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RESEARCH ARTICLE

Familiar environments enhance object and spatial memory in both younger and older adults

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Abstract Recent evidence suggests that familiarity with an environment may protect against spatial memory decline for familiar objects in older adults. We investigated whether a familiar context also reduces age-related decline in spatial memory for novel objects. Twenty-four younger and 23 older participants viewed a virtual rendering of a local environment along two different routes, each through a well-known (West) or lesser-known (East) area within the environment. Older and younger participants reported being more familiar with one (i.e. West) area than the other. In each trial, participants were presented with one route and were instructed to learn ten novel objects and their locations along the route. Following learning, participants immediately completed five test blocks: an object recognition task, an egocentric spatial processing (direction judgement) task, an allocentric spatial processing (proximity judgement) task and two pen-and-paper tests to measure cognitive mapping abilities. First we found an age effect with worse performance by older than younger adults in all spatial tasks, particularly in allocentric spatial processing. However, our results suggested better memory for objects and directions, but not proximity judgements, when the task was associated with more familiar than unfamiliar contexts, in both age groups. There was no benefit of context when a separate young adult group ($N = 24$) was tested, who reported being equally familiar with both areas. These results suggest an important facilitatory role of context familiarity on object recognition, and in particular egocentric spatial memory, and have implications for enhancing spatial memory in older adults.

Keywords Ageing · Spatial navigation · Virtual reality · Familiarity context effects · Recognition

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Introduction

Relative to the younger brain, the healthy ageing brain is subject to a number of functional, structural and biochemical changes, all affecting cognitive processing (Park and Reuter-Lorenz 2009). Among the most prominent of these are the age-related structural changes that occur within the hippocampus, resulting in reduced spatial learning and memory (Antonova et al. 2009; Driscoll et al. 2003; Konishi et al. 2013; Moffat et al. 2001). While the decline in spatial navigation abilities of older adults for recently learned or novel environments is well documented (see Moffat 2009 for review), relatively little is known regarding the factors that mediate efficient spatial memory in older age. The current study assessed whether familiarity with an environment may support better spatial memory in older adults. Specifically, we investigated whether memory for embedded objects was affected by either a familiar or unfamiliar environmental context in terms of object recognition, egocentric processing (direction judgement), allocentric processing (proximity judgement) and cognitive mapping abilities.

The ability to navigate in large-scale spaces, i.e. environments in which all the spatial information cannot be encoded from a single viewpoint (Castelli et al. 2008), is a complex skill comprised of several cognitive functions. In

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addition to relying on the integration of inputs from multiple sensory modalities such as vision, the vestibular and proprioceptive systems (Berthoz and Viaud-Delmon 1999), spatial navigation requires the perception of self-motion over time, i.e. path integration, where the representation of the current spatial location and orientation is continually updated (e.g. Wiener et al. 2011). Path integration is thought to interact with memory for landmarks in the environment (Etienne and Jeffery 2004). Successful navigation requires the ability to recognise and remember salient landmarks and their locations, the binding of landmarks to their spatial context, routes taken and the spatial relationship between landmarks in the environment (Newman et al. 2007). Landmarks, both distal and proximal, may be utilised during navigation to orientate oneself to the environment and inform one's heading direction (Epstein and Vass 2014; Steck and Mallot 2000). Landmarks in an environment can serve to function as beacons or as associative cues during route learning depending on their location within the environment (Waller and Lippa 2007). A beacon is a landmark that is very close to a goal location and enables an individual to travel by moving towards the landmark. However, landmarks function as associative cues when they are located at the centre of a decision point along a route and are associated with a directional response (e.g. left or right turn). Whereas beacon-based route learning requires the encoding of item-specific information only, encoding a landmark as an associative cue requires more cognitive resources as the directional information associated with the landmark must also be learned (Waller and Lippa 2007). Thus, the spatial knowledge acquired during route learning may vary significantly contingent upon the function that landmarks in the environment serve.

The brain appears to depend on specialised mechanisms for the recognition of objects or landmarks to inform spatial navigation, primarily the parahippocampal cortex (PHC) (Epstein and Kanwisher 1998; Epstein 2005). Neuroimaging research has suggested that the PHC shows greater activation for environmental stimuli, such as buildings, urban streets and landscapes compared to everyday non-spatial objects during passive viewing (Epstein and Kanwisher 1998; Epstein 2005). Furthermore, the PHC has been found to respond more strongly to objects that define the surrounding space compared with objects with weak spatial definition, even when no background or contextual information is provided (Mullally and Maguire 2011). It is possible that parahippocampal activations for objects presented without a scene background occur because the landmark object can be considered a cue for a place, or as a foundation for an implied scene (Troiani et al. 2014). Furthermore, behavioural data have shown that memories for scenes associated with highly familiar landmarks were more detailed and vivid compared to memories associated with less familiar landmarks (Robin and Moscovitch 2014). While older adults have generally been shown to be worse at recognising landmarks than younger adults (e.g. Head and Isom 2010; Liu et al. 2011), landmark recognition has been shown to be comparable to that of younger adults when the environment is familiar (e.g. Campbell et al. 2014; Kirasic 1989). Therefore, it is possible that recognition memory for novel objects may benefit from a familiar environment context.

Two separate spatial strategies may be used to achieve successful landmark-based navigation. An egocentric strategy, which can be either beacon-based or associative cue-based, may be used when following a familiar route, either by moving towards a landmark that brings one closer to the goal location without use of directional information or by the encoding of a sequence of bodily turns associated with landmarks and their locations (Hartley et al. 2003; Waller and Lippa 2007; Wiener et al. 2013). Egocentric spatial processing has been shown to be dependent upon the caudate nucleus of the striatum which supports action-based response learning (Hartley et al. 2003). Neuroimaging studies have reported an age-related reduction in caudate nucleus volume (Raz et al. 2003), corresponding with reduced memory in older relative to younger adults for directions associated with a landmark (Head and Isom 2010). However, older adults tend to rely more on egocentric strategies than younger adults (Rodgers et al. 2012), with spatial learning associated with activation in the caudate nucleus of older relative to younger adults when solving spatial tasks (Schuck et al. 2015). However, there is evidence that environment familiarity may mediate age-related deficits in making direction judgements. For example, Kirasic (1991) used a real-world setting and reported better performance by older adults on measures of egocentric spatial memory when the testing environment was familiar rather than unfamiliar.

While an egocentric strategy may be used in a familiar environment, an allocentric spatial strategy may be used when exploring a new environment as it involves a more global representation or "cognitive map" of the environment in which landmark locations are characterised by their spatial relationship to one another (O'Keefe and Nadel 1978; Tolman 1948). Allocentric spatial processing is dependent on hippocampal function which supports flexible viewpoint-invariant encoding of the environment necessary during initial spatial learning until an environment becomes familiar (Hartley et al. 2003; Wolbers and Büchel 2005). Successful and efficient navigation does not rely on one strategy alone but rather requires switching between these strategies as dictated by the demands of the environment (Harris et al. 2012; Rich and Shapiro 2009). Ageing is thought to reduce allocentric spatial processing, with the older brain associated with a reduced volume of

the hippocampus (Raz et al. 2010). For example, Head and Isom (2010) reported that older adults travelled longer distances than younger adults to locate a target landmark in an unfamiliar virtual maze and were less accurate at identifying landmarks and recognising scenes in a wayfinding condition assessing allocentric processing. Neuroimaging studies have supported these findings demonstrating reduced activation in the hippocampus of older adults while performing spatial memory tasks (Moffat et al. 2006). While the respective spatial processes associated with these brain regions are subject to age-related decline, older adults who rely more on egocentric spatial processing (Rodgers et al. 2012) also have more difficulty in forming a cognitive map (Iaria et al. 2009) and display more difficulty in switching navigational strategies (Harris et al. 2012).

However, some findings suggest that hippocampal-dependent allocentric processing in older adults may be subject to individual differences, and that this process may also be improved through spatial navigation training. For example, Konishi et al. (2013), using a virtual spatial strategy task, found that although older adults demonstrated a shift from a hippocampal-related navigational strategy to one mediated by the caudate nucleus, there was sustained activation in the hippocampus of those older adults who utilised an allocentric spatial strategy (Konishi et al. 2013). Moreover, spatial navigation abilities of older adults can be improved with training. For example, Lövdén et al. (2012) conducted a four-month-long computerised spatial memory training intervention combined with treadmill walking and found that older adults showed training-related improvements in spatial navigation that were even greater than those of trained younger adults. Furthermore, the training had a protective effect on hippocampal function, as the hippocampal volume of the intervention group of older adults remained constant post-intervention and at 4-month follow-up, while the hippocampal volume of the treadmill-only control group decreased consistent with longitudinal age-related decline (Lövdén et al. 2012).

Research conducted on spatial navigation tasks within large-scale environments also suggests that allocentric spatial processing may be improved by familiarity with the environment (Maguire et al. 2000; Woollett and Maguire 2010). In a longitudinal study, Hirshhorn et al. (2012) found that mental navigation of a newly learned environment involved the hippocampus. However, once the environment was well learned, extrahippocampal regions such as the PHC were activated during mental navigation tasks. There is some evidence to suggest that performance of older adults on tasks assessing allocentric processing may be mediated by the familiarity of the environment. For example, previous research has shown age-related differences in the pointing to landmark locations within familiar and unfamiliar environments (Muffato et al. 2015), with better performance in familiar environments. These results suggest that older adults retain the ability to build a mental representation of a familiar environment (Meneghetti et al. 2013). Rosenbaum et al. (2012) also found a benefit for spatial memory in older adults for well-known environments learned long ago, with comparable performance to younger adults on a test of mental navigation. Furthermore, the authors found no age-related differences on a proximity judgement task conducted within a highly familiar area learned by older adults in the remote past. Moreover, Campbell et al. (2014) found that environment familiarity had a positive effect on measures of topographical memory in older adults, again with comparable performance to their younger counterparts on tasks such as landmark name recall and recognition, landmark map localisation and route recall.

In contrast to previous studies in which the effect of the familiarity of both landmark objects and environment was investigated on spatial cognition in older adults, we investigated whether environment familiarity also benefits spatial memory for novel objects not generally found in the particular environment. This was achieved by using a virtual representation of routes taken through familiar and less familiar areas within the Trinity College Dublin campus. Within each route, we embedded common objects at intersection points, and all objects were novel to these particular locales. Following a learning session in which participants viewed one of the two routes, we assessed participants' object recognition, egocentric and allocentric spatial processing, and ability to form cognitive maps using a set of five tasks adapted from previous studies (Head and Isom 2010; Maguire et al. 1996). We hypothesised that familiarity with the environmental context would provide a benefit for spatial memory of novel objects, and that this familiarity benefit would be particularly found in older adults (e.g. Rosenbaum et al. 2012) whose spatial cognition is generally worse than that of younger adults.

Method

Participants

Forty-eight younger (36 female; $M = 24.48$, SD = 5.81, range 18–39) and 23 older (18 female; age range 61–79, mean age = 69.87, SD = 5.52) participants volunteered to take part in the experiment for nominal pay or course credit. We recruited two subpopulations of younger adults: 24 undergraduate and postgraduate students from Trinity College Dublin, the University of Dublin (TCD) (18 female; age range 18–37, mean age = 23.29, SD = 5.39) or 24 younger adults who were not members of the University (18 females; age range 18–39, mean age = 25.67, SD = 6.08). The students

were recruited from a broad range of disciplines across the University to ensure they were equally familiar with all areas of the College campus. Due to this groups' familiarity with the campus as a whole, their performance on tasks across both areas was used to assess whether any inherent differences were present between the areas which may facilitate performance in one context over another. Non-members of TCD were recruited via email and represented young adults who had never been members of the University of Dublin. All younger participants reported normal or corrected-to-normal vision and normal hearing.

Older participants were all community dwelling and were recruited by advertising through local ageing organisations and local media. We applied the following inclusion criteria when recruiting older participants: aged 60 years of age or older, reported normal or corrected-to-normal vision and hearing, no evidence of cognitive impairment (assessed by the Montreal Cognitive Assessment—MoCA) and ability to follow instructions for testing. All older adults had normal global cognitive function (MoCA; $M = 27.59$, SD $= 1.65$) (Nasreddine et al. 2005), and none were excluded for mild cognitive impairment based on a score of below 23 on the MoCA (Luis et al. 2009). All older participants had normal visual acuity, as measured by the ETDRS acuity chart ($M = 0.09$ logMAR, SD $= 0.12$) and contrast sensitivity ($M = 1.96$, SD $= 0.11$, assessed using the Pelli-Robson contrast sensitivity test) for their age. None of the participants reported a history of psychiatric or neurological illness.

Prior to testing, all participants indicated on a Likert scale, ranging from 1 to 9, their experience with (a) computers and (b) computer games. A score of 1 indicated no computer experience, a score of 5 indicated participants were fairly experienced with computers, and a score of 9 indicated they were very experienced. The Santa Barbara Sense of Direction Scale (SBSOD) (Hegarty et al. 2002) was also administered as a measure of self-reported environmental spatial ability for all participants. Higher scores on this measure indicated better sense of direction. Participant responses are summarised in Table 1.

We conducted a one-way ANOVA (with 3 participant groups as the between-group factor) on each of the test scores. First, it was important to ensure that there was no difference in self-reported sense of direction between groups as measured by the SBSOD scale. There was no effect of group [$F(2, 68) = 1.7$, $p = 0.19$, $\eta_p^2 = 0.05$], although there was a trend for older adults to rate their sense of direction as higher than that of either the students and younger adults (see Table 1). We found a main effect of participant group for ratings of computer experience [$F(2, 67) = 20.58$, $p < 0.001$, $\eta_p^2 = 0.38$] and computer game experience [$F(2, 67) = 10.1$, $p < 0.001$, $\eta_p^2 = 0.23$]. Post hoc comparisons (Tukey's unequal N HSD tests) revealed that older adults rated their computer experience and computer game experience much lower than either the student or younger adult cohorts ($ps < 0.05$).

Table 1 Characteristics and mean responses in students, younger adults and older adults across the SBSOD scale, experience with computers and computers games (standard deviations in parentheses)

	Students $N = 24$	Younger adults $N = 24$	Older adults $N = 23$
SBSOD	3.98 (0.9)	3.72 (1.11)	4.24 (0.87)
Computer experience	6.92 (1.5)	6.54 (1.41)	3.86 (2.25)
Computer game experience	4.92 (1.95)	4.46 (2.41)	2.27 (1.93)

High scores on the SBSOD indicate a good sense of direction, and high scores on each of the computer-based questions indicate a greater amount of experience

The experiment was approved by the School of Psychology Research Ethics Committee, Trinity College Dublin, and conformed to the Declaration of Helsinki. All participants provided informed, written consent prior to taking part in the experiment.

Stimuli and apparatus

Participants were tested in a windowed testing laboratory at the Institute of Neuroscience in Trinity College Dublin. The experiment was programmed, and responses were acquired using Presentation® software (http://www.neurobs.com). The experiment was presented on a Dell Latitude E4300 laptop and displayed on a HP L1710 17″ LCD colour monitor. The screen resolution was set to 1024 × 768 pixels. The videos subtended an approximate visual angle of 32.67° horizontally and 18.8° vertically encompassing the entire stimuli dimensions onscreen from a viewing distance of 57 cm at which participants were positioned.

Virtual environment

Trinity College Dublin is a campus-based University situated in the centre of the city of Dublin, Ireland. The campus footprint is elongated along an East–West axis, with the main entrance to the college at the West end of the campus. The West end of the campus is very familiar and has both historic and cultural status within Ireland: the buildings within the West end of the campus are approximately 200 years old, and it is home to one of the most visited artefacts in Ireland (the Book of Kells). In comparison, the East end of the campus is less familiar, the buildings are relatively modern, and it offers no landmark attractions for the visiting public.

Both ends of the campus were modelled as virtual environments representing all the building and landscape

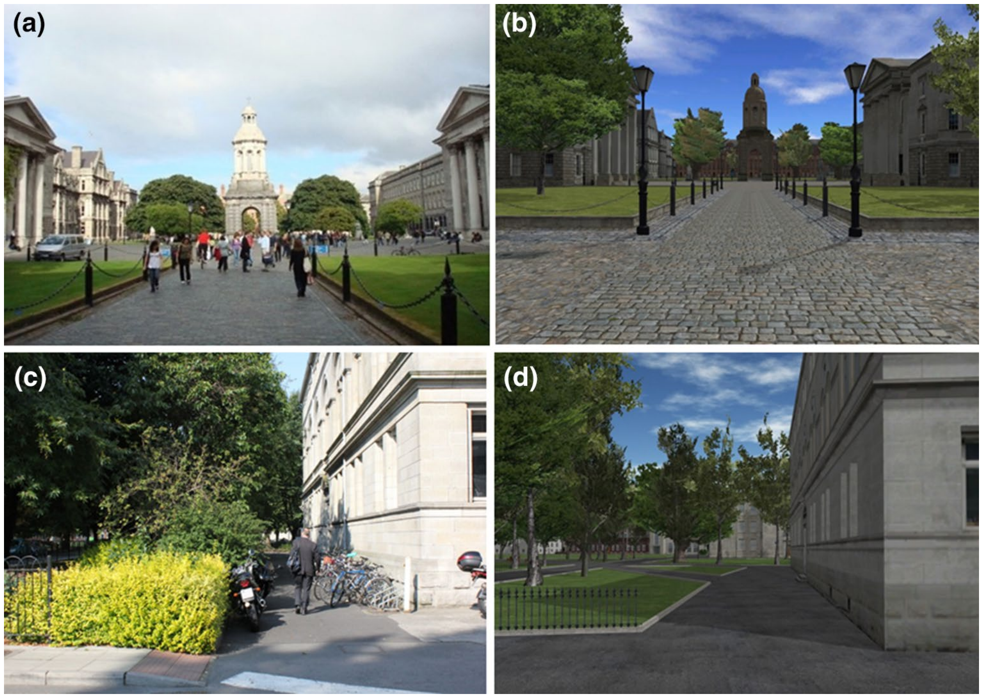

Fig. 1 Examples of images from the **a** real and **b** virtual West area and the **c** real and **d** virtual East area of the Trinity College Dublin campus

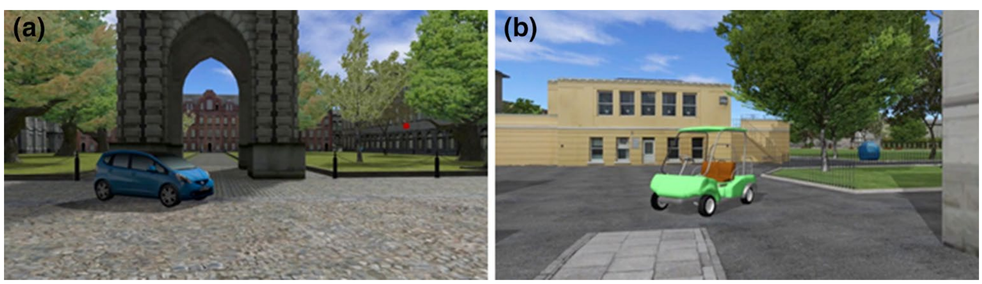

Fig. 2 Example images of target objects embedded at intersections along the **a** familiar and **b** less familiar routes

architecture within each of the East and West ends (see Fig. 1). Navigation through these areas was simulated using a proprietary engine based on Ogre 3D. Specifically, navigation was simulated using a virtual camera which was positioned at typical eye height (1.6 m above the ground) and followed a predefined path within each area (West or East) at a speed of 2 m/s. The route followed existing paths and obstacles were always avoided. Each scene was rendered at 30 fps, and the engine exported uncompressed images at 720p resolution that were afterwards converted to a video and compressed using the H.264 codec. We created two videos each for the East (less familiar) and West (familiar) virtual routes, and videos of each end were used during the learning phase of the experiment. There were 10 intersections along each route; thus, route complexity was equated across each area. The route through the East campus contained 4 left turns, 3 right turns and 3 straight-ahead directions, encompassing an area of approximately 26,400 m^2. The route through the West end of campus contained 4 left turns, 2 right turns and 4 straight-ahead directions, encompassing an area of approximately 33,000 square metres.

We embedded target objects along each route (see Fig. 2). During the simulated navigation, a unique target object appeared in the centre of each intersection as soon as the camera came within 20 metres of the intersection. Within each scene, the average height of each object was simulated to be approximately 2.13 m. There were 20 target objects in all, divided into two sets (for list of target objects, see Table 2). Each set was allocated to one route, and objects were counterbalanced across routes yielding the four different learning routes (i.e. East end with target

Table 2 Two sets of target objects, each of which was allocated to each of the East and West routes and counterbalanced across participants

Target set A	Distractor set A	Target set B	Distractor set B
Dublin flag	Triquetra flag	Irish flag	French flag
Green golf cart	Red golf cart	Beige golf cart	Red golf cart
Red telephone box	Blue telephone box	Blue telephone box	Silver telephone box
Blue motor bicycle	Red motor bicycle	Red motor bicycle	Blue motor bicycle
Blue car	Red car	Orange truck	White truck
Yellow forklift	Red forklift	Blue racing bicycle	Blue mountain bicycle
Beige marble fountain	Brown marble fountain	Bronze statue (mother and child)	Bronze statue (single figure)
Brown outhouse	Red outhouse	Grey air vent	White air vent
Silver shopping cart	Blue shopping cart	Grey tannoy speakers	White tannoy speakers
Grey stone wishing well	Red brick wishing well	Cream tent	Blue tent

Corresponding distractor objects are also listed

set A or B; West end with target set A or B), yielding two different versions of each route. Each participant was presented with both an East and West route during the experiment and both target sets of objects.

Test stimuli

The test phase of the experiment was comprised of three computer-based tasks and 2 pen-and-paper tasks. Each task was designed to assess different components of spatial memory.

For the object recognition task, screen shots of colour-rendered images of target objects were taken from each route and edited using GNU Image Manipulation Programme (http://www.gimp.org) to eliminate all contextual information, such as buildings or trees, while maintaining the image properties (i.e. size, colour and perspective) of each object. The object images were presented against a black background and subtended an approximate visual angle of between 3.68° and 13.89° horizontally and 9.74° and 11.79° vertically, with the participants seated 57 cm from the screen. There were 10 target objects and 10 distractor objects presented in each test. Distractor objects were different exemplars of the same category of object as a target object and shared similar object but not image properties with the target objects. For example, the distractor object for the target object green golf cart was a different exemplar, i.e. a red golf cart with different features shown from a slightly different view (see Fig. 3 for an example).

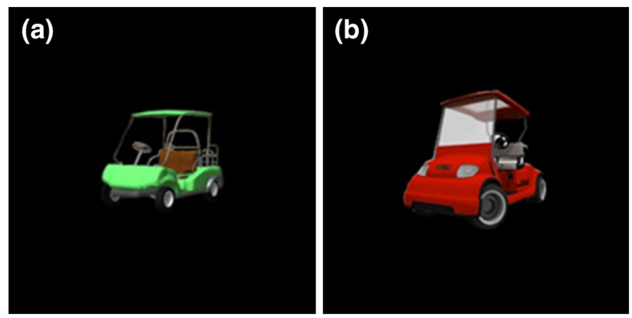

Fig. 3 Example images from the stimulus set of **a** a target object and **b** a distractor object presented during the object recognition task

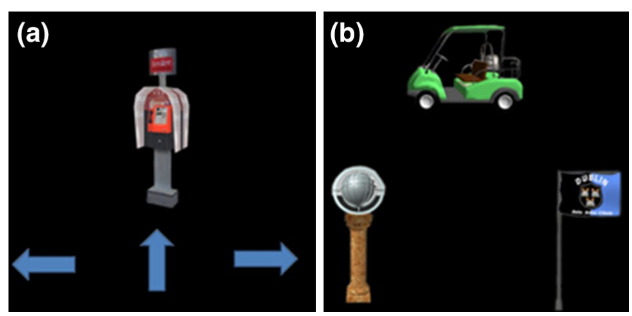

Fig. 4 An example of images of test stimuli from **a** a direction judgement trial and **b** a proximity judgement trial

The test for egocentric spatial processing (i.e. self-to-object orientation) involved a direction judgement task (see Head and Isom 2010), where the ability to remember which specific direction was taken when the object was encountered during the route was assessed. Due to the placement of the object in the centre of each intersection, the associative cue function of the landmark was assessed. For this task, a stimulus included a single image of a target object (without contextual information) presented together with three images of an arrow pointing left, upwards and right which provided a visual cue for possible direction taken. See Fig. 4a for an example of a stimulus in this category.

An assessment of allocentric (i.e. object-to-object orientation) spatial processing was conducted using a proximity judgement task based on Maguire et al. (1996). Specifically, this task assessed participants' knowledge of the

Euclidean distance between the objects within each campus area. A stimulus comprised of a scene of three object images, arranged in a triangular formation with an image of a target object positioned on top and two images of other target objects taken from the route and positioned underneath (see Fig. 4b). All object images were of the same relative size as shown during the route. The object in the top position in the scene was the reference object, and all target objects were presented in this position across trials. The lower two objects were chosen from the route in pseudorandom order, ensuring that the lower two objects were not encountered sequentially next to the reference object on the route (i.e. this helped avoid using an egocentric strategy to solve the task).

The final two tests were conducted using a printed out map, each scaled to 1496 × 917 pixels and measuring 11.9 × 28.9 cm on size A4 paper for both areas through campus. In the first, “target landmark location” task, the test stimulus was a 2D scaled map of the East or West end of the College campus. None of the target objects were indicated, and the task for the participants was to indicate, on the map, the locations that they remembered encountering a target object (by marking “X” on the map). In the other, “target landmark naming” task, the test stimulus was again a 2D scaled map of the route through the East or West section of campus. Each map was marked with a number of “X”s which marked the location of each target object along the route. Participants were required to identify the target object by providing the name of the object at each location indicated on the map.

Design

The overall experimental design was based on a 2-way mixed, factorial design with participant group (two younger adult groups and one older adult group) as the between-group factor, and familiarity of the campus area through which a route was learned (i.e. familiar West area and less familiar East area) as the within-group factor.

The dependent variables for the object recognition, direction judgement and proximity judgement tasks were accuracy scores and response times. The dependent variable for the landmark location task was distance error. Distance error was calculated by allotting a score of 1 point if the participant marked an “X” within 2 cm of the exact location of the target object, 0.5 point if they were within 3 cm of the target objects’ location and 0.33 point if they were within 4 cm of the target objects’ location. Scoring of this task was validated by another independent judge who was blind to the research question. A paired t test confirmed no significant difference between the distance error scores of the two judges [$t(70) < 1$]. The dependent variable for the target landmark naming task was naming accuracy. Responses were marked as correct if the participant correctly named or identified each of the landmarks. The experimenter clarified any verbal descriptions of landmarks that were unclear or ambiguous.

There were two main blocks to the task, based on area familiarity, and block order was counterbalanced across participants. Each block began with a video presentation of a route through the area, which was immediately repeated. The five tests immediately followed the presentation of the route, comprising three computer-based tasks and two pen-and-paper tests. The order of presentation of trials within each of the object recognition, direction judgement and proximity judgement tasks was randomised across participants. To minimise cross-over effects, the five tasks were presented in the same sequential order across participants: object identification, direction judgement, proximity judgement, landmark location and landmark naming.

Procedure

Prior to testing, all participants were presented with a questionnaire in which they indicated using a Likert scale ranging from 1 to 9 their experience with (a) computers and (b) computers games as well as completing the SBSOD questionnaire (see participants section). Participants were then presented with a map of the college campus and were required to provide familiarity ratings to each of the East and West ends of the campus (see pre-validation study below).

For the main experiment, which consisted of two consecutive experimental blocks, participants were instructed to view the video presented at the beginning of each block and to pay attention to the route, the target objects they encountered, and the location of each of the target objects in the scene. It was made clear to participants that target objects referred to the objects that appeared at each intersection.

In the learning phase, each video of the route was presented twice to each participant. During the test phase, participants could take a self-timed break between each of the five different tasks. The first of these tasks, the object recognition task, consisted of 20 trials, including 10 trials of target objects from the route and 10 trials of distractor objects. Each trial for the three computer-based tasks was preceded by a fixation cross-presented for 500 ms. The visual stimulus of the object, either target object or distractor object, was then presented until a response was made or for a total of 5 s. Response times were recorded from the onset of the visual stimulus for each computerised task. Participants were asked to indicate as quickly and as accurately as possible whether or not they had seen the object on the previous route shown by pressing one of two assigned keys (“z” and “m”) on the keyboard.

There were 10 trials in the direction judgement task. A visual stimulus in the direction judgement task (a target object and arrows, as described in the Stimulus section) was presented until a keyboard response was made or for a total of 20 s. Participants were asked to indicate as accurately as possible whether the target object from the route was associated with a right turn, left turn or maintained a straight-ahead course by pressing one of three corresponding keys (i.e. left, up or right arrow) on a keyboard.

There were 20 trials in the proximity judgement task. A visual stimulus in the proximity judgement task comprised of 3 target objects (see Stimulus section), which remained on screen until a keyboard response was made, or for a total of 20 s. Participants were required to choose which of two objects, presented below the reference object in each stimulus, was closer (as the crow flies or in bee-line distance) to the reference object's location by pressing one of two keys on the keyboard ("z" and "m" for left object and right object, respectively). The object closest to the reference object in each trial of the proximity judgement task was congruent across Euclidean and route distance in 87.5 % of trials.

The three computer-based tasks were then followed by two paper-based tasks, presented in the same sequential order of "target landmark location" followed by "target landmark naming" across all participants. The "target landmark location" memory task was a measure of allocentric "cognitive mapping" (Moffat and Resnick 2002). In the first task, participants had to either indicate, with an X, the location of each of the 10 target objects (landmarks) along the route, and in the second task had to provide the name of the target object (landmark) at each of 10 indicated locations along the route (target object naming). The entire experiment took between 30 and 45 min for each participant to complete.

Validation of the virtual environment

In order to validate the virtual representation of the Trinity College campus, 15 current members of staff and students who had worked/studied in TCD for at least 2 years were shown 10 (static) images, which represented snapshots from the virtual routes taken through the East (5 images) and West (5 images) areas of the campus. They were subsequently asked to indicate the location of each image on a 2D map of the College campus. The dependent variable for this task was distance error which was calculated as described for the landmark location task. Mean percentage performance accuracy was high for both the East ($M = 84$, SD = 20.28) and West ($M = 86.66$, SD = 12.34) areas. A paired t test confirmed no significant difference between accuracy performance across the two areas of campus [$t(14) < 1$]. These results indicated that persons working or studying in TCD could readily recognise the virtual rendered images of the campus and could locate each image with a high degree of precision.

Pre-validation study

We first wanted to validate our a priori distinction between the West and East ends of the college campus as being more or less familiar, respectively. To that end, prior to testing, all participant groups provided familiarity ratings for each of two areas within the real campus environment. Participants were shown an aerial view of the campus map and an image depicting an example of a building located in either the East or West areas of the campus to help localise the participant on the map. Using a Likert scale from 1 to 7, participants were asked to indicate how familiar they were with each area. A score of 1 indicated "not at all familiar", whereas a score of 7 indicated "highly familiar" with that area.

The mean ratings to each of the areas, across the participant groups, are shown in Table 3. T tests were conducted on participants' ratings to each area across groups. As expected, the TCD student group indicated that they were highly familiar with both the East and West areas of college, and there was no difference in their familiarity ratings across College areas. In contrast, and again as expected, the ratings from the young adult group indicated that they were significantly more familiar with the West than East area of college. A mixed ANOVA confirmed these results. There was a main effect of route [$F(1, 61) = 31.9$, $p < 0.001$, $\eta_p^2 = 0.34$] with post hoc analysis using the Tukey HSD test revealing that the West area ($M = 4.84$, SD = 1.88) was rated as more familiar than the East area ($M = 3.75$, SD = 2.03; $p < 0.001$). There was a main effect of participant group [$F(2, 61) = 11.36$, $p < 0.001$, $\eta_p^2 = 0.27$], with

Table 3 Mean familiarity ratings provided to the East and West areas of the Trinity College campus (standard deviations in parentheses) provided by each participant group

Participant groups	West	East	t test	p value
TCD students	5.9 (0.91)	5.4 (1.19)	$t(23) = 1.65$	0.12
Younger adults	4.65 (1.58)	2.52 (1.27)	$t(23) = 6.61$	0.001
Older adults				
Familiarity ratings	4.05 (2.40)	3.52 (2.32)	$t(23) = 1.56$	0.13
Building name score	2.80 (1.01)	1.67 (0.72)	$t(14) = 5.26$	0.001
Building location score	2.60 (1.3)	1.53 (0.74)	$t(14) = 3.10$	0.008

The mean recognition and location scores to buildings from each area are also shown for the older adults only. T test results indicate significant differences in familiarity across areas for all groups except TCD students and older adults (see text for further details)

higher ratings by students ($M = 5.65$, SD $= 0.81$) than younger ($M = 3.59$, SD $= 1.21$) or older adults ($M = 3.79$, SD $= 2.23$) (all ps < 0.001). A significant interaction between route and group [$F(2, 61) = 8.73$, $p < 0.001$, $\eta_p^2 = 0.22$] suggested a difference in ratings across areas for the younger adults only ($p < 0.001$) but not for the students ($p = 0.66$) or older adults ($p = 0.59$).

Although the ratings from the older adults suggested that they were more familiar with the West than East area of college, this difference failed to reach significance. Furthermore, their familiarity ratings to the East area of the campus indicated that they felt neither familiar nor unfamiliar with that area (see Table 3). While the difference between self-reported familiarity for the two areas was smaller for the older compared to the younger adults, previous findings have reported that older adults' scores taken from subjective measures do not match those obtained from objective measures particularly in terms of sense of direction and wayfinding abilities (see Rosenbaum et al. 2012; Taillade et al. 2013), possibly due to age-related difficulties in metacognition (Vanderhill et al. 2010). As such, in order to disambiguate this finding, we decided to obtain a further, objective measure of familiarity from the older adult group only. Fifteen of the total number of older adults completed the new test. Participants were shown images of five randomly chosen buildings from each of the two areas and were asked to name each of the buildings, and then were asked to mark each building's location on a map of the East and West area. The results from paired t tests (see Table 3) indicated that older adults recognised and were able to accurately locate more buildings in the West area compared to the East area, suggesting greater familiarity with the West area of the college. For convenience, we henceforth refer to the West area of college as the "familiar" area, and the East area shall be referred to as the "less familiar" area.

Results

The TCD student sample was specifically recruited because, to this group, both the West and East areas of the College campus were equally familiar. Although we had carefully ensured that all target objects were presented within each area, by counterbalancing the target sets across areas, we nevertheless wanted to ensure that there were no inherent differences between the areas which may facilitate performance in one context over another. To that end, we analysed performance by the student participant group separately from the other two groups.

We first conducted a series of paired t tests to compare students' accuracy and response time performance across the areas for all five tasks. First, there was no difference in accuracy performance in each of the three computer-based tasks, namely object recognition, direction and proximity judgement tasks or the two map-based tasks across the routes through the two areas of campus (see Table 4). We then measured the students' response times in each of the three computer-based tasks. Again, we found no difference in the time taken to make a correct response (i.e. hits) on each task across the different contexts (see Table 5).[1] With the exception of differences in accuracy performance to the direction judgement task across the two routes, which approached significance, these results ensured that the context of the West and East areas of college was similar and that neither facilitated better memory performance across the range of tests. In other words, these results assured us that there are no inherent differences across the areas that may account for any performance differences that may be found between areas for the younger and older adults.

Table 4 Mean performance accuracy of the student group across the object recognition, direction judgement, proximity judgement, object landmark naming and object landmark location memory tasks (with standard deviations in parentheses)

	Familiar	Less familiar	t test results	p value
Object recognition	92.71 (8.47)	92.92 (7.06)	$t(23) = 0.1$	0.92
Direction judgement	82.92 (20.32)	75.00 (19.11)	$t(23) = 1.96$	0.06
Proximity judgement	71.67 (12.99)	75.63 (14.62)	$t(23) = 1.45$	0.16
Landmark locating	64.70 (24.74)	59.49 (25.72)	$t(23) = 1.17$	0.25
Landmark naming	87.08 (25.45)	82.92 (24.93)	$t(23) = 1.06$	0.30

In the main analyses of the results, we compared performance across the (non-student) younger and older adults whose previous familiarity scores (see Table 3) had indicated that the West end of the College campus was more familiar than the East end. We first analysed the data based on ratings for computer experience with age group (younger, older) as the between-group factor, route (familiar or less familiar area) as the within-group factor and the composite "computer experience" score as the covariate were conducted on the mean accuracy scores and response time data for each of the computer-based tasks (object recognition task, direction and proximity judgement tasks). For each group separately (i.e. students, younger adults, older adults), and for each task, trials with outlier response times were removed from further analyses. Response times

[1] Response times of more than 2.5 standard deviations above or below the trial mean of the group were considered outliers (approximately 4.86 % of the data were removed).

Table 5 Mean reaction times of the student group across the object recognition, direction judgement and proximity judgement tasks (with standard deviations in parentheses)

	Familiar	Less familiar	*t* test	*p* value
Object recognition	1060 (315)	1169 (350)	$t(22) = 1.87$	0.08
Direction judgement	1416 (752)	1364 (582)	$t(21) = 0.6$	0.56
Proximity judgement	3598 (1588)	3569 (1473)	$t(22) = 0.89$	0.38

Table 6 The mean reaction time taken (in milliseconds) to the correct trials in each of the object recognition, direction judgement and proximity judgement tasks across the younger and older adult groups (with standard deviations in parentheses)

Route	Younger adults		Older adults	
	Familiar	Less familiar	Familiar	Less familiar
Object recognition	1082 (321)	1166 (369)	1540 (412)	1539 (446)
Direction judgement	1253 (587)	1456 (739)	2297 (1053)	2332 (930)
Proximity judgement	3580 (1115)	3151 (1163)	3793 (1886)	4069 (1819)

The RTs are presented for routes taken through familiar and less familiar areas in the college environment

of more than 2.5 standard deviations above or below the trial mean of the respective group were considered outliers (approximately 2.82 % of the data were removed). Due to a technical error, the "computer experience" data were missing for one older adult. Initial analyses using separate mixed ANCOVAs revealed no effect of computer experience [all $F(1, 43) < 1$], nor any interaction between computer experience and route for accuracy performance for the object recognition, direction judgement or proximity judgement tasks (all *p*s = n.s). Furthermore, computer experience did not correlate with accuracy performance for any dependent measure across participant groups (all *p*s = n.s.). Since computer experience did not affect the main findings, we decided henceforth to conduct separate mixed ANOVAs (again with group and route as factors) on the mean accuracy on the above-computerised tasks as well as the pen-and-paper target landmark naming and target landmark location tasks. However, computer experience did interact with route for reaction times on the object recognition and proximity judgement tasks and so was included as a covariate on all reaction time analyses only. The mean reaction times for younger and older adults across the object recognition, direction judgement and proximity judgement tasks are reported in Table 6.

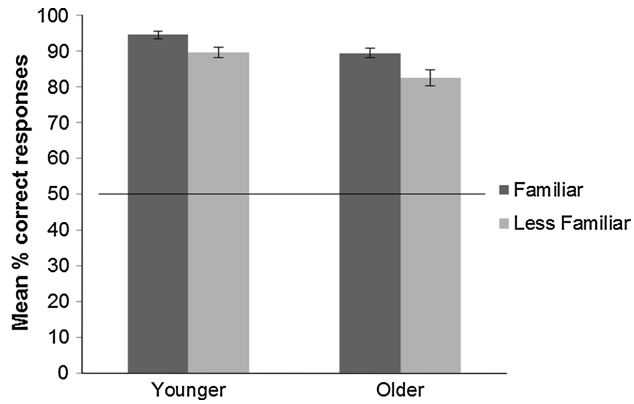

Fig. 5 Mean percentage accuracy performance on the object recognition task across younger and older adult group for the routes through the familiar and less familiar areas. *Error bars* indicate ±1 standard error of the mean. Chance performance in this task was 50 % as indicated

Object recognition task

The results of the ANOVA on accuracy scores revealed a main effect of participant group [$F(1, 45) = 14.42$, $p < 0.001$, $\eta_p^2 = 0.24$] with worse performance in the older ($M = 86.09$, SD = 6.12) than younger ($M = 92.19$, SD = 4.85) adults. There was a main effect of route [$F(1, 45) = 17.12$, $p < 0.001$, $\eta_p^2 = 0.28$] with better recognition of objects encountered along the route through the familiar ($M = 92.13$, SD = 5.87) than less familiar ($M = 86.28$, SD = 9.53) area. The interaction between route and group [$F(1, 45) < 1$] failed to reach significance, suggesting that younger and older adults recognised target objects more accurately when encountered along the route in the familiar area (younger: $M = 94.58$, SD = 4.87; older: $M = 89.57$, SD = 5.82) compared to those in the less familiar area (younger: $M = 89.79$, SD = 7.29; older: $M = 82.61$, SD = 10.32) as shown in Fig. 5.

Direction judgement task

An analysis of accuracy performance on the direction judgement task revealed a main effect of participant group [$F(1, 45) = 19.99$, $p < 0.001$, $\eta_p^2 = 0.31$] with older adults remembering the direction taken less well ($M = 56.96$, SD = 17.37) than younger ($M = 77.71$, SD = 14.37) adults. There was a main effect of route [$F(1, 45) = 47.01$, $p < 0.001$, $\eta_p^2 = 0.51$], with better directional memory for objects encountered along the route through the familiar ($M = 77.87$, SD = 21.16) than less familiar ($M = 57.23$, SD = 22.04) area. The interaction between participant group and route failed to reach significance [$F(1, 45) < 1$], suggesting that both older and younger adults remembered directions more accurately in a familiar environment

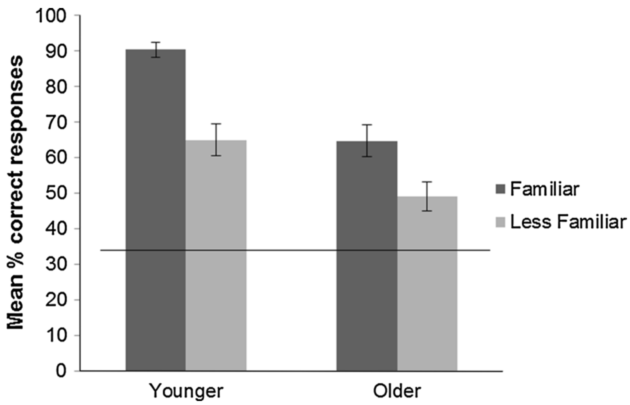

Fig. 6 Mean accuracy performance on the direction judgement task across the younger and older adult groups for the routes through the familiar and less familiar areas. *Error bars* indicate ±1 standard error of the mean. Chance performance of 33 % is indicated

compared to the less familiar area (as shown in Fig. 6). The performance of the older adults was generally poor on this task, and we analysed their data relative to chance performance (33.33 %) using a single-sample *t* test. Older adults' performance was significantly better than chance for both routes through either familiar [$t(22) = 6.95$, $p < 0.001$] or less familiar [$t(22) = 4.06$, $p = 0.001$] areas.

Proximity judgement task

A mixed ANOVA conducted on the accuracy performance in the proximity judgement task revealed a main effect of participant group [$F(1, 43) = 20.03$, $p < 0.001$, $\eta_p^2 = 0.31$] with older adults performing worse at judging relative proximity between objects ($M = 55.76$, SD = 7.13) than younger adults ($M = 67.71$, SD = 10.73). There was no effect of route [$F(1, 45) < 1$], or any interaction between participant group and route [$F(1, 45) < 1$]. The performance of the older adults was generally poor on this task, and we analysed their data relative to chance performance (50 %) using a single-sample *t* test. Older adults' performance was significantly better than chance for both routes through either the familiar [$t(22) = 2.44$, $p = 0.023$] or less familiar [$t(22) = 2.71$, $p = 0.013$] areas (see Fig. 7).

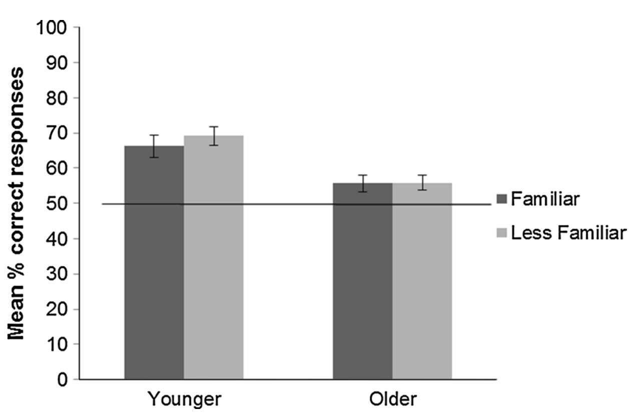

Fig. 7 Mean percentage accuracy performance on the proximity judgement task across younger and older adult group for the routes through the familiar and less familiar areas. *Error bars* indicate ±1 standard error of the mean. Chance performance in this task was 50 % as indicated

Reaction times

Three separate ANCOVAs (with computer experience included as a covariate) conducted on the reaction times to the trials with correct responses only (i.e. hits) for the three computerised tasks revealed a main effect of participant group for the object recognition [$F(1, 40) = 9.11$, $p = 0.004$, $\eta_p^2 = 0.19$] and direction judgement [$F(1, 41) = 9.71$, $p = 0.003$, $\eta_p^2 = 0.19$] tasks. Older adults responded more slowly than younger adults on both tasks (all *p*s < 0.001). There was no effect of group for the proximity judgement task [$F(1, 42) < 1$]. A main effect of route was found for the object recognition task only [$F(1, 40) = 5.03$, $p = 0.031$, $\eta_p^2 = 0.11$] with faster responses to the route through the familiar than less familiar area ($p < 0.05$). A significant interaction between route and computer experience was found for the object recognition [$F(1, 40) = 4.22$, $p = 0.046$, $\eta_p^2 = 0.1$] and proximity judgement tasks [$F(1, 42) = 7.01$, $p = 0.011$, $\eta_p^2 = 0.14$]. Separate Pearson's correlations between computer experience and response times to recognise the target objects from the routes across the two campus areas were conducted. For both the familiar [$r(44) = -0.3$, $p = 0.044$] and less familiar areas [$r(44) = -0.357$, $p = 0.012$], there was a negative correlation between computer experience and reaction times. Similarly, two separate Pearson's correlations carried out between computer experience and response time for the proximity judgement on the routes through the familiar and less familiar areas revealed no correlation found between these factors for the familiar area [$r(44) = -0.02$, $p = 0.91$]. For the route through the less familiar area, there was a significant negative correlation between computer experience and reaction times [$r(44) = -0.36$, $p = 0.013$]. Together, these findings suggest that those with greater computer experience responded more quickly across both routes on the object recognition task and to the route through the less familiar area on the proximity judgement task. No other significant effects were found (all *p*s = n.s.).

Landmark location task

The landmark location task involved indicating the location of the target objects encountered on each route on a 2D map of each area (East or West) of the College. A mixed ANOVA was conducted on the mean accuracy scores on this task. We

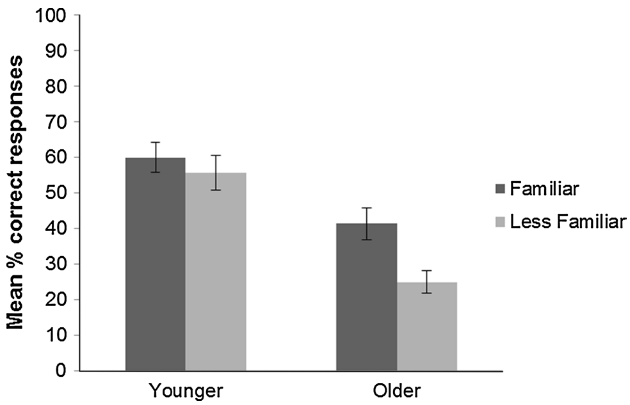

Fig. 8 Mean accuracy at locating the target objects in the landmark location task across the younger and older adult groups for the routes through the familiar and less familiar areas. *Error bars* indicate ±1 standard error of the mean

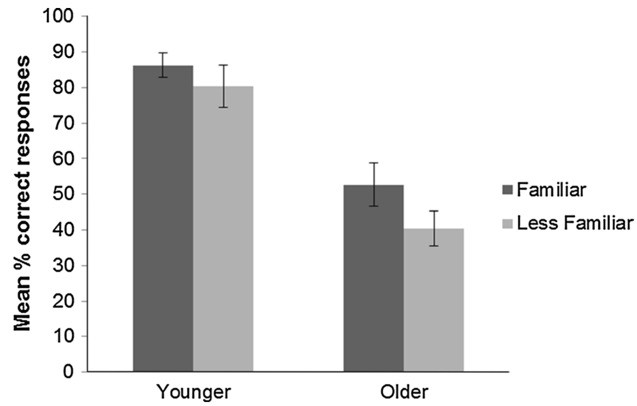

Fig. 9 Mean accuracy at naming the target objects in the landmark naming task across the younger and older adult groups for the routes through the familiar and less familiar areas. *Error bars* indicate ±1 standard error of the mean

found a main effect of participant group [$F(1, 45) = 22.79$, $p < 0.001$, $\eta_p^2 = 0.34$] with worse performance for older ($M = 33.17$, SD = 15.67) than younger ($M = 57.89$, SD = 19.53) adults. There was a main effect of route [$F(1, 45) = 11.09$, $p = 0.002$, $\eta_p^2 = 0.2$] with better performance for locating target objects in the familiar ($M = 50.9$, SD = 23.27) than the less familiar area ($M = 40.68$, SD = 25.05). The interaction between participant group and route approached significance [$F(1, 45) = 3.77$, $p = 0.058$, $\eta_p^2 = 0.08$], as shown in Fig. 8. Post hoc comparisons (Bonferroni-corrected t tests) were conducted to analyse this relative benefit of a familiar environment across older and younger adults on this task. Older adults were significantly better [$t(22) = 3.79$, $p = 0.001$] at locating target objects in the familiar ($M = 41.36$, SD = 21.75) than the less familiar area ($M = 24.98$, SD = 15.26). In contrast, there was no benefit of area for the younger adults [$t(23) = 0.97$, $p = 0.34$] (familiar: $M = 60.05$, SD = 21.26; less familiar: $M = 55.73$, SD = 23.43).

Landmark naming task

The landmark naming task involved identifying each target object encountered along each route on a 2D map of the East and West areas of college as indicated on a map. A mixed ANOVA conducted on the mean accuracy scores revealed a main effect of participant group [$F(1, 45) = 43.79$, $p < 0.001$, $\eta_p^2 = 0.5$]: performance was worse in the older ($M = 46.52$, SD = 18.12) than younger ($M = 83.33$, SD = 19.93) adult group. The difference in landmark naming performance to the familiar ($M = 69.79$, SD = 29) and less familiar ($M = 60.85$, SD = 33.09) areas failed to reach significance [$F(1, 45) = 3.53$, $p = 0.067$, $\eta_p^2 = 0.07$]. There was no interaction between participant group and route [$F(1, 45) < 1$], as shown in Fig. 9.

Correlations between performance on the object recognition and performance on direction judgement, proximity judgement, landmark locating and landmark naming tasks

When an object was encountered along each route, participants were instructed to remember the object itself, as well as the direction taken at that object's location. As such, it is feasible to assume that objects were either represented within a spatial context (i.e. together with the direction taken) or as object representations which are independent from the spatial context (e.g. Hollingworth and Henderson 1998; Oliva and Torralba 2007). To assess these possibilities, we investigated whether accuracy performance by the younger and older adult groups together on the object recognition task was related to performance on all spatial tasks. First, we conducted separate correlations on the accuracy performance between the object recognition task and direction judgement task, irrespective of route. We found a significantly positive correlation across these tasks [$r(45) = 0.51$, $p < 0.001$]. The positive correlation between performance accuracy on these two tasks indicates that better performance on object recognition is associated with better spatial memory for directions taken (see Fig. 10a).

In the second analysis, we investigated whether accuracy performance on the object recognition task was related to performance on the proximity judgement task regardless of route. We found a significantly positive correlation across these tasks [$r(45) = 0.47$, $p < 0.001$]. The positive correlation between performance accuracy on these two tasks indicates that better performance on object recognition was associated with better memory for relative object positions (see Fig. 10b).

A separate correlation was also conducted on the accuracy scores between accuracy performance on the object

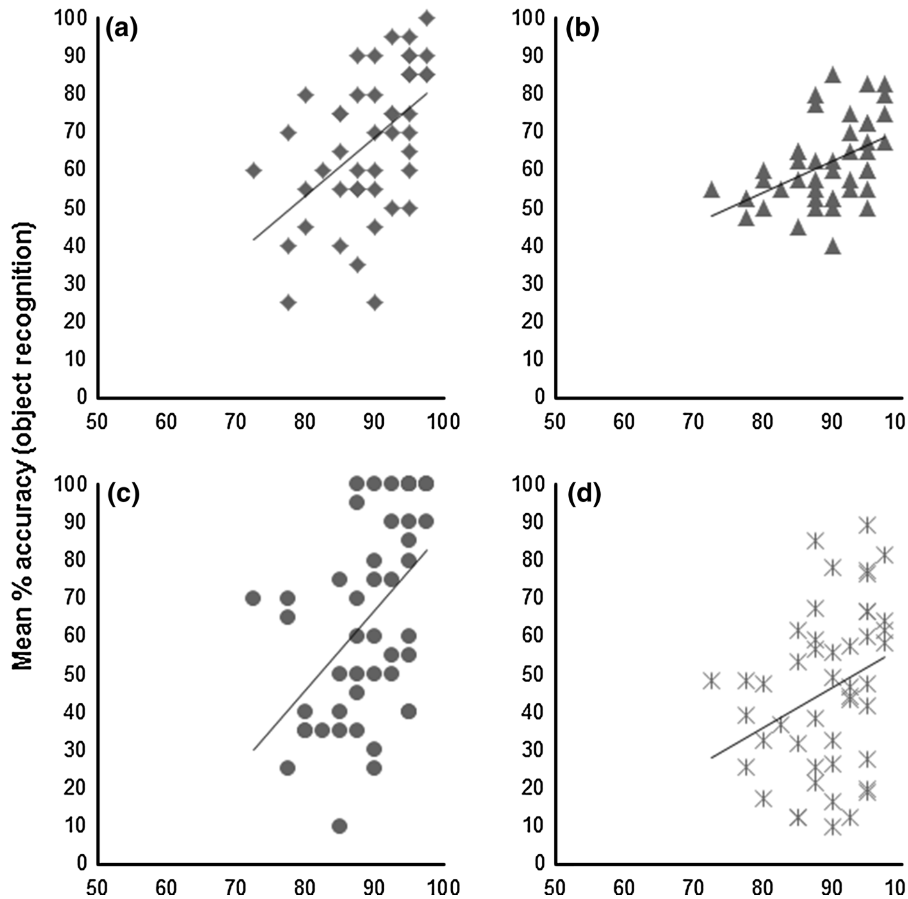

Fig. 10 Plots showing the correlation between accuracy performance on the object recognition task and **a** direction judgement, **b** proximity judgement, **c** landmark locating and **d** landmark naming tasks for performance across younger and older adults only

recognition and landmark locating task. Again, we found a significantly positive correlation across these tasks [$r(45) = 0.31$, $p = 0.031$] (see Fig. 10c), indicating that better performance on object recognition was associated with better memory for the location of target objects on a map. The correlation conducted on the accuracy performance between the object recognition and landmark naming task revealed a significantly positive correlation across these tasks [$r(45) = 0.5$, $p < 0.001$] (see Fig. 10d). These correlations were also conducted on performance of the younger and older groups separately. However, while the correlations between object recognition and direction judgement, proximity judgement and landmark naming for both groups were consistently in a positive direction, these correlations failed to reach significance.[2]

We also assessed whether performance was better across trials for each target object in the direction judgment, proximity judgement, landmark location and landmark naming tasks when that target object was correctly recognised compared to when it was forgotten (see Fig. 11). To that end we conducted a by-item analysis with route (familiar,

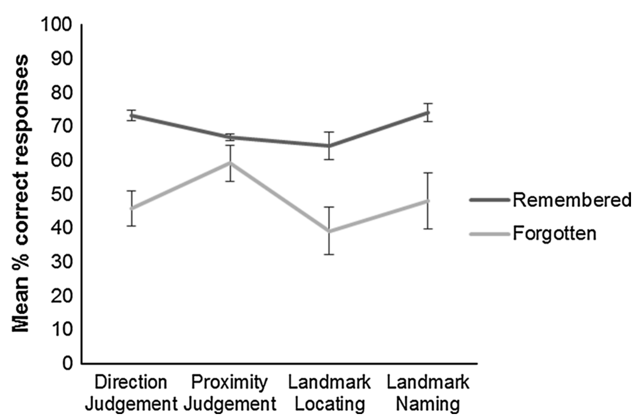

Fig. 11 Mean accuracy across the direction judgement, proximity judgement, landmark location and landmark naming tasks for remembered compared to forgotten target objects. *Error bars* indicate ±1 standard error of the mean

[2] Younger adults: correlations between object recognition and direction judgement [$r(22) = 0.28$, $p = 0.19$], proximity judgement [$r(22) = 0.29$, $p = 0.16$], landmark location [$r(22) = 0.05$, $p = 0.81$] and landmark naming [$r(22) = 0.26$, $p = 0.21$]. Older adults: object recognition and direction judgement [$r(21) = 0.36$, $p = 0.09$], proximity judgement [$r(21) = 0.29$, $p = 0.19$], landmark location [$r(21) = 0.02$, $p = 0.92$] and landmark naming [$r(21) = 0.23$, $p = 0.3$].

less familiar), target object (remembered, forgotten) and task (direction judgment, proximity judgement, landmark location and landmark naming) as factors on a trial-by-trial basis. There was a main effect of target object [$F_2(1, 9) = 24.04$, $p < 0.001$, $\eta^2_p = 0.73$], with a higher percentage of remembered ($M = 69.67$, SD = 5.36) relative to forgotten target objects ($M = 48.12$, SD = 14.41). The effect of route and task failed to reach significance (p = n.s.). There was a significant interaction between target object and task [$F_2(3, 7) = 3.13$, $p = 0.042$, $\eta^2_p = 0.26$], with better performance on the direction judgement, landmark location and landmark location tasks when the object was remembered compared to when it was forgotten (all ps < 0.01). No other significant interactions were found (all ps = n.s.).

Taken together, the consistent findings of positive correlations between the object recognition task and the proximity judgement, landmark locating and landmark naming tasks, suggest that better performance on the object recognition task was associated with better spatial memory as assessed across a range of tasks. The item analysis further suggests that spatial memory across tasks was better when target objects were remembered relative to when they were forgotten.

Discussion

The aim of this study was to investigate whether the familiarity of an environment affected spatial memory and memory for novel objects embedded in the environment. We compared the effect of familiar and less familiar environments on memory in younger and older adults using a virtual representation of the campus of Trinity College Dublin. First, we found no evidence for significant performance differences across College areas on all of the spatial memory tasks in student members of Trinity College who reported being equally familiar with both areas (although in the direction judgement task performance was marginally better for the West area of campus). We then compared the performance of older adults and younger adults, who were both more familiar with one area (West) of the College campus than another (East). First, we found that older adults performed worse than their younger counterparts across all tasks. However, our findings indicated a benefit for environment familiarity for both younger and older adults on their performance in recognising novel objects and in judging the correct direction taken at each object. Moreover, our results suggested that older adults' recall of landmark locations on a map was better for objects embedded in the familiar area than in the less familiar area within the College campus. No such benefit was found when the task involved judging the relative proximity of objects to each other.

Our results are consistent with previous findings suggesting age differences in spatial memory for familiar versus unfamiliar environments (e.g. Bruce and Herman 1983; Campbell et al. 2014; Kirasic 1989, 1991; Muffato et al. 2015). However, the results from the current study extend these findings in an important way: here we show that the benefit provided by environment familiarity also impacts on object recognition and egocentric processing of novel items in both younger and older adults, but not for judging the relative proximity between these novel items. As the East area of campus was less familiar to both younger and older adults, the novel objects placed in the centre of each intersection along the route likely functioned as associative cues which participants relied upon to remember the direction taken at each object (Waller and Lippa 2007). Previous research has found that older adults tend to rely more on beacon-based than associative cue-based egocentric strategies when navigating through a novel environment (Wiener et al. 2013), which may have further hindered their performance on the direction judgement task in the less familiar area relative to younger adults. However, within the familiar area, it is possible that participants may have used their knowledge about the environment from long-term memory to memorise the route (Schinazi and Epstein 2010). In line with the results of the object recognition and direction judgement tasks, research conducted on the role of schemas in memory formation has demonstrated that the presence of a cognitive framework (or schema) facilitates new learning both when the new information is congruent or incongruent (i.e. novel) to that schema (van Kesteren et al. 2012). Therefore, it is possible that the schema related to the contextual cue of the well-known West area of campus allowed for more robust encoding of events occurring at specific locations within that area (i.e. the embedded novel objects). Previous findings have also suggested that familiar, as opposed to less familiar, landmarks or locations provide a more robust spatial cue or context in which an event can be constructed and thus remembered with more details and vividness, improving scene memory pertaining to that landmark (Robin and Moscovitch 2014; Robin et al. 2015). Furthermore, in line with faster reaction times for object recognition in the familiar compared to less familiar area, Robin and Moscovitch (2014) found that retrieval times were faster for scene memories based on more familiar than less familiar cues, suggesting that less effortful cognitive processes were involved in recalling an event based on a highly familiar spatial context.

Regarding the proximity judgement task, the allocentric processing necessary to successfully complete the task relies on the hippocampus, a structure known to have reduced activation during spatial learning tasks in older adults (Moffat et al. 2006). The successful completion of this task requires knowledge relating to the topographical

spatial relationship between target objects. Humans have been shown to be quite efficient at estimating the proximity to a distant target location using parameters such as direction, Euclidean distance and route distance (Howard et al. 2014; Thorndyke and Hayes-Roth 1982). Using a paradigm designed to separate the Euclidean distance from path distance to a goal location, Howard et al. (2014) were able to identify distinct brain activations depending on the type of distance being represented. Specifically, they found that posterior hippocampal activity was correlated with the path distance to the goal location, while entorhinal activity was correlated with the Euclidean distance to goal location. However, trials within the proximity judgement task in the current study were not separated in terms of Euclidean or route distance between the reference object and the closer object. Therefore, it is possible that trials could have been solved by either an egocentric or allocentric spatial strategy. Nevertheless, all participants found the proximity judgement task challenging as suggested by their accuracy performance (i.e. students 73.65 %, younger adults 67.71 % and older adults 55.76 % accuracy on average) and by the slow reaction times by both the younger groups and older adults relative to other tasks (see Table 6). This finding is indicative of the use of allocentric processing which requires the use of additional cognitive operations, necessitating longer response times compared to egocentric processing (Byrne et al. 2007). In particular, older adults performed worse on this measure than younger adults.

In contrast to our results, Rosenbaum et al. (2012) found no difference in performance between younger and older adults on a proximity judgement task, suggesting a general benefit for a highly familiar environment on allocentric processing in older adults. The current study found no benefit for environment familiarity on proximity judgements for either the younger cohorts or older adults. However, there are some important differences between these studies that may account for these differences in the proximity judgement tasks. First, the objects referred to by Rosenbaum et al. (2012) were landmarks which were already familiar within the environment and could potentially be used for navigation, whereas the objects used in the current study were novel and therefore unfamiliar within the context of the familiar environments and had little to do with navigation. A second methodological difference between the studies is that in the present study we used a virtual rendering of a familiar environment, whereas the Rosenbaum et al. (2012) study was based on the veridical city of Toronto. A virtual environment allows the experimenter to present important information about spatial layout while also controlling for extraneous information which may be irrelevant to the task, such as the presence of other people or traffic, but may affect performance. However, results of the validation study demonstrated that participants were easily able to locate scenes from the virtual routes used in the current study on a map of the area, suggesting the virtual environment was a faithful rendering of the real TCD campus. Furthermore, previous studies have shown a strong correlation between spatial memory performance for virtual and real-world environments across younger, older and clinical populations (Cushman et al. 2008; Lloyd et al. 2009; Sorita et al. 2013).

Another possible difference between the studies is that the older adults in our study may not have been presented with sufficient time to form a cognitive map of the testing environment during the course of the experimental session. Research has shown that older adults take longer to form a cognitive map than their younger counterparts (Iaria et al. 2009; Rosenbaum et al. 2012); therefore, it remains an outstanding issue as to whether or not performance in the proximity judgement task would improve with longer learning time. Furthermore, because the environment utilised by Rosenbaum et al. was well known to older adults in the remote past, it is possible that extrahippocampal regions may have supported performance on the proximity judgement task, as opposed to the hippocampus (Hirshhorn et al. 2012; Rosenbaum et al. 2007), resulting in comparable performance to younger adults.

Our results are similar to those reported by Head and Isom (2010) from their wayfinding condition: relative to younger adults, older adults in the current study had difficulty recalling where a target landmark object was located on a 2D map of each area through which the routes traversed, as well as difficulty with naming the target landmarks on the map. Older adults' performance on these tasks, as well as on the proximity judgement task, is indicative of an inability to form, or recall, a sufficient cognitive map of each environment (Head and Isom 2010; Moffat et al. 2001). However, older adults' performance suggested a benefit for landmark location memory in the familiar area compared to the less familiar area. This result was not found for younger adults, who found several tasks easier and performed comparably well across the two routes. The ability to localise target landmarks on a 2D aerial view map when originally learned from a first person perspective has been considered a measure of "cognitive mapping" ability (Moffat and Resnick 2002). However, it is possible that this task could be solved using either allocentric or egocentric spatial processing in the current study. Specifically, the 2D map as presented to participants may have provided sufficient cues to complete the task by associating egocentric directional information with a location. For example, the 2D map contained an outline of the buildings in the area which may have provided a context to recall which particular target object was associated with a given location, particularly in the familiar environment where the buildings and their locations were well known. Given that previous

studies have reported that older adults consistently rely on an egocentric strategy when an allocentric strategy is required to solve a spatial task (Wiener et al. 2013), it is likely that older adults relied on an egocentric-based strategy to solve the landmark location task. It is possible therefore that the current finding suggests that familiarity with an environment mediated older adults' ability to localise objects presented within that environment through use of an egocentric spatial strategy.

Although the current study took both objective and self-reported measures of familiarity, future research could also provide more objective measures of familiarity such as the frequency and duration of visits to the different areas of the campus. Epstein et al. (2007a, b) used participants' overall magnitude of the BOLD response in cortical regions involved in spatial orientation to photographs of the well-known area of the campus relative to photographs of the lesser-known area as an index of familiarity. However, in the current study the performance of students who were equally familiar with both areas was not different across the two routes. In contrast, younger adults who rated the West end of campus as more familiar than the East end performed better on the familiar route in the object recognition and direction judgement tasks than on the route they rated as less familiar. These data suggest that the self-reported familiarity by both the students and younger adults was predictive of their subsequent performance across the familiar and less familiar routes and, moreover, that the participant groups had been categorised correctly.

The results from neuroimaging studies provide insight into the possible neural underpinnings of the behavioural effects observed in our study. The two distinct spatial representations of an environment, egocentric and allocentric, are thought to be mediated by separate brain regions. Egocentric spatial processing has been shown to be supported more by the caudate nucleus, whereas allocentric processing is supported by the hippocampus (e.g. Hartley et al. 2003; Iaria et al. 2003; Maguire et al. 1998; Packard and McGaugh 1996). The relative navigational skills of each individual has been shown to differentially activate these brain regions, with accurate wayfinding performance (allocentric spatial processing) activating the right posterior hippocampus and accurate route following or learning (egocentric spatial processing) activating the head of the right caudate nucleus (Hartley et al. 2003).

The hippocampus receives the input, via the entorhinal cortex, from the PHC, which in turn receives inputs primarily from the visuospatial association areas in the dorsal visual stream, as well as from other structures including the retrosplenial cortices (e.g. Davachi et al. 2003; Suzuki and Amaral 1994). Research on visual scene processing suggests that the retrosplenial cortical region plays an important role in situating the local scene within the broader spatial environment (Epstein et al. 2007a, b), while the PHC is implicated in mediating contextual association between objects as well as increasing activation for navigationally relevant landmarks (Aminoff et al. 2007; Janzen and van Turennout 2004). More pertinently, Epstein et al. (2007a) reported stronger activations to images of familiar locations than to images of unfamiliar locations in the parahippocampal region, retrosplenial cortex and transverse occipital sulcus of younger adults, with experience modulating the visual processing of these scenes. The strength of activation in the PHC to the presentation of scenes was also found to positively correlate with self-reported navigational abilities (Epstein et al. 2005).

The current results suggest that these findings may be extended to the representations of novel objects embedded within a familiar environment. For example, the findings reported by Hayes et al. (2007) suggest that the PHC is involved not only in scene processing, but may also reinstate visual context to an object to mediate successful episodic memory retrieval. This finding is relevant to the current study, as during the test phase of the experiment all images of objects from the two routes were presented on black backgrounds, devoid of contextual information. It is plausible that successful recognition of these objects was supported via the PHC in which the familiar context learned during passive viewing of the route through the familiar area was associated with each object. Furthermore, better performance in recognising target objects from the environment was associated with better performance on all other tasks reported in the current study. However, there was an age effect present in all tasks; therefore, it is possible that group differences in performance were driving the correlation. To that end, although correlations conducted for the younger and older groups separately failed to reach significance, there were positive correlations between object recognition and direction judgement, proximity judgement and landmark naming for both groups. Furthermore, when a target object was successfully remembered, spatial memory across tasks was better for that object compared to if an object was forgotten. These findings suggest that target objects were represented within the spatial context (i.e. together with the direction taken) in which they were learned as opposed to being represented independently of spatial context (e.g. Hollingworth and Henderson 1998).

Previous studies have reported comparable spatial memory performance of younger and older adults for familiar environments (e.g. Campbell et al. 2014; Kirasic 1991; Muffato et al. 2015; Rosenbaum et al. 2012) though this was not found to be the case in the current study. However, the aforementioned studies were based on landmarks already familiar within the environment, whereas the current study required the effortful binding of novel objects to the environment context, which may have proved more

difficult for older relative to younger adults. It is also possible that more general age-related declines in cognitive function such as information processing speed, working memory, visuospatial memory and executive function (Cabeza et al. 2005) may have contributed to the lack of interaction between age group and route due to the overlap of the cognitive processes necessary for efficient global cognitive function and spatial navigation (Taillade et al. 2013).

Older adults have been shown to have reduced volume and reduced activity in the PHC compared to younger adults (Antonova et al. 2009), which may explain the age-related decline in performance across the object recognition and direction judgement tasks. The results of Meulenbroek et al. (2004) suggest that this age difference may be due to a reduction in the ability to bind the target object to its background context, based on reduced parahippocampal activity. However, while Chee et al. (2006) found that older age is associated with a reduction in the ability of the hippocampus to efficiently bind objects to novel backgrounds, the authors also found evidence for preserved background processing in the PHC of older adults. Kessels et al. (2005) also reported an age-related decline in the ability to bind an object to its spatial location. Similarly, older adults have been found to have stronger activation in the PHC in an contextual memory retrieval task consistent with an age-related increase in familiarity-based recognition (e.g. Cabeza et al. 2004). Furthermore, Craik and Schloerscheidt (2011) found that when target objects, previously learned within a particular context, were subsequently presented in the original, switched, new or no context (i.e. a blank background), then older adults performed better in a recognition test when the object was presented with no context compared to a new context. These findings suggest that older adults' recognition performance was influenced by the combined activation of the representation of the object and its context, and that an unfamiliar context was more detrimental to performance than no context. While the current study does not provide direct evidence of a neuroanatomical substrate for representations of novel objects in a familiar environment, the results are consistent with the above evidence for stronger activations within spatial cortical regions for stimuli located in a familiar scene or background. Future research using neuroimaging techniques is needed to explore this finding further.

Overall, the response times of the older adults were slower on the measures of object recognition and direction judgement relative to the younger adult groups. Again, as we found no interaction between age group and route for any of the computerised tasks, it is possible that slower response times were in part the result of impaired processing speed with increasing age (Salthouse 1996). However, there was no difference in the response times of older or younger adults to the proximity judgement task. The increased reaction times of both age groups suggest that the probable use of allocentric processing to effectively solve this task was particularly cognitively demanding (Byrne et al. 2007). As well as reaction time variability being a consequence of cognitive ageing (e.g. Hultsch et al. 2002), slower reaction times by older adults on computer-based tasks could be due to a lack of fluency with the use of computers, though not indicative of worse spatial memory per se (Moffat et al. 2001). Interestingly, although age differences were evident in self-ratings of experience with computers and computer games, the composite score of these variables did not contribute to the participants' accuracy performance on any of the measures. However, computer experience correlated with reaction times for the object recognition task on both the familiar and less familiar routes and proximity judgement task on the less familiar route only, but not with reaction times on the direction judgement task for either route. This suggests that those with less computer experience responded more slowly, particularly on the more difficult or cognitively demanding tasks such as proximity judgement.

In summary, this study successfully replicated a consistent finding in the literature of impaired spatial learning with ageing, which has previously been demonstrated in human as well as in comparative studies, using both real-world and virtual environments (e.g. Begega et al. 2001; Head and Isom 2010; Kirasic 1991; Moffat 2009; Wiener et al. 2012, 2013; Wilkniss et al. 1997). Furthermore, by utilising a virtual representation of both a familiar and less familiar environment, we found that environment familiarity benefitted object recognition and egocentric spatial processing in both younger and older adults. In particular, environment familiarity mediated older adults' ability to remember the relative locations of objects presented within that environment. Although more research is necessary to ascertain exactly how familiar environments support these cognitive benefits, the current findings suggest that context familiarity may free up cognitive resources for learning new information presented within this spatial context (Allen 1999; Kirasic 1991).

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