and was hosted on Qualtrics. Only the measures of interest for the current study are described in more depth here.

To measure episodic autobiographical memory and spatial navigation abilities, we used the Survey of Autobiographical Memory (SAM; Palombo et al., 2013). The SAM is a validated (Petrican, Palombo, Sheldon, & Levine, 2020; Sheldon et al., 2016) self-report questionnaire designed to assess trait-level autobiographical memory abilities in four domains: episodic, spatial, semantic, and future. The spatial items on the SAM largely assess navigation abilities (as opposed to other spatial processes such as scene construction; Selarka, Rosenbaum, Lapp, & Levine, 2019). Items were rated on a Likert scale from 1 (strongly disagree) to 5 (agree strongly). Total scores on each of the four memory domains can be derived using a weighting algorithm on the raw item ratings, developed during the original validation of the SAM, but in the present study we calculated domain scores by averaging the raw scores across items, to preserve the scale of measurement for purposes of comparison with our other key questionnaire of interest.

Imagery ability was assessed using the OSIQ (Blajenkova et al., 2006). The OSIQ measures two domains of imagery: (1) object imagery, or the ability to vividly imagine specific features such as colour and shape; and (2) spatial imagery, or the ability to imagine spatial relations and transformations. However, not all the items on this questionnaire load cleanly on one or the other domain; several have factor loadings that are equal in magnitude but opposite in direction on both domains, a pattern indicating that they are not measuring *either* object or spatial imagery but rather tapping into both. Our participants completed the full questionnaire, but we used a

reduced set of items (seven object and seven spatial). These items were selected on the basis of a principal components analysis (PCA) that identified the items that loaded cleanly onto two orthogonal dimensions (Eslami, Fan, Levine, & Abdi, 2020). Items were rated on a Likert scale from 1 (totally disagree) to 5 (totally agree). Object and spatial imagery scores were each calculated by taking the average of all the items in that domain.

Finally, we included measures of personality (Big Five Inventory; John, Donahue, & Kentle, 1991; John, Naumann, & Soto, 2008) and depression (PHQ9; Kroenke et al., 2001) in order to rule out alternative explanations for the anticipated relationships between the SAM and OSIQ. Analyses of these measures can be found in the OSM.

Statistical analysis

Although we previously used multiple correspondence analysis to take into account the qualitative nature of Likert ratings in developing and validating the scale (Palombo et al., 2013), we use PCA here because it is more intuitive to visualize and understand. PCA is generally conducted on standardized scores, but since all the variables in this analysis were already on the same scale, we conducted the analysis on mean-centred but unstandardized scores. All analyses were conducted using R version 4.0.2. PCA was run using the *ExPosition* package (version 2.8.23; Beaton, Fatt, & Abdi, 2014). To address the relationship between the SAM and OSIQ, we first ran linear models with effect sizes obtained using the *lmsupport* package (version 2.9.13; Curtin, 2018). We next ran a partial least squares correlation (PLSC) using the *TInPosition* package (version 0.13.6.1; Beaton et al., 2014). While inferential statistics can be obtained (e.g., via bootstrapping methods) for both PCA and PLSC, we focused here on interpreting visualizations and on the magnitude of contributions, because our large sample size leads to highly precise estimates and thus very low *p*-values for almost every effect investigated, regardless of its size, theoretical significance, or importance. Our complete analysis scripts and output can be found at our OSF link.

Results

We first examined the factor structure of the SAM to replicate the finding in the original validation report that episodic autobiographical memory and spatial navigation abilities were independent (Palombo et al., 2013). To begin with, we conducted a PCA on the dataset reported on by Palombo et al. (2013; originally analyzed using multiple correspondence analysis) in order to validate this approach. As expected, this analysis replicated the main conclusions from the multiple correspondence analysis (see OSM).

We then conducted a PCA on the SAM in the present, larger data set (Fig. 1, bottom left and right). The scree plot (Fig. 1, top left) suggested five significant dimensions, but we focus on the first two dimensions here (visualizations of Dimensions 3–5 can be found in the OSM). The first dimension, explaining 27.18% of the variance, reflected overall high memory abilities across the domains. We previously demonstrated that the episodic and semantic items from Dimension 1 can be dissociated as they differentially relate to gender, mood, and memory performance (Palombo et al., 2013; see also Armson et al., 2020; Berntsen et al., 2019; Coutanche, Koch, & Paulus, 2020; Sheldon et al., 2016). We therefore treated these sets of items as distinct in subsequent analyses. The second dimension, explaining 12.94% of the variance, separated spatial items from items in the other three domains. As reported in the OSM, this factor structure was unrelated to gender, personality dimensions as measured by the BFI, or depressive symptoms as measured by the PHQ9, and it replicated in two independent samples of participants. This replication speaks to the overall stability of the SAM's factor structure, given that our sample was biased towards individuals with an interest in their own memories; the fact that the factor structure of the SAM held in two large independent datasets composed of participants not recruited on the basis of memory abilities supports the validity of the present findings.

Next, we assessed the relationship between the SAM and OSIQ, using both univariate and multivariate analyses. We first used linear regression to determine the differential contributions of OSIQ object versus spatial scores to SAM scores in each of the four domains, although we note that these analyses are limited in that: (1) domain scores are averaged across items and do not tell us about the relations between specific items, and (2) the four memory domains must be assessed in four separate models and do not allow for comparison of the relationship between the OSIQ and SAM domains in a single analysis. However, the regressions provide an intuitive way to understand the relationships between each domain, and we follow them up with multivariate visualizations and analyses that illustrate the same patterns of results at the item level.

The results from the four regressions are shown in Table 1. To correct for multiple comparisons the α level was set at 0.0125 (i.e., Bonferroni adjustment: .05/4). Given the size of our sample, all of the regression results were statistically significant; as such, we looked to the magnitude of partial η^2 to interpret the size of each effect. Critically, object and spatial imagery did not contribute equally to each of the four memory domains (Fig. 2): for episodic memory and future thinking, object imagery had a substantially larger effect size than spatial imagery did in predicting memory scores. The reverse was true for spatial navigation abilities: spatial imagery had a larger effect than did object imagery. There was no notable difference between object and spatial imagery in predicting semantic memory abilities. These findings were replicated in an

Fig. 1 Results of a principal components analysis on the Survey of Autobiographical Memory (SAM). **Top left:** Scree plot. **Bottom left:** Loadings of each subject on the first two dimensions. **Right:** Loadings of each SAM item on the first two dimensions. The horizontal axis on the latter two plots represents the first dimension, and reflects an overall high memory ability across domains. The vertical axis represents the second

dimension, and separates spatial navigation abilities from episodic and semantic memory as well as future thinking. Each point represents one SAM item (**right**) or one subject (**bottom left**), and letters in the item plot (**right**) represent the SAM domain: E = episodic, S = spatial, F = future, M = semantic. See OSM for full items corresponding to each label

independent sample and unaffected by the inclusion of a measure of social desirability derived from the BFI (see OSM).

While these univariate results give compelling indications about the relationship between episodic and spatial memory and imagery, our multivariate analyses incorporated the various factor scores in a single model and provided better visualization of the data. One multivariate approach is to project the OSIQ items into the factor space of SAM (see OSM); however, this simple visualization technique does not simultaneously analyze items from both questionnaires. To explicitly analyze the information common to the SAM and OSIQ,

we conducted a partial least squares correlation (PLSC) analysis on the items of the SAM and OSIQ. This analysis derives latent variables (LVs) that describe the shared variance between two sets of data, in this case the SAM items and the OSIQ items (Abdi & Williams, 2013).

Visual inspection of the questionnaire items in the first two dimensions resulting from this analysis (Fig. 3, right) indicated that, as predicted, spatial navigation abilities separated from other autobiographical memory abilities on the second dimension, but clustered together with spatial imagery items. Object imagery items tended to cluster with episodic, future,

Table 1. Regression results for models of each Survey of Autobiographical Memory (SAM) domain score (rows) predicted by object and spatial imagery scores

	Model R^2	Object					Spatial				
		β	SE	t	P	η^2	β	SE	t	p	η^2
Episodic	.33	0.52	0.01	57.26	< .001	.30	0.06	0.01	6.25	< .001	.005
Spatial	.19	0.09	0.01	8.55	< .001	.01	0.41	0.01	38.16	< .001	.16
Future	.53	0.84	0.01	84.17	< .001	.49	0.13	0.01	12.51	< .001	.02
Semantic	.06	0.16	0.01	16.00	< .001	.03	0.09	0.01	9.31	< .001	.01

Fig. 2 Scatterplots of regression analyses predicting domain scores on the Survey of Autobiographical Memory (SAM) with object and spatial imagery scores on the Object-Spatial Imagery Questionnaire (OSIQ). Points have been jittered to allow for better visualization of the spread of data

and semantic memory on the vertical dimension. These relationships were also apparent from the heat map of Pearson correlation coefficients between each of the items of the SAM and OSIQ (see OSM).

The scree plot (Fig. 3, left) indicated that the first two dimensions explained most of the variance decomposed by the PLSC (Dimension 1, 89.27%; Dimension 2, 9.85%); as such, we examined the contributions of each questionnaire item to the first two sets of latent variables (Fig. 4). LV1 reflected object imagery items, along with episodic autobiographical memory and future-thinking items. LV2 reflected spatial imagery items and spatial navigation items, although two semantic memory items also loaded just above average in the same direction as the spatial items and one future item loaded just above average in the opposite direction. However, the contributions of the spatial

navigation items clearly exceeded the average contribution as well as the contributions of these three other memory items – a configuration providing evidence for a clear dissociation between episodic memory, future thinking, and object imagery on the one hand, and spatial imagery and spatial navigation abilities on the other hand. We also conducted a PLSC on the SAM and OSIQ in an independent sample and replicated these results (see OSM).

Discussion

Researchers have recently increased their efforts to unify episodic memory and spatial cognition in a single theoretical framework that can account for the many similarities, both

Fig. 3 Results of a partial least squares correlation analysis on the Survey of Autobiographical Memory (SAM) and Object-Spatial Imagery Questionnaire (OSIQ). **Left:** Scree plot. **Right:** Loadings of the SAM and OSIQ items in the partial least squares analysis. The horizontal axis represents the first dimension, and reflects an overall high memory and imagery ability across domains. The vertical axis represents the second

dimension, and separates spatial navigation and spatial imagery abilities from episodic, future, and semantic memory, as well as object imagery. Each point represents one SAM or OSIQ item. Uppercase letters represent SAM domains: E = episodic, S = spatial, F = future, M = semantic. Lowercase letters represent OSIQ domains: o = object, s = spatial. See OSM for full item corresponding to each label

on cognitive and neural levels, between the two systems (e.g., Buzsáki & Moser, 2013). There has been relatively little research in humans relating episodic and spatial memory

abilities to other cognitive traits within an individual-differences framework. We found that episodic autobiographical memory and spatial navigation abilities are distinct, and

Fig. 4 Contributions of each item on the Survey of Autobiographical Memory (SAM) and Object-Spatial Imagery Questionnaire (OSIQ) to each of the first two latent variables resulting from a partial least squares correlation analyses between the two questionnaires. The dotted line in each plot indicates the absolute value of the average contribution;

coloured bars indicate contributions of items that exceed this average in magnitude. Each bar represents one SAM or OSIQ item. Uppercase letters represent SAM domains: E = episodic, S = spatial, F = future, M = semantic. Lowercase letters represent OSIQ domains: o = object, s = spatial

that the relationships of these abilities to forms of visual mental imagery shed new light on the differential processes underlying episodic memory and spatial processing.

We first replicated findings from previous reports using the SAM (Palombo et al., 2013) showing that self-reported spatial navigation ability is independent from episodic and semantic memory and future autobiographical thinking when analyzed in a multidimensional space (see also Berntsen et al., 2019). While there is shared variance in overall spatial navigation and memory abilities, as evidenced by the first dimension in the PCA and PLSC analyses (likely owing to the positive manifold; Spearman, 1925), spatial navigation is orthogonal to episodic memory and future thinking in the second dimension. This finding aligns with previous work showing that SAM-spatial (but not SAM-episodic) scores relate to navigation performance (Clark et al., 2019; Selarka et al., 2019), but it stands in contrast to the body of work emphasizing the overlap between the processes driving spatial navigation and episodic memory, as in cognitive map theory, where spatial navigation and episodic memory are viewed as different instantiations of the same underlying process.

One reason for this discrepancy could be the rodent-based research methods and history that cognitive map theory is built upon. This theoretical framework stemmed largely from work investigating the role of the hippocampus – a structure well accepted to be crucial in both navigating spatial environments and constructing detailed episodes from past experiences (e.g., Burgess, Maguire, & O’Keefe, 2002). The discovery in the rodent hippocampus of place cells, which fire when the animal revisits a particular spatial location, was seminal in setting the groundwork in this area, and researchers have been eager to extend these findings to learn more about human navigation and memory. However, further study found that while hippocampal neurons in rodents respond mainly to the place where the animal is located, analogous hippocampal neurons in primates – sensitive to foveation and a highly developed visual system – respond to where a monkey is looking (Rolls & Wirth, 2018). It is possible that the hippocampal system began as a navigational system, as in rodents, but through evolution developed representations for more complex spatial and temporal information, forming the basis of episodic memory (O’Keefe, Burgess, Donnett, Jeffery, & Maguire, 1998) – but the extent to which rich episodic memory retrieval in humans depends on navigational processes remains in question.

An alternative to cognitive map theory views scene construction as the key component linking spatial and episodic memory and aligns with the idea that the human hippocampal system has developed to emphasize visual processing (rather than mental maps) to reconstruct memories of past events (Hassabis & Maguire, 2007; Rubin & Umanath, 2015). Recent work has corroborated this view, showing that navigation and non-spatial episodic memory can be dissociated in healthy adults (Ngo, Weisberg, Newcombe, & Olson, 2016).

Furthermore, patient work shows that scene memory and episodic memory are similarly supported by the medial temporal lobes, whereas more schematic forms of spatial memory, such as navigation, are independent (Robin, Rivest, Rosenbaum, & Moscovitch, 2019). Accordingly, we found that the ability to form vivid mental images of specific objects and scenes corresponded to episodic memory ability. The ability to imagine schematics and spatial relationships between items, on the other hand, corresponded more closely with spatial navigation ability and demonstrated dissociations from object imagery and episodic memory. This finding suggests that the importance of spatial processing in episodic memory retrieval may not be in the mapping process, but in the construction of a spatial context to which further event details can be added (Hassabis & Maguire, 2007).

Our results contribute to the body of work investigating the relationship between visual imagery and autobiographical memory. Previous studies have yielded mixed results. Vannucci, Pelagatti, Chiorri, and Mazzoni (2016) showed that – compared to those reporting low object imagery – individuals reporting strong object imagery were faster to generate autobiographical memories in response to cue phrases and reported more sensory and perceptual details and associated visual images in their memories; however, Sheldon, Amaral, and Levine (2017) found that interfering with visual imagery processes impeded recall of event details (particularly spatial ones) more for individuals high in spatial imagery, while its impact did not differ for individuals with differing object imagery abilities. Aydin (2018) found that object imagery was related to phenomenological characteristics such as the level of sensory and perceptual details retrieved in relation to past experiences, whereas spatial imagery predicted the level of episodic specificity of past events. Clark et al. (2019) reported that navigation performance dissociated from autobiographical memory retrieval and scene construction, and they speculated that navigation reflects schematic spatial imagery, whereas autobiographical memory draws upon vivid imagery for objects and scenes. They also suggested that a dissociation of function along the long axis of the hippocampus underlies this effect, such that navigation and spatial imagery rely on posterior subregions, whereas episodic memory and object imagery rely on anterior subregions. This could also be a potential neural substrate of our finding that vivid object imagery was associated with rich self-reported episodic autobiographical memory, while spatial imagery tapped into the relatively independent construct of navigational ability.

Our findings also align with evidence from individuals with aphantasia, who report having no phenomenological experience of visual mental imagery and have correspondingly low OSIQ-object scores, yet have OSIQ-spatial scores matching those of controls (Dawes, Keogh, Andrillon, & Pearson, 2020; Keogh & Pearson, 2018). Like individuals with SDAM, those with aphantasia report a lack of subjective

reliving when they remember past experiences (Greenberg & Knowlton, 2014; Zeman, Dewar, & Della Sala, 2015, 2016), a pattern indicating that intact spatial imagery is not sufficient for episodic autobiographical memory recall.

While we focused here on interpreting the relationship between self-reported episodic memory and spatial navigational abilities, it is worth noting that future autobiographical thinking was also highly related to episodic memory and seemed even more strongly dissociated from spatial navigation abilities (Addis & Schacter, 2012). The future subscale of the SAM largely assessed individuals' ability to imagine specific future events, and may have thus acted as an indirect measure of detailed object imagery. Future work may be better able to dissociate detailed imagery for future scenes versus the imagination of a series of events unfolding in the future, and address how these forms of future thinking relate to episodic memory and spatial navigation.

A limitation to these findings is the use of self-report as opposed to performance-based measures. In particular, there is evidence that self-reported autobiographical memory abilities do not always correspond to performance on autobiographical memory tests (Clark & Maguire, 2020; but see Armson et al., 2020); this dissociation could be due to measurement differences across tests of trait (i.e., lifetime) abilities versus tests of recall for single events, which can be accomplished with non-episodic processes or, depending on how events are cued, may not reflect one's propensity to episodically re-experience events in general (Palombo et al., 2015; see also Fan, Romero, & Levine, 2020). As for navigation, there is a closer coupling between trait- and performance-based measures (Selarka et al., 2019), possibly because objective feedback is more readily available for navigation (i.e., whether or not one has arrived at the destination) than for autobiographical memory, particularly the subjective aspect of re-experiencing, for which there is often no objective criterion. Moreover, our findings concur with those reported in relation to spatial navigation performance (Clark et al., 2019), and we conducted detailed control analyses to rule out several alternative explanations, such as an overall social desirability bias in self-report (see OSM). Nonetheless, further work augmenting findings from trait measures with performance measures will help clarify the nature of these relationships.

Another caveat to our interpretation is that our measure of navigation ability focused on navigating familiar environments, whereas the cognitive map theory literature largely studies new-route learning; and the OSIQ-object scale focuses on measuring imagery vividness, whereas scene construction theory also emphasizes the coherent integration of scene components. While the current findings cannot speak to these aspects of the distinction between cognitive map and scene construction theory, they provide a novel piece in this puzzle by focusing on individual differences in memory and spatial abilities as lifelong traits, rather than as measured by task

performance. Finally, although our sample was not random, as indicated earlier, its large size and our supplemental control analyses render it no less generalizable to the healthy adult population than are conventional small samples of college undergraduates. We also replicated our key findings in two large, independently collected datasets that were recruited from the community, rather than from a population of individuals interested in their own memory abilities, further supporting the generalizability of the results reported here.

In conclusion, we show that episodic memory and spatial navigation are independent constructs at the trait level, and that these forms of memory correspond to different forms of mental imagery. Our data suggest that the importance of spatial processing in episodic memory may not be in the formation of a spatial map, but rather in the retrieval of a spatial context or scene. While research investigating and emphasizing the importance of "space" in episodic memory has proliferated, independent streams of work have focused on different meanings of the term. Space undoubtedly plays a critical part in episodic memory at both the cognitive and neural levels, but further clarity is needed when assessing which aspects of spatial memory are driving this overlap.

Acknowledgements We thank Aida Eslami for assistance in the statistical analyses and Asaf Gilboa for helpful comments on earlier drafts of the manuscript. CLF is supported by an Alexander Graham Bell Canada Graduate Scholarship from NSERC. BL is supported by CIHR grant MOP-148940.

Open practices statement The studies reported in this article were not formally preregistered. The data have not been made available on a permanent third-party archive because our Institutional Review Board ruled that we could not post the data; requests for the data can be sent via email to the corresponding author. The complete questionnaires and our analysis scripts are available online at <https://doi.org/10.17605/OSF.IO/JD4Q8>.

References

- Abdi, H., & Williams, L. J. (2013). *Partial Least Squares Methods: Partial Least Squares Correlation and Partial Least Square Regression* (Vol. 930, Issue 59, pp. 549–579). https://doi.org/10.1007/978-1-62703-059-5_23
- Addis, D. R., & Schacter, D. (2012). The Hippocampus and Imagining the Future: Where Do We Stand? *Frontiers in Human Neuroscience*, 5. <https://doi.org/10.3389/fnhum.2011.00173>
- Armson, M. J., Diamond, N. B., Levesque, L., Ryan, J., & Levine, B. (2020). *The relationship between eye movements and autobiographical recollection is mediated by individual differences in autobiographical capacity* [Manuscript submitted for publication].
- Aydin, C. (2018). The differential contributions of visual imagery constructs on autobiographical thinking. *Memory*, 26(2), 189–200. <https://doi.org/10.1080/09658211.2017.1340483>
- Beaton, D., Fatt, C. R. C., & Abdi, H. (2014). An ExPosition of multivariate analysis with the singular value decomposition in R.

- Computational Statistics & Data Analysis*, 72(0), 176–189. <https://doi.org/10.1016/j.csda.2013.11.006>
- Behrens, T. E. J., Muller, T. H., Whittington, J. C. R., Mark, S., Baram, A. B., Stachenfeld, K. L., & Kurth-Nelson, Z. (2018). What Is a Cognitive Map? Organizing Knowledge for Flexible Behavior. *Neuron*, 100(2), 490–509. <https://doi.org/10.1016/j.neuron.2018.10.002>
- Bellmund, J. L. S., Gärdenfors, P., Moser, E. I., & Doeller, C. F. (2018). Navigating cognition: Spatial codes for human thinking. *Science*, 362(6415). <https://doi.org/10.1126/science.aat6766>
- Berntsen, D., Hoyle, R. H., & Rubin, D. C. (2019). The Autobiographical Recollection Test (ART): A Measure of Individual Differences in Autobiographical Memory. *Journal of Applied Research in Memory and Cognition*, 8(3), 305–318. <https://doi.org/10.1016/j.jarmac.2019.06.005>
- Blajenkova, O., Kozhevnikov, M., & Motes, M. A. (2006). Object-spatial imagery: A new self-report imagery questionnaire. *Applied Cognitive Psychology*, 20(2), 239–263. <https://doi.org/10.1002/acp.1182>
- Burgess, N., Maguire, E. A., & O'Keefe, J. (2002). The Human Hippocampus and Spatial and Episodic Memory. *Neuron*, 35(4), 625–641. [https://doi.org/10.1016/S0896-6273\(02\)00830-9](https://doi.org/10.1016/S0896-6273(02)00830-9)
- Buzsáki, G., & Moser, E. I. (2013). Memory, navigation and theta rhythm in the hippocampal-entorhinal system. *Nature Neuroscience*, 16(2), 130–138. <https://doi.org/10.1038/nn.3304>
- Clark, I. A., Hotchin, V., Monk, A., Pizzamiglio, G., Liefgreen, A., & Maguire, E. A. (2019). Identifying the cognitive processes underpinning hippocampal-dependent tasks. *Journal of Experimental Psychology: General*. <https://doi.org/10.1037/xge0000582>
- Clark, I. A., & Maguire, E. A. (2020). Do questionnaires reflect their purported cognitive functions? *Cognition*, 195, 104114. <https://doi.org/10.1016/j.cognition.2019.104114>
- Collin, S. H., Milivojevic, B., & Doeller, C. F. (2017). Hippocampal hierarchical networks for space, time, and memory. *Current Opinion in Behavioral Sciences*, 17, 71–76. <https://doi.org/10.1016/j.cobeha.2017.06.007>
- Conway, M. A. (2005). Memory and the self. *Journal of Memory and Language*, 53(4), 594–628. <https://doi.org/10.1016/j.jml.2005.08.005>
- Coutanche, M. N., Koch, G. E., & Paulus, J. P. (2020). Influences on memory for naturalistic visual episodes: Sleep, familiarity, and traits differentially affect forms of recall. *Learning & Memory*, 27(7), 284–291. <https://doi.org/10.1101/lm.051300.119>
- Curtin, J. (2018). *lmSupport: Support for Linear Models*. <https://CRAN.R-project.org/package=lmSupport>
- Dawes, A. J., Keogh, R., Andrillon, T., & Pearson, J. (2020). A cognitive profile of multi-sensory imagery, memory and dreaming in aphasia. *Scientific Reports*, 10(1), 10022. <https://doi.org/10.1038/s41598-020-65705-7>
- Ekstrom, A. D., & Ranganath, C. (2018). Space, time, and episodic memory: The hippocampus is all over the cognitive map. *Hippocampus*, 28(9), 680–687. <https://doi.org/10.1002/hipo.22750>
- Epstein, R. A., Patai, E. Z., Julian, J. B., & Spiers, H. J. (2017). The cognitive map in humans: Spatial navigation and beyond. *Nature Neuroscience*, 20(11), 1504–1513. <https://doi.org/10.1038/nn.4656>
- Eslami, A., Fan, C., Levine, B., & Abdi, H. (2020). *Revising and condensing the Object-Spatial Imagery Questionnaire* [Unpublished manuscript].
- Fan, C. L., Romero, K., & Levine, B. (2020). Older adults with lower autobiographical memory abilities report less age-related decline in everyday cognitive function. *BMC Geriatrics*, 20(1), 308. <https://doi.org/10.1186/s12877-020-01720-7>
- Gilboa, A. (2004). Autobiographical and episodic memory—One and the same? *Neuropsychologia*, 42(10), 1336–1349. <https://doi.org/10.1016/j.neuropsychologia.2004.02.014>
- Goodhew, S. C., & Edwards, M. (2019). Translating experimental paradigms into individual-differences research: Contributions, challenges, and practical recommendations. *Consciousness and Cognition*, 69, 14–25. <https://doi.org/10.1016/j.concog.2019.01.008>
- Greenberg, D. L., & Knowlton, B. J. (2014). The role of visual imagery in autobiographical memory. *Memory & Cognition*, 42(6), 922–934. <https://doi.org/10.3758/s13421-014-0402-5>
- Hassabis, D., & Maguire, E. A. (2007). Deconstructing episodic memory with construction. *Trends in Cognitive Sciences*, 11(7), 299–306. <https://doi.org/10.1016/j.tics.2007.05.001>
- John, O. P., Donahue, E. M., & Kentle, R. L. (1991). *The Big Five Inventory—Versions 4a and 5.4*. University of California, Berkeley, Institute of Personality and Social Research.
- John, O. P., Naumann, L. P., & Soto, C. J. (2008). Paradigm shift to the integrative Big Five trait taxonomy: History, measurement, and conceptual issues. In *Handbook of personality: Theory and research*, 3rd ed. (pp. 114–158). Guilford Press.
- Keogh, R., & Pearson, J. (2018). The blind mind: No sensory visual imagery in aphasia. *Cortex*, 105, 53–60. <https://doi.org/10.1016/j.cortex.2017.10.012>
- Kroenke, K., Spitzer, R. L., & Williams, J. B. W. (2001). The PHQ-9: Validity of a brief depression severity measure. *Journal of General Internal Medicine*, 16(9), 606–613. <https://doi.org/10.1046/j.1525-1497.2001.016009606.x>
- Levine, B., Svoboda, E., Hay, J. F., Winocur, G., & Moscovitch, M. (2002). Aging and autobiographical memory: Dissociating episodic from semantic retrieval. *Psychology and Aging*, 17(4), 677–689. <https://doi.org/10.1037/0882-7974.17.4.677>
- McDermott, K. B., Szpunar, K. K., & Christ, S. E. (2009). Laboratory-based and autobiographical retrieval tasks differ substantially in their neural substrates. *Neuropsychologia*, 47(11), 2290–2298. <https://doi.org/10.1016/j.neuropsychologia.2008.12.025>
- Ngo, C. T., Weisberg, S. M., Newcombe, N. S., & Olson, I. R. (2016). The relation between navigation strategy and associative memory: An individual differences approach. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 42(4), 663–670. <https://doi.org/10.1037/xlm0000193>
- O'Keefe, J., Burgess, N., Donnett, J. G., Jeffery, K. J., & Maguire, E. A. (1998). Place cells, navigational accuracy, and the human hippocampus. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 353(1373), 1333–1340. <https://doi.org/10.1098/rstb.1998.0287>
- O'Keefe, J., & Nadel, L. (1978). *The Hippocampus as a Cognitive Map*. Oxford University Press.
- Palombo, D. J., Alain, C., Söderlund, H., Khuu, W., & Levine, B. (2015). Severely deficient autobiographical memory (SDAM) in healthy adults: A new mnemonic syndrome. *Neuropsychologia*, 72, 105–118. <https://doi.org/10.1016/j.neuropsychologia.2015.04.012>
- Palombo, D. J., Sheldon, S., & Levine, B. (2018). Individual Differences in Autobiographical Memory. *Trends in Cognitive Sciences*, 22(7), 583–597. <https://doi.org/10.1016/j.tics.2018.04.007>
- Palombo, D. J., Williams, L. J., Abdi, H., & Levine, B. (2013). The survey of autobiographical memory (SAM): A novel measure of trait mnemonics in everyday life. *Cortex*, 49(6), 1526–1540. <https://doi.org/10.1016/j.cortex.2012.08.023>
- Petrican, R., Palombo, D. J., Sheldon, S., & Levine, B. (2020). The Neural Dynamics of Individual Differences in Episodic Autobiographical Memory. *ENeuro*. <https://doi.org/10.1523/ENEURO.0531-19.2020>
- Poulter, S., Hartley, T., & Lever, C. (2018). The Neurobiology of Mammalian Navigation. *Current Biology*, 28(17), R1023–R1042. <https://doi.org/10.1016/j.cub.2018.05.050>
- Robin, J., Rivest, J., Rosenbaum, R. S., & Moscovitch, M. (2019). Remote spatial and autobiographical memory in cases of episodic amnesia and topographical disorientation. *Cortex*, 119, 237–257. <https://doi.org/10.1016/j.cortex.2019.04.013>

- Rolls, E. T., & Wirth, S. (2018). Spatial representations in the primate hippocampus, and their functions in memory and navigation. *Progress in Neurobiology*, 171, 90–113. <https://doi.org/10.1016/j.pneurobio.2018.09.004>
- Rubin, D. C., & Umanath, S. (2015). Event memory: A theory of memory for laboratory, autobiographical, and fictional events. *Psychological Review*, 122(1), 1–23. <https://doi.org/10.1037/a0037907>
- Schiller, D., Eichenbaum, H., Buffalo, E. A., Davachi, L., Foster, D. J., Leutgeb, S., & Ranganath, C. (2015). Memory and Space: Towards an Understanding of the Cognitive Map. *Journal of Neuroscience*, 35(41), 13904–13911. <https://doi.org/10.1523/JNEUROSCI.2618-15.2015>
- Selarka, D., Rosenbaum, R. S., Lapp, L., & Levine, B. (2019). Association between self-reported and performance-based navigational ability using internet-based remote spatial memory assessment. *Memory*, 27(5), 723–728. <https://doi.org/10.1080/09658211.2018.1554082>
- Sheldon, S., Amaral, R., & Levine, B. (2017). Individual differences in visual imagery determine how event information is remembered. *Memory*, 25(3), 360–369. <https://doi.org/10.1080/09658211.2016.1178777>
- Sheldon, S., Farb, N., Palombo, D. J., & Levine, B. (2016). Intrinsic medial temporal lobe connectivity relates to individual differences in episodic autobiographical remembering. *Cortex*, 74, 206–216. <https://doi.org/10.1016/j.cortex.2015.11.005>
- Spearman, C. (1925). Some Issues in the Theory of “g” (including the Law of Diminishing Returns). *Nature*, 116(2916), 436–439. <https://doi.org/10.1038/116436a0>
- Tolman, E. C. (1948). Cognitive maps in mice and men. *The Psychological Review*, 55(4), 189–208.
- Tulving, E. (1972). Episodic and semantic memory. In *Organization of memory* (Vol. 1, pp. 381–403). <https://doi.org/10.1017/S0140525X00047257>
- Tulving, E. (2002). Episodic Memory: From Mind to Brain. *Annual Review of Psychology*, 53(1), 1–25. <https://doi.org/10.1146/annurev.psych.53.100901.135114>
- Underwood, B. J. (1975). Individual differences as a crucible in theory construction. *American Psychologist*, 30(2), 128–134. <https://doi.org/10.1037/h0076759>
- Vannucci, M., Pelagatti, C., Chiorri, C., & Mazzoni, G. (2016). Visual object imagery and autobiographical memory: Object Imagers are better at remembering their personal past. *Memory*, 24(4), 455–470. <https://doi.org/10.1080/09658211.2015.1018277>
- Zeman, A., Dewar, M., & Della Sala, S. (2015). Lives without imagery – Congenital aphantasia. *Cortex*, 73, 378–380. <https://doi.org/10.1016/j.cortex.2015.05.019>
- Zeman, A., Dewar, M., & Della Sala, S. (2016). Reflections on aphantasia. *Cortex*, 74, 336–337. <https://doi.org/10.1016/j.cortex.2015.08.015>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.