Age and Sex Effects on Facets of Topographical Memory of Highly Familiar Environments

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Candidate's Declaration

I, Jamie Campbell, candidate for the degree of Doctorate of Psychology (Clinical Neuropsychology) at Macquarie University, do hereby certify that:

i. The papers and thesis contained herein comprise entirely my original work towards the degree, and that I was principally responsible for the formulation of research, methodological design, selection of testing materials, recruitment and testing of participants, statistical analyses and authoring of each paper and section of the thesis;

ii. This work has not been submitted to any other university or institution for a higher degree;

iii. The thesis' included papers is less than 40 000 words in length, excluding tables, references and appendices;

iv. Ethics approval for the research was obtained from Macquarie University Ethics Review Committee (Human Research): HSHE30OCT2009-D00040

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Jamie I. Campbell

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Within the thesis the format of the papers has been held consistent. The papers have not been formatted according to individual journal submission requirements.

Abstract

Topographical memory is a multifaceted construct that encompasses memory for environments, landmarks and routes. While research suggests that age and sex influence topographical memory in non-human animals, the impact of these variables on topographical memory in humans is less clear, especially in the context of highly familiar (as opposed to newly-learned) environments. The aim of the research reported in the current thesis was to examine age and sex differences in topographical memory of environments that had been familiarised over years and decades, across three papers. The first paper comprises a systematic review of the literature conducted in order to evaluate the evidence of age and sex differences in topographical memory. A search yielded 11 studies that examined age differences and 34 studies that examined sex differences in topographical memory. For *newly-learned* environments, the review found consistent evidence of age and sex differences (in favour of males and younger adults) on some tasks of memory of environmental configurations. Age differences (in favour of younger adults) were also found on all tasks of route memory. For *highly familiar* environments, the studies were few in number and the findings were inconsistent. The second paper of this thesis presents an empirical study that examines age and sex differences in topographical memory of an environment highly familiar to participants (i.e. Sydney). Sixty-three healthy adults, ranging between 20 and 79 years of age, completed the Sydney City Test of Topographical Memory (SCTTM; Hepner, 2006), in addition to several spatial and verbal cognitive tasks. The study found no significant age or sex effects on the ability to name Sydney landmarks from photographs, localise landmarks on a map of the Sydney central business district, or describe how to get from one Sydney landmark to another. On the other hand, a curvilinear relationship was found for males in the ability to determine cardinal

directions and determine the directions of landmarks from a vantage point depicted in a photograph, with highest performance at middle-age. In the case of females, a linear decline was found between age and ability to determine directions of landmarks, while no relationship was found between age and ability to determine cardinal directions. Correlations were found between several cognitive tasks and SCTTM subtests, and these are detailed in the paper. The third paper of this thesis examined the utility of the SCCTM in detecting topographical memory impairments in a 38 year old male anterior temporal lobectomy patient who had complained of topographical memory problems following surgery. TA's performance on the SCTTM was compared to 10 normal male participants of similar age and familiarity with the target environment and also in relation to the large-group SCTTM data developed in the second paper. TA was found to perform poorly on all SCCTM subtests, highlighting the value of the SCCTM in profiling topographical memory in a left temporal lobectomy patient. Implications of the three papers and future research direction are discussed.

General Introduction

Topographical memory refers to memory of landmarks, routes and the spatial relationships between landmarks. The ability to recognise and efficiently navigate environments is an important skill that has been shown to be impaired in those suffering a number of different neurological conditions including Alzheimer's disease (Monacelli, Cushman, Kavcic, & Duffy, 2003), limbic encephalitis (Rosenbaum, Gao, Richards, Black, & Moscovitch, 2005), and cerebrovascular accident (Hepner, Mohamed, Fulham, & Miller, 2007). Despite its importance, topographical memory has been researched less frequently than other domains of memory and this is attributable to several different reasons. Firstly and perhaps due to the methodological difficulties associated with quantifying largely personalised knowledge of environments, few standardised tests of topographical memory exist. Moreover, of the topographical memory tests that do exist, such tests tend to examine memory of environments that have never been personally navigated by the test-taker, such as recognition of photographs of world famous landmarks (Mina et al., 2010) or recognition of photographs depicting scenes of an unfamiliar environment (Warrington, 1996). Secondly and more fundamentally, a lack of consistency in terminology and the lack of an established conceptual framework in topographical memory research have impeded progress in the field. This limitation in the research is not surprising given the diversity of ways in which topographical memory has been assessed in the literature. Studies purporting to assess topographical memory have used a range of stimuli including 2D maps (Galea & Kimura, 1993), videotapes depicting routes (Cushman, Stein, & Duffy, 2008) and virtual-world or real-world environments that have previously been actively explored by subjects (Head & Isom, 2010; Castelli, Corazzini, & Germiniani, 2008; Kirasic, 2000). Consequently, outcome measures used to assess topographical memory are numerous and commonly include accuracy in localising landmarks on a map of the environment (Head & Isom, 2010; Kirasic, 2000; Evans, Brennan, Skorpanich, & Held, 1984), accuracy in pointing in the direction of landmarks not visible from the testing position (Castelli et al., 2008; Richardson, Powers, & Bouaquet, 2011), the number of directional errors (Castelli et al., 2008; Monacelli et al., 2003) or path length taken (Head & Isom, 2010) when attempting to retrace a previously-learned route, and the ability to recall and recognise landmarks from the environment (Kirasic, 2000; Evans et al., 1984).

Brunsdon, Nickels, and Coltheart (2007) present a framework of topographical knowledge that recognises a number of cognitive processes that underlie topographical memory (see Figure 1). The model highlights the important role of a visual-spatial working memory system in successfully undertaking tasks of topographical memory. Visual-spatial working memory interacting with long-term memory (which holds representations of the learned environment), is proposed to be a critical process that underlies performance on tasks such as map-drawing or describing routes. Brunsdon et al.’s (2007) model also highlights an important contribution of an attention/executive system and a semantic knowledge system, the former being critical for complex topographical knowledge tasks that involve such processes as planning (e.g., describing a route), while the inclusion of the latter was based on the authors’ assumption that topographical knowledge is supported by background knowledge of the environment.

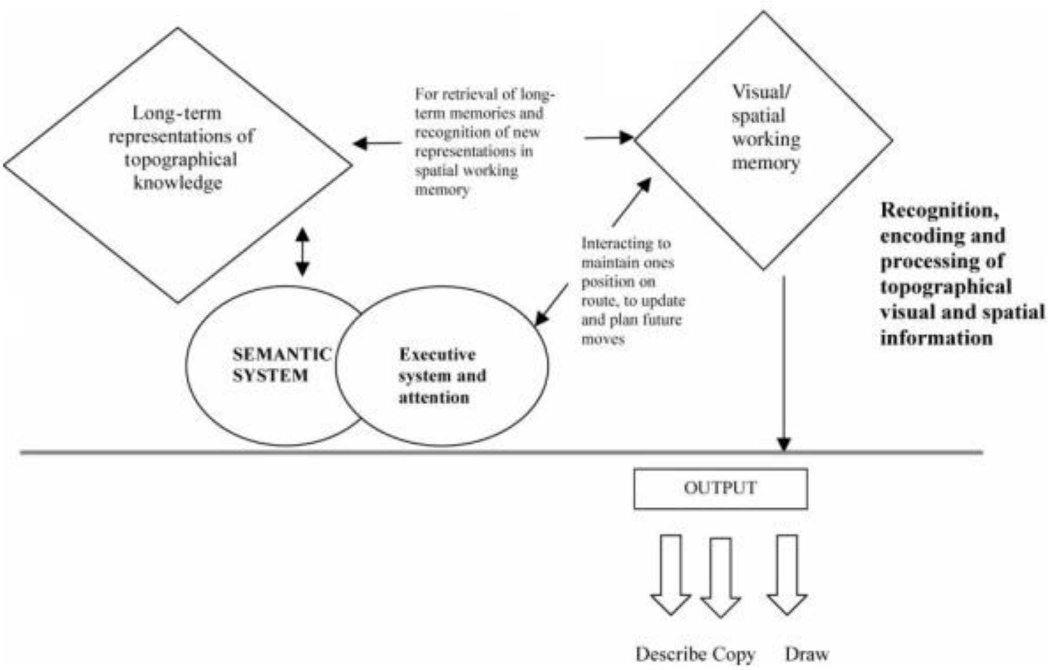

Figure 1

Portion of Brunsdon et al.'s (2007) Integrated Model of Topographical Processing

One area of interest in the topographical memory literature, and the focus of this thesis, concerns whether topographical memory changes across the human lifespan and differs between males and females. Studies from the animal literature are consistent in indicating that topographical memory deteriorates across the lifespan and is superior in males in some species of animals (Begega et al., 2001; Gallagher, Burwell, & Burchinal, 1993; Winocur & Moscovitch, 1990; Gaulin & FitzGerald, 1986). In contrast, studies that examine age and sex differences in topographical memory in humans are fewer in number, and to date such studies have not been systematically examined. The first paper of this thesis comprises a systematic review of the literature, conducted in order to evaluate evidence as to whether there exist age and sex differences in topographical memory in humans. Based on a taxonomy commonly adopted in previous research (Aguirre & D'Esposito, 1999; Siegel & White, 1975;

O’Keefe & Nadel, 1978), the systematic review delineates measures that tap into three major facets of topographical memory: environmental configurational memory, route memory and landmark memory. Given previous evidence that memories of newly-learned environments and memories of familiar environments may be underpinned by different neural systems (Maguire, Nannery, & Spiers, 2006; Rosenbaum et al., 2000; Hirshhorn, Grady, Rosenbaum, Winocur, & Moscovitch, in press), studies that utilised newly-learned and familiar environments were considered separately. A search yielded 11 studies that examined age differences and 34 studies that examined sex differences in topographical memory. While the review found a sufficient number of studies that have examined age and sex differences in some facets of topographical memory of *newly-learned* environments for conclusions to be drawn, few studies were found in the search that have examined age and sex differences in topographical memory of *familiar* environments, and the sparse results were largely inconsistent. Thus, the first paper highlighted the need for further research into age and sex differences in the context of topographical memory of familiar environments.

In view of the limitations of the literature highlighted in the systematic review, the second paper of this thesis describes an empirical study that examined age and sex differences in topographical memory of a highly familiar environment. Sixty-three healthy adults, ranging between 20 and 79 years of age, completed the Sydney City Test of Topographical Memory (SCTTM; Hepner, 2006). The SCTTM is composed of six subtests that assess facets of topographical memory, namely memory of environmental configurations, routes and landmarks. Participants were all highly familiar with the target environment (i.e., the Sydney region). The relationship between facets of topographical memory and specific spatial and verbal cognitive skills which are known to both differ between males and females and deteriorate across the adult lifespan was examined in order to determine whether those aspects of cognition may potentially explain or at least contribute to any observed age and sex differences in topographical memory. The research detailed in the second paper also allowed the opportunity to develop data for the SCTTM.

The third paper examined the utility of the SCCTM in detecting impairments in memory of a highly familiar environment in patient TA, a 38 year old male who had undergone a left temporal lobectomy as treatment for pharmacologically intractable epilepsy. TA's performance on the SCCTM was compared to a group of 10 male control subjects of similar age and familiarity with the target environment (i.e., Sydney) and also in relation to the large-group SCCTM data developed in the second paper.

The thesis concludes with a discussion of the major findings of the current research, an appraisal of the limitations of the studies and recommendations for future research.

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Sex and Age Effects on Facets of Three-Dimensional Topographical Memory in Humans: A Systematic Review

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Abstract

Sex and age have been shown to influence topographical memory in animals, but the way in which these variables impact on this ability in humans is less well understood. A systematic review of the literature was conducted in order to determine whether sex or age affects three facets of topographical memory: environmental configuration memory, route memory and landmark memory. A search yielded 34 studies of three-dimensional topographical memory that examined sex differences and 11 studies that examined age differences. In the context of *newly-learned environments*, the literature suggested a male advantage on one measure of environmental configuration memory (heading orientation), though only in the case of real-world (as opposed to virtual) environments. The literature was consistent in showing no sex differences on measures of memory of newly learned routes. Regarding age differences in facets of topographical memory of newly-learned environments, studies are largely consistent in finding that younger adults outperform older adults on one measure of environmental configuration memory (localising landmarks on a map), and on all measures of route memory that were examined. The evidence was too limited to say for certain whether sex or age affects landmark memory of newly-learned environments. Few studies have examined sex and age differences in topographical memory for *familiar* environments, and the results were largely inconsistent. Altogether the current review indicated that, while there is limited evidence of sex differences (in favour of males) and age-related decline in select facets of topographical memory, the presence of such effects is dependent on the types of task and outcome measures that are used, on whether the context involves real-world or virtual-world environments and (possibly) whether the environment is newly-learned or familiar. The findings highlighted the need for further

research into sex and age differences in topographical memory, particularly for familiar environments.

Introduction

Memory for environmental configurations, routes and landmarks, known as topographical memory, is of fundamental importance from an evolutionary perspective. That is, the ability to recognise and efficiently navigate previously explored territory has considerable survival value (Kimura, 2000). One line of inquiry, and the focus of this systematic review, concerns whether topographical memory in humans differs between males and females and across the adult lifespan. While there is a large body of research that examines sex and age differences in topographical memory in animals (e.g., Begega et al., 2001; Lee, Miyasato, & Clayton, 1998), the number of studies that investigate the effects of these variables on topographical memory in humans is relatively limited.

The available literature pertaining to human topographical memory is highly diverse in terms of the methodologies employed, and these vary considerably in terms of the extent that they are likely to tap into the cognitive processes that underlie memory of real-world environments. Indeed, studies ranging from those utilising two-dimensional (2D) map-learning tasks (e.g., Galea & Kimura, 1993) to those that examine memory of real-world or three-dimensional (3D) virtual environments, learned by either active or passive navigation (i.e., ‘walking’ in the environment vs. watching the environment on a videotape; e.g., Head & Isom, 2010; Cushman, Stein, & Duffy, 2008), have all purported to investigate some form of memory of environments. Nevertheless, studies that examine memory of table-top spatial arrays or environments depicted on videotape or by 2D maps lack elements that may be important in the development of memory of real-world environments, such as locomotion cues and the ability to have a full 360 degree view of the to-be-learned environment. The present review was conducted in order to examine the evidence of human sex and age differences in topographical memory in the context of real or 3D virtual environments that have been actively explored, with respect to three facets of topographical memory (environmental configuration memory, route memory and landmark memory, each detailed in the next paragraph).

Facets of Topographical Memory

Topographical memory has been divided into three facets: configuration memory, route memory and landmark memory (Siegel & White, 1975; O'Keefe & Nadel, 1978).
The first two facets are considered more spatial in nature. Environmental configuration memory (also referred to as 'allocentric') refers to 'map-like' representations, which include memory of the spatial relationships between landmarks. Such memory provides the opportunity for flexible navigation, allowing the individual to determine short-cuts and other novel detours to landmarks within the environment. Route memory, on the other hand, refers to linear and sequential memory of specific routes, which incorporates associations between specific sequences of body-movements and cues in the environment. Such memories are less flexible in nature and are ineffective for navigating from one destination to another if any route other than that specifically learned is used. While route memory is subserved by the posterior parietal lobe, environmental configuration memory has a critical hippocampal contribution (Astur, Taylor, Mamelak, Philpott, & Sutherland, 2002; Burgess, Maguire, & O'Keefe, 2002), in addition to involvement of the retrosplenial cortex and posterior cingulate cortex (Aguirre & D'Esposito, 1999), at least in the case of newly-learned environments. Not all components of topographical memory are spatial in nature, as indicated by the common inclusion in frameworks of landmark memory (e.g., Aguirre & D'Esposito, 1999; Siegel & White, 1975). Landmark memory refers to the ability to recognise

environmental landmarks, which serve as important points of decision during wayfinding, and is subserved by the lingual and fusiform gyrus, and possibly the parahippocampal gyrus (Aguirre & D'Esposito, 1999).

Measures of these three facets of topographical memory vary widely across studies. Environmental configuration memory has been investigated by asking subjects to (i) point in the direction of a landmark that is not visible from the testing position ("heading orientation"), (ii) label or draw the spatial position of landmarks on a map of the environment ("landmark map localisation") or (iii) navigate to a landmark using the shortest route possible (under conditions where a non-linear environment had previously been navigated and the shortest route had not been explicitly learned, e.g., Cubuku & Nasar, 2005; Foreman, Stanton-Fraser, Wilson, Duffy, & Parnell, 2005). Ways in which route memory has been examined include measuring (i) the number of turning errors or (ii) the path length as subjects attempt to re-walk a previously learned route (e.g., Castelli, Corazzini, & Geminiani, 2008; Wilkniss, Jones, Korol, Gold, & Manning, 1997; Lovden et al., 2007). Landmark memory is commonly assessed by measuring subjects' ability either to (i) recall names of landmarks or (ii) recognise photographs of scenes and landmarks (e.g., Head & Isom, 2010).

Based on investigations of the breakdown of topographical memory, Aguirre and D'Esposito (1999) have introduced a taxonomy of topographical disorientation, with three separable profiles. The first profile is that of egocentric spatial disorientation, which involves a deficit in representing the spatial relationships of objects relative to the self (i.e., egocentric space). Impairments of this fundamental aspect of topographical memory result in individuals performing poorly on all way-finding tasks, including those requiring only linear right and left judgements, regardless of how personally familiar the environment may have been (Aguirre & D'Esposito, 1999). The second profile is that of heading disorientation, which reflects impairment in representing the spatial configuration of landmarks independently of the body's position in space (i.e., allocentric space). Hence, directional information cannot be obtained from correctly identified landmarks, resulting in a loss of a sense of direction (Aguirre & D'Esposito, 1999). The third profile implicates a non-spatial facet of topographical memory, namely landmark agnosia. Individuals with a landmark agnosia have difficulties navigating because they are unable to recognise landmarks, despite intact perceptual ability and general object identification.

Given the empirically-based taxonomy provided by Aguirre and D'Esposito (1999), and the findings of other studies that conceptualise topographical memory as multifaceted in nature (e.g., Siegel & White, 1975; O'Keefe & Nadel, 1978), any systematic review of human age and sex effects of topographical memory would need to explore this at the level of the three most salient facets reflected in the literature (i.e., memory for environmental configurations, memory for routes, and memory for landmarks).

Sex and Age Effects on Topographical Memory and the Role of the Hippocampus: Findings from Animal Studies

The importance of the hippocampus for spatial memory has been established in the animal literature (e.g., Gallagher & Pelleymounter, 1987; Geinisman, Detoledo-Morrell, Morrell, & Heller, 1995; Lee et al., 1998). Studies have demonstrated differences between males and females of certain species in memory for environments. Interestingly, these sex differences appear to be underpinned by differences in hippocampal size and home-range navigation in these species (see Lee et al., 1998, for a review). Male meadow voles have larger home ranges and have been found to perform better at maze-learning tasks relative to female meadow voles, whereas male and female pine voles do not differ in home-range size or maze-learning performance (Gaulin & FitzGerald, 1986). While male meadow voles have been found to have larger hippocampal volume compared to female meadow voles, no sex differences in hippocampal volume have been observed in pine voles (Jacobs, Gaulin, Sherry, & Hoffman, 1990). A relationship between spatial memory demands and hippocampal volume is also seen in parasitic species of birds (Lee et al., 1998; Reboreda, Clayton, & Kacelnik, 1996). Female brown-headed cowbirds, which are required to locate and remember the location of a host nest to lay its eggs, have greater hippocampal volume compared to male brown-headed cowbirds, which do not assist in the parasitic behaviour (Sherry, Forbes, Khurgel, & Ivy, 1993).

Evidence from animal studies also indicates that memories for environmental configurations and memories of routes deteriorate across the lifespan. Using various outcome measures on the Morris Water Maze (Morris, 1981), such as average path length and average latency to reach the platform hidden within the environment, studies have consistently found that younger rats perform better than older rats on this task (Begega et al., 2001; Gallagher, Burwell, & Burchinal, 1993). Younger rats have also been shown to make fewer directional errors than older rats when learning to solve a simple maze composed of several turns (Winocur & Moscovitch, 1990). The hippocampus appears to play an important role in underlying the age-related decline observed in spatial facets of topographical memory; structural and functional deterioration of the hippocampus across the lifespan of rats has been shown to be related to loss of spatial memory (Kadar, Silbermann, Brandeis, & Levy, 1990; Barnes, Suster, Shen, & McNaughton, 1997).

The animal literature therefore indicates that topographical memory is influenced by both sex and age, and these relationships appear to be underpinned by the hippocampus. In humans, reduced activation of the hippocampus has been found in older adults relative to younger adults when learning the spatial layout of a virtual environment (Moffat, Elkins, & Resnick, 2006). While there is little evidence of differences between men and women in hippocampal size (Moffat, Kennedy, Rodrigue, & Raz, 2007), functional magnetic resonance imaging evidence suggests a greater involvement of this structure when processing environmental information in men compared to women (Gron, Wunderlich, Spitzer, Tomczak, & Riepe, 2000). Therefore, it is possible that sex and age differences in topographical memory may also exist in humans, and these effects may similarly be underpinned by the hippocampus.

Memory of Newly-Learned Versus Familiar Environments

In humans, there is evidence from the patient and neuroimaging literature suggesting that memories for newly-learned and highly familiar environments may differ in their level of reliance on the hippocampus, and hence may be differentially impacted by advancing age and possibly by the effect of sex. The literature suggests an important role of the hippocampus in environmental configuration memory (Astur et al., 2002; Burgess et al., 2002; Iaria, Chen, Guariglia, Ptito, & Petrides, 2007) and route memory (Ghaem et al., 1996) of *newly-learned* environments in humans. As pointed out by Maguire (1997), recently acquired memories of environments may be akin to episodic memories (which, as defined by Nilsson (2003), are memories that involve the recollection of personal experiences, are dependent on the hippocampus, and decline with advancing age). The role of the hippocampus in topographical memory of *highly familiar* environments in humans, however, is less clear, with some evidence suggesting that the hippocampus remains important (Maguire, Frackowiak, & Frith, 1997), while other evidence suggesting that the structure is not recruited for such memories (Rosenbaum, Ziegler, Winocur, Grady, & Moscovitch, 2004). It has been suggested that, while rich detailed spatial representations of well-learned environments may remain critically dependent on the hippocampus, broad and schematic spatial representations of well-learned environments may become more widely distributed in the brain and therefore be relatively resistant to the effects of advancing age (Rosenbaum et al., 2000). The latter representations may become akin to semantic memories (memories of facts and general knowledge that do not require recollection of an event, are thought to be relatively independent of the hippocampus, and appear to remain relatively stable across the adult lifespan) (Nilsson, 2003).

In a functional magnetic resonance imaging study, Hirshhorn, Grady, Rosenbaum, Winocur, and Moscovitch (in press) explored changes in brain activation as normal individuals performed tasks of topographical memory of their home city, initially within a few months of moving into the city and then after a year of living in the environment. Significant activation of the hippocampus was found only in the first session, while unique activation was found in extra-hippocampal regions in the second session. Patients with extensive hippocampal injury have been shown to have reasonably preserved way-finding skills in the context of highly familiar environments, despite being poor at navigating newly-learned environments (Rosenbaum, Gao, Richards, Black, & Moscovitch, 2005; Rainville et al., 2007; Maguire, Nannery, & Spiers, 2006). Notably, one case study found a deficit when more fine-grained navigation of a familiar environment was examined (i.e., navigating along non-major roads, Maguire et al., 2006), consistent with the notion that, regardless of the level of familiarity, very detailed spatial information of environments may remain dependent on the hippocampus.

Given that well-established memories of environments may be less dependent on the hippocampus compared to memories of newly-learned environments, in reviewing the literature on ageing effects of topographical memory it would be necessary to distinguish between studies that utilise newly-learned environments and those that utilise familiar environments. Furthermore, as differences between the male and female hippocampus might account for the sex-related differences in topographical memory, it is possible that any sex differences in topographical memory observed in humans may disappear once the environment is highly familiar and memory is transferred to other parts of the brain. Thus, it may also be important to differentiate between studies that utilise newly-learned environments and familiar environments in reviewing studies that explore sex effects.

The Current Review

The purpose of the current systematic review was to determine whether environmental configuration, route and landmark memory decline with advancing age and whether these facets of topographical memory differ between males and females. While some reviews have been undertaken that explore age or sex differences in memories of environments (e.g., Moffat, 2009; Coluccia, & Louse, 2004), these have generally been in the form of narrative reviews, have been limited to investigating only spatial aspects of topographical memory or have included studies that did not involve any form of navigation of the target environment (i.e., memory of a 2D map). Moreover, no review has been published that differentiates between newly-learned and familiar environments. Thus, to the best of the author’s knowledge, there have been no systematic reviews investigating the impact of human ageing and sex on the three facets of topographical memory detailed above. Studies that have examined sex differences in topographical memory will be reviewed first, followed by a review of studies that have examined age differences in topographical memory.

Method

Articles that formed the basis of this review were obtained by two separate searches in the PsychINFO database using a single Boolean expression for each search. One search centred on exploring sex differences in topographical memory, the other search explored age differences in topographical memory. The expression in each search included several common synonyms of topographical memory because of the various terms used in the relevant literature (see Figure 1 and 2). The Boolean expression was entered in the ‘Multi-field Search’ search type of PsychINFO. The search was limited to studies that were published in the English language, conducted using human subjects, and were conducted between 1900 and December 2011. Unpublished theses, books and book chapters were not explored in this review.

The primary author followed a three-stage selection strategy for each search. Firstly, the titles and abstracts of all papers that were retrieved from the Boolean Search were screened by the primary author (JC) for their relevance. All articles that explored the issue of topographical memory and human ageing or sex differences were then retrieved from the database. In cases where it was unclear from the abstract whether or not the article was relevant, the article was retrieved for further investigation. Secondly, all retrieved papers were investigated in detail to identify candidate papers based on the inclusion and exclusion criteria (see below). Thirdly, the reference lists of candidate papers were screened for other eligible studies and several authors of candidate papers were contacted for information on any other eligible papers. The reference lists from articles retrieved from stage three were also investigated to identify candidate papers based on the inclusion and exclusion criteria.

Inclusion Criteria

The inclusion criteria were as follows:

1. Studies that involved healthy and independent human adults older than 16 years of age, with no history of psychiatric or neurological disorder.
2. Studies that explored age or sex differences in topographical memory of a real or 3D virtual environment (via single or multiple-learning trials).
3. Studies that employed target environments that were: a) larger than a room; b) no larger than a city region; and c) could not be completely surveyed from a single vantage point.
4. For studies that examined age differences in topographical memory, studies must have specified either a) the age range of the entire sample, or b) the mean or age range of the individual age groups that were compared.

Exclusion Criteria

The exclusion criteria were as follows:

1. Studies that recruited individuals who specialised in geography (e.g., geography students).
2. Studies that involved navigation of environments depicted through video clips or static slides, or involved navigation that was not from a ground-level first-person perspective.

3. Studies that did not specify the level of familiarity participants had with the target environment, or studies that recruited a mixed sample of participants that were unfamiliar and familiar with the environment.
4. Studies that provided the participant with maps or other navigational aids during the recall phase of the study.
5. Studies that involved time-based outcome measures or estimating distances.
6. Single-case studies, opinion papers, traditional narrative reviews, unpublished papers, books, book chapters, and papers without scientific evidence.

While studies that involved learning an environment passively (e.g., via a video clip) were excluded, studies that involved participants being transported along the environment in a wheelchair and permitted participants to survey the environment as they were guided were accepted in the review. Outcomes measures that involved merely stating distances or that were predominantly time-based (e.g., time to reach landmark) were excluded, as these were deemed to not necessarily tap into memory processes. In addition, it was necessary to exclude some studies due to potentially biased or vague instructions or scoring methodology (e.g., participants being asked to recall only landmarks that are of 'particular interest' to them personally). Landmark map localisation tasks could include map-labelling (i.e., pinpointing landmarks on a map) and map-sketching (i.e., drawing a map depicting the environment and landmarks). In the case of the map-sketching, studies were only included if the scoring criteria were provided and based on clear quantitative measures (i.e., centimetres from the landmarks true position). As group differences are required to assess age and sex differences in topographical memory, single-case studies were excluded.

The review aimed to examine memory of personally navigated environments rather than what could be considered ‘geographical’ knowledge, which may have been primarily learned by means other than direct experience (e.g., geography classes or observing a map). Consequently, only studies that investigated memory of environments no larger than the area of a city region were included (e.g., studies that explored environmental knowledge at the level of states and countries were excluded). At the other extreme, while large house and supermarket environments were included in the review, because they afford some degree of navigation to comprehend, studies that employed room-sized environments (i.e., 5 x 5 metres) were excluded, as such small environments could too easily be surveyed from the one vantage point. Finally, studies that utilised open, sparse environments that lacked any form of environmental occlusions (e.g., all parts of the environment could be surveyed from a single 360 degree rotation) were excluded.

In cases where two or more accepted articles contained the same author and it was unclear whether the papers each reflected a different study or were in fact the same study (with the same sample), the authors were contacted for verification. The search yielded 34 studies that examined sex effects and 11 studies that examined age effects in topographical memory (See Figure 1 and 2).

Given the possibility that some non-significant studies may have failed to reach significance due to lack of a sufficient sample size, for each outcome measure the total sample size of each non-significant study was noted and then compared to the study that achieved significance with the lowest total sample size. The following decision rules were then formulated: 1) studies that failed to reach significance with minimum cell sizes (i.e. group sizes) greater than 30 were, for the purpose of the review, deemed non-significant; 2) studies that failed to reach significance with sample sizes less than the study that achieved significance with the smallest sample size (and had cell sizes less than 30) were noted in the review as potentially having insufficient sample sizes to detect significant differences; 3) studies that failed to reach significance with sample sizes less than double but at least equal to that of the study that achieved significance with the smallest sample size and had *p*-values less than .15 (and had cell sizes less than 30) were noted in further detail in the review as potentially lacking sufficient sample sizes to detect significant differences (on the other hand, if such studies had *p*-values greater than .15 they were deemed non-significant); 4) studies that failed to reach significance and had sample sizes of at least double that of the study that achieved significance with the smallest sample size were deemed in the review as non-significant. Though admittedly arbitrary, these decision rules were based on the assumption that cell sizes of 30 (or more than double the sample size of that used in significant studies) should be more than sufficient to detect significant group differences. On the other hand, the decision rules concerning studies with less than double the sample size than that used in significant studies were adopted to draw attention to studies that potentially lacked a sufficient sample size.

The findings of the literature concerning age and sex effects of topographical memory are outlined in separate sections below, subdivided according to each of the three facets of topographical memory. The findings are further subdivided according to specific measures used to assess environmental configuration memory (e.g., heading orientation and landmark map localisation), route memory (e.g., number of incorrect turns and path length) and landmark memory (e.g., landmark free recall and landmark recognition). Studies that utilised environments that were newly-learned by participants and studies that utilised environments that were familiar to participants prior to the study, are also presented separately. In the review, a trend towards a finding for a particular topographical memory measure was defined in instances where the findings of at least two-thirds of the studies (i.e., > 66%) were consistent. Where less than two-thirds of the studies were consistent, or there are fewer than three relevant studies for a particular topographical memory measure, the finding were considered either inconsistent or inconclusive due to an insufficient number of findings, respectively (once any limitations due to sample sizes were taken into account). Unless otherwise specified, 'younger adults' refers to adults between 16 and 45 years of age, while 'older' adults' refers to adults at least 59 years of age (with no upper limit). The age ranges used in 'middle-aged adults' groups varied across studies and will therefore be specified in each instance below. A number of papers were retrieved that conducted multiple studies or experiments (or contained multiple conditions) within a single paper. Multiple experiments within a single paper were included as 'separate studies' provided the studies used different samples or a different methodology. Thus, in some sections of this review, the number of studies and measures is greater than the total number of papers retrieved.

SEARCH TERM (DATABASE: PsychINFO [‘Multi-Field Search’]):

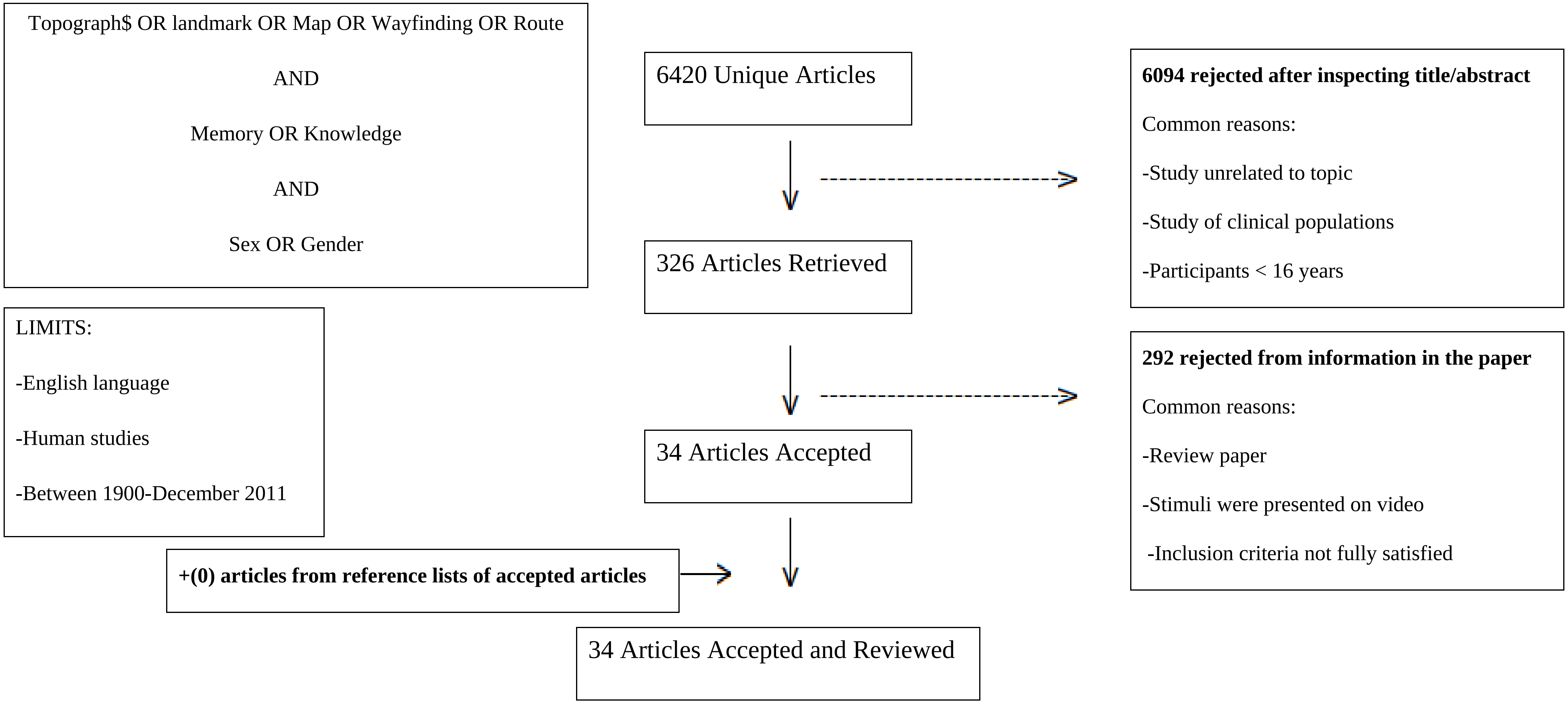

Figure 1

Flowchart Detailing Search Strategy, Stages of Selection and Common Reasons for Article Rejection for Literature Examining Sex Differences in Topographical Memory

SEARCH TERM (DATABASE: PsychINFO [‘Multi-Field Search’]):

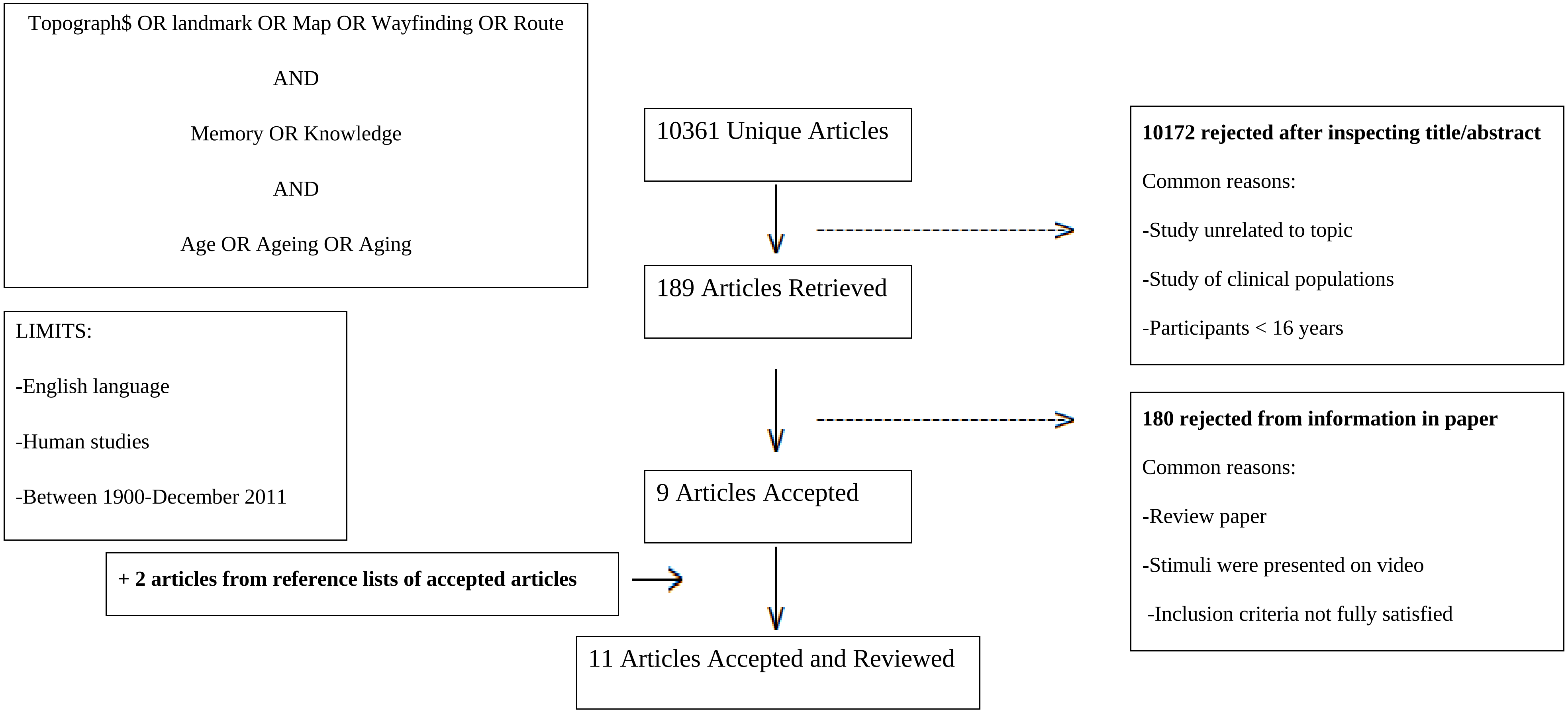

Figure 2

Flowchart Detailing Search Strategy, Stages of Selection and Common Reasons for Article Rejection for Literature Examining Age Differences in Topographical Memory

Results

Sex Differences in Topographical Memory

Sex differences in environmental configuration memory

Twenty-seven papers were found in the search that explored sex differences in environmental configuration memory (see Table 1). Eighteen papers explored this in the context of a newly-learned environment and 10 papers utilised familiar environments.[1]

Newly-learned environments. Of the 29 measures of environmental configuration memory used in the 18 papers that examined memory of newly-learned environments, a male advantage was found on 17 measures (59%). No sex differences were found in the remaining 12 measures of environmental configuration memory (41%). The studies employed a diverse range of environments, from virtual mazes (Castelli et al., 2008), virtual shopping centres (e.g., Tlauka, Brolese, Pomeroy, & Hobbs, 2005) and virtual towns (e.g., Cubukcu & Nasar, 2005), to real-world supermarkets (e.g., Kirasic, 2000), suburbs (e.g., Ishikawa, & Montello, 2006) and a zoo (Munzer, Zimmer, Schwalm, Baus, & Aslan, 2006).

Of the various measures of environmental configuration memory, one of the most common was heading orientation. Males were found to be more accurate than females on tasks of heading orientation in 8 of the 13 studies that investigated this measure in newly-learned environments (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006, two studies; Richardson, Powers, & Bousquet, 2011a – one experiment; Castelli et al., 2008; Lawton, & Morrin, 1999; Lawton, Charleston, & Zieles, 1996; Ishikawa, & Montello, 2006; Silverman et al., 2000). The remaining five studies of heading

[1] Richardson et al. 2011a conducted studies that examined both newly-learned and familiar environments

orientation found no significant sex differences (Richardson et al., 2011a – one experiment; Richardson & Collaer, 2011b; Tlauka et al., 2005; Cubukcu & Nasar, 2005; McNamara, Rump, & Werner, 2003), but two of these may have had insufficient sample sizes (McNamara et al., 2003; Tlauka et al., 2005). Of these two studies, one study approached significance ($0.05 < p < 0.1$, Tlauka et al., 2005) and the *p*-value of another was not reported (McNamara et al., 2003). An even stronger trend for a sex difference in heading orientation became apparent when studies that utilised real-world environments were considered separately from those that used virtual-world environments; four out of five studies using a real world environment found a significant male advantage in heading orientation whereas only four out of eight found a male advantage for virtual world environments. Thus, the presence of sex differences in heading orientation appears to be dependent on the type of environment employed by studies.

The ability to localise landmarks on maps was a second common measure of environmental configuration memory. The literature was found to be inconsistent regarding sex differences in this ability for newly-learned environments. Of the 11 studies examining newly-learned landmark map localisation, 4 found a significant difference in favour of males (Tlauka et al., 2005; Castelli et al., 2008; Lovden et al., 2007, condition one; Ishikawa, & Montello, 2006), while 6 found no sex differences (Head & Isom, 2010, two experiments; Lovden et al., 2007, condition two; Kober & Neuper, 2011; Munzer et al., 2006; Kirasic, 2000). One study from the latter group may have lacked a sufficient sample size and had approached significance ($0.05 < p < 0.1$, Lovden et al., 2007). A further study presented conflicting evidence, finding a significant male advantage on one measure of environmental configuration memory but not on another measure, both measures being based on the same map sketch drawn by participants (Montello, Lovelace, Golledge, & Self, 1999).

Four studies explored sex differences in efficiently navigating directly to a landmark using the shortest path length possible, and these findings were inconsistent. Two studies reported no sex differences on this measure (Head & Isom, 2010; Kober & Neuper, 2011), while two studies found a male advantage (Choi, McKillop, Ward, & L'Hirondelle, 2006; Silverman et al., 2000). One non-significant study (Kober & Neuper, 2011) had a smaller sample size (N = 27) compared to the study that achieved significance using the smallest sample size (Choi et al., 2006, N = 35) raising the possibility that the former study may have lacked sufficient power, though it is notable that the former study showed no evidence of approaching significance (p = 0.4).

Familiar environments. Of the 14 measures of environmental configuration memory used in the 10 papers that examined memory for familiar environments, a male advantage was found in 6 measures (43%) while no sex differences were found in the remaining 8 measures of environmental configuration memory (57%). The majority of the papers that explored sex differences in environmental configuration memory of familiar environments did this in the context of university campuses that participants attended. The other papers utilised participants' hometown (Evans, Brennan, Skorpanich, & Held, 1984) or the wider region around their university campus (Zinser, Palmer, & Miller, 2004, condition two; Richardson et al., 2011a). It is probably important to note that only two of these studies considered whether subject groups differed in level of familiarity/exposure to the target environment, although in both cases males and females were found to be matched on this variable (Zinser et al., 2004;

Holding, 1992). No other study specified whether males and females had similar navigation experience with the target environment.

The findings of the eight studies that examined heading orientation were inconsistent overall. Three studies found a male advantage (Waller, 2000; Bryant, 1982; Prestopnik, & Roskos-Ewoldsen 2000) and five studies found no sex differences (Kozlowski & Bryant, 1977; Richards et al. 2011a; Bell & Saucier, 2004; Kirasic, Allen & Siegel, 1984, experiment one and two). When considering only studies that required participants to make landmark direction judgements in vivo (e.g., from the actual vantage point; Waller, 2000; Bell & Saucier, 2004; Kirasic et al., 1984, experiment one; Richardson et al., 2011a), and not from an imagined position in the environment, there is a tendency for such studies to find no sex differences (three of the four studies found no sex differences). However, the sample sizes in all five non-significant studies were relatively small (samples ranged from 40-48) compared to those used in the significant studies (samples ranged from 85-151), raising the possibility that the former studies may have lacked sufficient power to detect sex differences. *P*-values were not available in three of the four non-significant studies. The fourth non-significant study showed no evidence of a trend towards significance ($p > 0.8$; Richardson et al., 2011a).

The findings of the six studies that explored sex differences in the ability to localise landmarks on a map of a familiar environment were also inconsistent. Three studies found that males were better at this task compared to females (Holding, 1992, condition one and two; Zinser et al., 2004, condition one) while three studies found no sex differences (Waller, 2000; Evans et al., 1984; Zinser et al., 2004, condition two).

There were no studies of familiar environments that investigated the participants' ability to recall the shortest route to a landmark.

Summary of the environmental configuration memory literature with regard to sex effects

The presence of a sex effect appears dependent on whether the learnt environment is real or virtual, the type of task used to assess environmental configuration memory, and whether the environment is new or familiar. The only measure of environmental configuration memory to show a consistent male advantage was heading orientation in newly-learned, real-world environments. A different pattern seems to emerge when heading orientation is studied for familiar environments. Under these circumstances, males are more likely to perform similarly to females, though this again may be task dependent, and is most apparent in in-vivo studies with relatively small sample sizes. All other findings relating to sex differences in environmental configuration memory in new and familiar environments were inconsistent.

Sex differences in route memory

Ten papers were retrieved that explored sex differences in route memory (see Table 2), all utilising newly-learned environments. No paper was found that utilised familiar environments.

Newly-learned environments. Of the 12 measures of route memory used in the 10 papers that utilised newly-learned environments, a male advantage was found on 3 measures (25%), while no sex differences were found on the remaining 9 measures (75%). The target environments utilised in the studies included virtual mazes (e.g., Lovden et al., 2007; Castelli et al., 2008), a real-world zoo (Munzer et al., 2006) and a botanical garden (Nori, Grandicelli &, Giusberti, 2009). Each study examined the ability to retrace a previously-learned linear route, either in the learned arrangement (i.e., from the starting position to the endpoint) or in the reverse direction (i.e., from the endpoint to the starting location). Importantly, any observed sex differences in measures of route memory could not be explained by differences between men and women in computer or videogame experience in any of the virtual-world studies that examined this potential confound.

Of the eight studies that examined the number of incorrect turns made when attempting to retrace a newly-learned route, only two studies found that males made significantly fewer incorrect turns than females (Moffat, Hampson, & Hatzipantelis, 1998; Moffat, Zonderman, & Resnick, 2001), while six studies found no sex differences (Castelli et al., 2008; Montello et al., 1999; Nori et al., 2009; Barrash, 1994; Munzer et al., 2006; Choi et al., 2006). Three of the six non-significant studies had relatively small sample sizes (samples ranged from 35 and 40 participants across the three studies) and thus may have lacked sufficient statistical power, though it is important to add that only one of the three studies showed any evidence of a trend towards significance ($p < 0.15$; Choi et al., 2006).

Three of four studies found no differences between males and females in their average path length when attempting to retrace a newly-learned route (Moffat et al., 2001; Head & Isom, 2010; Lovden et al., 2007, condition one). These non-significant studies utilised environments that were composed of straight corridors and 90 degree turns at decision points. The remaining study found a sex difference in average path length (in favour of males) in an environment that was composed of bendy corridors and turning points of irregular angles (Lovden et al., 2007, condition two).

Summary of the route memory literature with regard to sex effects

The literature reveals that males and females do not differ in terms of their ability to remember a newly learned route, irrespective of methodology. No studies were found that explored sex differences in route memory using familiar environments.

Sex differences in landmark memory

Six papers were retrieved that explored sex differences in landmark memory (see Table 3). Three papers utilised newly-learned environments and three papers utilised environments that were familiar to participants.

Newly-learned environments. Of the five measures of landmark memory used in the three papers that utilised newly-learned environments, a female advantage was found on three measures (60%), while no sex differences were found on the remaining two measures (40%). Environments examined in these studies included virtual maze-like environments (Jansen-Osman & Wiedenbauer, 2004; Head & Isom, 2010) and a real-world supermarket (Kirasic, 2000). Only one study (Kirasic, 2000) explicitly warned participants that they would be tested on their memory of landmarks prior to learning the environment.

Only two papers examined sex differences in the ability to recall the names of landmarks that had been seen in a newly-learned environment. One paper found that females performed better at the task than males (Jansen-Osman & Wiedenbauer, 2004). The second paper had mixed findings. When participants learned the environment by being provided with a guided tour, females freely recalled more landmarks than males (Head & Isom, 2010). However, no sex differences were found in this outcome measure when participants learned the environment through free exploration (Head & Isom, 2010).

Studies examining sex differences in recognising photographs of landmarks and scenes from a newly-learned environment were also insufficient in number, with only two studies being found. Females outperformed males on this measure in one study (Head & Isom, 2010), while another study found no differences between males and females (Kirasic, 2000).

Familiar environments. Of the four measures of landmark memory used in the three papers that utilised familiar environments, a male advantage was found on three measures (75%) while no sex differences were found on the remaining measure (25%). The majority of papers that explored landmark memory of a familiar environment utilised participants' campuses (Herman, Kail, & Siegel, 1979; Saucier et al., 2002), while one study utilised participants' hometown (Evans et al., 1984). Only one study (Saucier et al., 2002) provided participants with a tour of the familiar environment before testing landmark memory. The other two studies did not involve a tour or any other opportunity for participants to explore the familiar environment during the study and instead examined participants' pre-existing memory of the target environments. None of the studies specified whether males and females were similar in navigation experience with the target environment.

Two studies examined sex differences in landmark free recall. One found that males were able to freely recall the names of more landmarks on their campus than females (Herman et al, 1979), while one study found no significant sex difference in the ability to freely recall landmarks within their hometown (Evans et al., 1984).

Of the two studies that examined the ability to recognise photographs of scenes from a familiar environment both found a male advantage (Saucier et al., 2002; Herman et al., 1979).

Summary of the landmark memory literature with regard to sex effects

There are currently an insufficient number of studies that have examined sex differences in landmark memory for it to be possible to draw firm conclusions. It is, however, interesting to note that when significant differences in landmark memory are found, these are in favour of females when newly-learned environments are utilised, and in favour of males when familiar environments are utilised. Ultimately, this is based on a handful of studies and further research is warranted.

Table 1

Sex Effects of Environmental Configuration Memory: Summary of Study Measures and Findings

First Author	Sample Type	Sample Size: N (M/F)	Learning Type/Study Description	Main Measures	Performance
Castelli (2008)	University students	40 (20/20)	Virtual: route learning in a large maze	landmark direction	M > F
				Landmark map localisation	M > F
Cubuku (2005)	University students and staff	160 (95/65)	Virtual: free navigation of open environment	Landmark direction	M = F
Head (2010)	Adults	47 (20/27)	Virtual: free navigation of corridor environment	Landmark map localisation	M = F
				Distance travelled to landmark	M = F
		45 (17/28)	Virtual: tour of corridor environment	Landmark map localisation	M = F
Hegarty (2006)	Undergraduates	221 (83/135)[1]	Virtual or real-world tour of unfamiliar campus	Landmark direction (virtual)	M > F
				Landmark direction (real-world)	M > F
Kober (2011)	Young adults	27 (13/14)	Virtual: navigation of a large maze to landmark using shortest route	Distance travelled to landmark	M = F
				Landmark map labelling (recognition)	M = F
Lawton (1999)	Undergraduates	219 (96/123)	Virtual: route navigation of corridor environment	Direction of starting point	M > F
Lovden (2007)	Undergraduates	32 (16/16)	Virtual: route learning in corridor environment (movement coupled with treadmill)	Landmark map localisation (city layout)	M > F
				Landmark map localisation (variable layout)	M = F
Richardson (2011a)	University students and staff	32 (15/17)	Virtual: navigation of linear corridor environment	Direction of starting point	M > F
		40 (20/20)	Virtual/HMD: route navigation of open environment	Direction of landmark	M = F
			Virtual/HMD: photo realistic panoramic view of local city campus	Direction of landmark	M = F
Richardson (2011b)	Undergraduates	60 (30/30)	Virtual: navigation of large environment	Direction of landmark	M = F
Tlauka (2005)	Undergraduates	32 (16/16)	Virtual: tour of shopping centre	Landmark direction	M = F
				Landmark map labelling	M > F
Choi (2006)	Undergraduates	35 (15/20)	Locomotion: tour of large unfamiliar building	Path length to landmark	M > F
Ishikawa (2006)	Undergraduates	24 (11/13)	Locomotion: tour of unfamiliar region as car passenger	Landmark direction	M > F
				Sketch map	M > F
Kirasic (2000)	Undergraduates and elderly adults	240 (120/120)	Locomotion: tour of unfamiliar supermarket	Location labelling on a map	M = F

Table 1 (continued)

First Author	Sample Type	Sample Size: N (M/F)	Learning Type/Study Description	Main Measures	Performance
Lawton (1996)	Undergraduates	75 (20/55)	Locomotion: tour of unfamiliar building basement	Direction of starting point	M > F
McNamara (2003)	Undergraduates	24 (11/13)	Locomotion: tour of large unfamiliar park	Landmark direction	M = F
Montello (1999)	Adults (19-76 years old)	79 (36/43)	Locomotion: tour of unfamiliar campus	Map sketch (direction accuracy)	M > F
				Map sketch (distance accuracy)	M = F
Munzer (2006)	Young and middle-aged adults	64 (31/33)	Locomotion: tour of unfamiliar zoo	Scene map labelling	M = F
Silverman (2000)	Undergraduates	111(46/65)	Locomotion: tour of large unfamiliar wooded area	Direction of starting point	M > F
				Most direct route to starting point	M > F
Bell (2004)	Undergraduates	40 (20/20)	Locomotion: tour of familiar campus	Direction of landmark	M = F
Waller (2000)	University students and staff	151 (72/79)[2]	Locomotion: tour of familiar campus	Direction of landmark	M > F
				Map reconstruction	M = F
Bryant (1982)	Undergraduates	85 (40/45)	Mentally imagine standing in familiar location (campus)	Landmark direction	M > F
Evans (1984)	Young and elderly adults	119 (36/83)	Pre-existing memories of hometown	Landmark map localisation	M = F
Holding (1992)	Undergraduates	22 (11/11)	Pre-existing memories of familiar campus	Landmark map labelling	M > F
				Landmark map labelling	M > F
Kirasic (1984)	Undergraduates	48 (24/24)	Pre-existing memories of familiar campus	Direction of landmark (in-vivo vantage point)	M = F
				Direction of landmark (imagined vantage point)	M = F
Kozlowski (1977)	Undergraduates	45 (28/17)	Mentally standing in familiar location (campus)	Landmark direction	M = F
Prestopnik (2000)	Undergraduates	94 (38/56)	Mentally navigate a route through familiar campus	Direction of starting point	M > F
Zinser (2004)	Undergraduates	109 (35/74)	Pre-existing memories of familiar campus and surrounding region	Location map labelling (campus)	M = F
				Location map labelling (region)	M > F

N = total sample size; M = male; F = female; HMD = head-mounted display; **=** = no significant differences on task than; **>** = *better performance* on task than; **<** = *poorer performance* on task than; [1] The sex of three participants was not recorded; [2] Final N = 150 – it was unclear from article whether the dropped participant was male or female.

NOTE: **>** and **<** signs indicate better/poorer *performance* on the task (e.g., M >F for 'path length to target' means that males had *smaller* path lengths than females). The arrows do not necessarily relate to the direction of the measure.

Table 2

Sex Effects of Route Memory: Summary of Study Measures and Findings

First Author	Sample Type	Sample Size: N (M/F)	Learning Type/Study Description	Main Measures	Performance
Castelli (2008)	University students	40 (20/20)	Virtual: route learning in a large maze	Wrong turns	M = F
Head (2010)	Adults	45 (17/28)	Virtual: route recall of corridor environment	Distance travelled to endpoint	M = F
Lovden (2007)	Undergraduates	32 (16/16)	Virtual: learning route in corridor environment (movement coupled	Distance travelled to target (city layout)	M > F
			with treadmill)	Distance travelled to target (variable layout)	M = F
Moffat (1998)	Undergraduates	74 (40/34)	Virtual: learning to solve a linear maze	Mean number of spatial errors	M > F
Moffat (2001)	Members of public	117 (68/49)	Virtual: learning to solve a linear maze	Distance travelled to reach goal	M = F
				Incorrect turns	M > F
Barrash (1994)	Adults (18-78 years)	80 (40/40)	Locomotion: tour of unfamiliar complex hospital	Incorrect turns	M = F
Choi (2006)	Undergraduates	35(15/20)	Locomotion: tour through unfamiliar building	% original route retraced	M = F
Montello (1999)	Adults (19-76 years old)	79 (36/43)	Locomotion: tour of unfamiliar campus	Turn errors (Map sketch)	M = F
Munzer (2006)	Young and middle aged individuals	64 (31/33)	Locomotion: tour of large unfamiliar environment (zoo)	Route recognition test	M = F
Nori (2009)	Undergraduates	40 (20/20)	Locomotion: tour of large unfamiliar environment	Directional errors	M = F

N = total sample size; M = male; F = female; **=** = no significant differences on task than; **>** = *better performance* on task than; **<** = *poorer performance* on task than;

NOTE: **>** and **<** signs indicate better/poorer *performance* on the task (e.g., M >F for 'path length to target' means that males had *smaller* path lengths than females). The arrows do not necessarily relate to the direction of the measure;

Table 3

Sex Effects of Landmark Memory: Summary of Study Measures and Findings

First Author	Sample Type	Sample Size: N (M/F)	Learning Type/Study Description	Main Measures	Performance
Head (2010)	Adults	47 (20/27)	Virtual: free navigation of corridor environment	Landmark free recall	M = F
				Environmental Scene recognition	M < F
		45 (17/28)	Virtual: following route in corridor environment	Landmark free recall	M < F
Jansen-Osmann (2004)	Young adults	20 (10/10)	Virtual: memory of a maze	Landmark recall	M < F
Kirasic (2000)	Undergraduates and elderly adults	240 (120/120)	Locomotion: memory of an unfamiliar supermarket	Scene recognition	M = F
Saucier (2002)	Undergraduates	42 (20/22)	Locomotion: navigating familiar university campus	Landmark name recognition	M > F
Evans (1984)	Young and elderly adults	119 (36/83)	Pre-existing memories of hometown	Landmark free recall	M = F
Herman (1979)	Undergraduates	66 (33/33)	Pre-existing memories of familiar campus	Landmark free recall	M > F
				Landmark name recognition	M > F

N = total sample size; M = male; F = female; **=** = no significant differences on task than; **>** = *better performance* on task than; **<** = *poorer performance* on task than;

NOTE: **>** and **<** signs indicate better/poorer *performance* on the task (e.g., M >F for 'path length to target' means that males had *smaller* path lengths than females). The arrows do not necessarily relate to the direction of the measure.

Age Differences in Topographical Memory

Age differences in environmental configuration memory

Seven papers were found that explored age differences in environmental configuration memory (see Table 4). Five papers used newly-learned environments while two papers used familiar environments.

Newly-learned environments. Of the seven measures of environmental configuration memory used in the five papers that utilised newly-learned environments, younger adults outperformed older adults on five of the measures (71%), while no age differences were found on the remaining two measures (29%). Environments examined included virtual corridor-like environments (e.g., Lovden, Schellenbach, Grossman-Hutter, Kruger, & Lindenberger, 2005), virtual small towns (Iaria, Palermo, Committeri, & Barton, 2009; Cubuku & Nasar, 2005), and a real-world supermarket (Kirasic, 2000). Virtual-world studies outnumbered real-world studies, but observed age differences could not be explained by differences in computer or videogame experience in any of the studies that examined this potential confound. Four of the newly-learned environment studies compared an older adult group with a young adult group. The remaining study (Cubucku & Nasar, 2005) recruited adults between 18 and 48 years of age and treated age as a continuous variable.

In the only study that explored age differences in heading orientation in a newly-learned environment (Cubuku & Nasar, 2005), no relationship was found between the variables (the study treated age as a continuous variable).

The landmark map localisation studies yielded consistent results; three out of the four studies that explored differences between young and older adults on this measure found that younger adults performed better than older adults (Head & Isom, 2010, condition one; Lovden et al., 2005; Kirasic, 2000). The remaining study found no age group differences (Head & Isom, 2010, condition two).

Younger adults also performed significantly better than older adults in both studies that examined efficiency in navigating directly from one landmark to another using the shortest possible route. One study examined path length (Head & Isom, 2010), while the other study explored the number of trials in which participants deviated from the shortest route (Iaria et al., 2009; older adult age range: 50-69 years).

Familiar environments. Of the two measures of environmental configuration memory used in the two papers that utilised familiar environments, younger adults outperformed older adults on one measure (50%), while no age differences were found on the remaining measure (50%). Both studies utilised the subjects' hometown.

One study found no differences between young, middle-aged or older adults in heading orientation (middle-aged group age range = 45-49 years; Kirasic, 1989). Though the age group sizes of the study were relatively small (group sizes = 16), the non-significant finding is unlikely due to an insufficient sample size (study *F*-value < 1.2). The other study found that younger adults were more accurate than older adults at localising landmarks on a map (Evans et al., 1984).

Summary of the environmental configuration memory literature with regard to age effects

The majority of studies indicated that younger adults performed better than older adults on tasks of environmental configuration memory that involve localising landmarks on a map of a newly-learned environment. Studies using other measures of environmental configuration memory of newly-learned environments are currently too few in number to permit any firm conclusions to be drawn, but two out of two found younger subjects better than older subjects. To date, there are also too few studies that have explored age differences in environmental configuration memory of a familiar environment for any conclusions to be drawn.

Age differences in route memory

Five papers were found that examined differences between young and older adults in their memory of a route (see Table 5), all used newly-learned environments. No papers were found that utilised familiar environments.

Newly-learned environments. Of the six measures of route memory examined in the five papers, younger adults outperformed older adults in all instances (100%). All studies that explored age differences in route memory of newly-learned environments utilised corridor-style environments, such as virtual mazes (Lovden et al., 2005) and real-world hospitals (Barrash, 2001; Wilkniss et al., 1997).

Three out of three studies found that younger adults made fewer incorrect turns when attempting to retrace a newly-learned route compared to older adults (Moffat et al., 2001; Barrash, 1994; Wilkniss et al., 1997). Two of these studies also explored middle-aged individuals in their analyses. One study found a step-wise pattern following a single route-learning trial, where young adults (range: 18-39) made less incorrect turns than 40-49 year old adults, who in turn made less errors than both 50-59 and 60-69 year old adults, who in turn made less errors than the study's oldest adult group (age range: 70-79) (Barrash, 1994). The other study found that young adults made less incorrect turns than both middle-aged and older adults, though no significant difference was found between the latter two groups (Moffat et al., 2001).

All three studies that examined path length found that younger adults walked shorter path lengths when attempting to retrace a newly-learned route compared to older adults (Moffat et al., 2001; Lovden et al., 2005; Head & Isom, 2010). One of these studies also found that younger adults walked shorter paths than middle-aged adults (middle-aged adult group age range: 45-60 years, Moffat et al., 2001). The study also found a non-significant trend for middle-aged adults to outperform older adults on this outcome measure (Moffat et al., 2001).

Summary of the route memory literature with regard to age effects

There is reliable evidence demonstrating that younger adults make fewer spatial errors than older adults when attempting to re-walk a newly-learned route. Studies also consistently find that younger adults walk shorter path lengths than older adults when attempting to remember the newly-learned route. Currently, there are an insufficient number of studies that have included middle-aged adults for conclusions to be drawn regarding this age group. Though sparse in number, all found that younger adults perform better than middle-aged adults on measures of route memory. The studies were, however, inconsistent (in addition to being insufficient in number) regarding whether middle-aged adults differ in their route memory relative to older adults. The review did not find any study that examined age differences in route memory in the context of a familiar environment.

Age differences in landmark memory

Five papers were found that examined age differences in landmark memory of an environment (see Table 6). Four papers utilised newly-learned environments and one paper utilised familiar environments.

Newly-learned environments. Of the seven measures of landmark memory used in the four papers that utilised newly-learned environments, younger adults outperformed older adults on four of the measures (57%), while no age differences were found in the remaining three measures (43%). The studies used a variety of environments including virtual corridor-like environments (Head & Isom, 2010), a virtual town (Zakzanis, Quintin, Graham, & Mraz, 2009), a real world supermarket (Kirasic, 2000) and a real world hospital (Wilkniss et al., 1997).

Only one paper examined age differences in the ability to freely recall landmarks in a newly-learned environment. Compared to older adults, younger adults freely recalled more landmarks that had previously been seen while freely navigating a corridor-like environment (Head & Isom, 2010). On the other hand, the same study found no age differences in landmark free recall when, instead of free exploration, participants had learned the environment by following arrows along a prescribed route.

The four studies that examined age differences in the ability to recognise photographs of scenes and landmarks from a newly-learned environment were inconsistent. Two studies found that younger adults performed better than older adults (Kirasic, 2000; Head & Isom, 2010), while two studies found no age differences on this measure (Zakzanis et al., 2009 – older adult age range: 52-83 years; Wilkniss et al, 1997). However, one of the non-significant studies had a very small sample size (N = 15) and thus may have lacked sufficient sample size to detect age differences (Zakzanis et al., 2009). Moreover, the other non-significant study approached significance (P = 0.09, Wilkniss et al., 1997).

Familiar environments. In the only study to examine age differences in landmark memory of a familiar environment, younger adults were found to be able to freely recall more buildings within a specified region in their hometown compared to older adults (Evans et al., 1984).

Summary of the landmark memory literature with regard to age effects

To date, there are generally an insufficient number of studies that have examined age differences in landmark memory of newly-learned or familiar environments to warrant any conclusions being drawn. Only in the case of studies that examined age differences in landmark recognition of newly-learned environments were an adequate number of studies found. However, these studies showed inconsistent findings overall.

Table 4

Age Effects of Environmental Configuration Memory: Summary of Study Measures and Findings

First Author (Year)	Age Group = Sample Size (Range or Mean [sd])	Learning Type/Study Description	Main Measures	Performance
Cubuku (2005)	N = 160(18-48)	Virtual: free navigation of open environment	Landmark direction	Y = O
Head (2010)	Y = 16(20[1]); O = 31(71[8])	Virtual: free navigation of corridor environment	Distance to reach landmarks	Y > O
			Landmark map localisation	Y > O
	Y = 13(20[1]); O = 32(70[9])	Virtual: tour of corridor environment	Landmark map localisation	Y = O
Iaria (2009)	Y = 30(19-30); O = 25(50-69)	Virtual: free navigation of town	Deviations from shortest route	Y > O
Lovden (2005)	Y = 16(20-30); O = 16(60-69)	Virtual: route learning of indoor area (movement coupled with treadmill)	landmark map labelling	Y > O
Kirasic (2000)	Y = 120(18.2-28.5); O = 120(60.2-84.9)	Locomotion: tour of an unfamiliar supermarket	Location labelling on a map	Y > O
Evans (1984)	Y = 72(26-45); O = 47(60-80)	Pre-existing memories of hometown	Landmark map localisation	Y > O
Kirasic (1989)	Y = 16(22-27); M = 16(45-59); O = 16(65-74)	Pre-existing memories of hometown	Direction of landmark	Y =M = O

Y = Young adults group; **M** = Middle-aged adults group; **O** = Older adults group; **N** = Total sample size; **sd** = Standard deviation; **=** = no significant differences between the groups; **>** = *better performance* on task than; **<** = *poorer performance* on task than;. **NOTE**: **>** and **<** indicate better/poorer *performance* on the task (e.g., Y > O for 'path length to target' means that younger adults had *smaller* path lengths than older adult). It does not necessarily relate to the direction of the measure.

Table 5

Age Effects of Route Memory: Summary of Study Measures and Findings

First Author	Age Group = Sample Size (Range or Mean [sd])	Learning Type/Study Description	Main Measures	Performance
Head (2010)	Y = 13(20[1]); O = 32(70[9])	Virtual: tour of corridor environment	Distance travelled to endpoint	Y > O
Lovden (2005)	Y = 16(20-30); O = 16(60-69)	Virtual: route learning of indoor area (movement coupled with treadmill)	Distance to target	Y > O
Moffat (2001)	Y = 28(18-45); M = 43(45-65); O = 46(65-NA)	Virtual: learning to solve a linear maze	Distance travelled to reach goal	Y > M;Y > O; M = O
			Wrong turns	Y > (M = O);
Barrash (1994)	N = 80(18-78)	Locomotion: route recall in an unfamiliar complex hospital	Incorrect turns (1st trial)	Y >M> (M2=M3)> O
Wilkniss (1997)	Y = 25(18-21); O = 25(59-81)	Locomotion: tour of a linear route in an unfamiliar hospital	Wrong turns	Y > O

Y = Young adults group; **M** = Middle-aged adults group; ; **M2, M3** etc = Middle-aged adults group (second group, third group etc); **O** = Older adults group; **NA** = information not available; **Sd** = Standard deviation; **=** = no significant differences between the groups on task performance; **>** = *better performance* on task than; **<** = *poorer performance* on task than; **NOTE**: **>** and **<** signs indicate better/poorer *performance* on the task (e.g., Y > O for 'path length to target' means that younger adults had *smaller* path lengths than older adult). It does not necessarily relate to the direction of the measure.

Table 6

Age Effects of Landmark Memory: Summary of Study Measures and Findings

First Author	Age Group = Sample Size (Range or Mean [Sd])	Learning Type/Study Description	Main Measures	Performance
Head (2010)	Y = 16(20[1]); O = 31(71[8])	Virtual reality: free navigation of corridor environment	Landmark free recall	Y > O
			Scene recognition	Y > O
	Y = 13(20[1]); O = 32(70[9])	Virtual reality: tour of corridor environment	Landmark free recall	Y = O
Zakzanis (2009)	Y=8(20-30); O =7(52-83)	Virtual reality: tour of a virtual city	Recognition of landmarks	Y = O
Kirasic (2000)	Y = 120(18.2-28.5); O = 120(60.2-84.9)	Locomotion: tour of an unfamiliar supermarket	Scene recognition	Y > O
Wilkniss (1997)	Y = 25(18-21); O = 25(59-81)	Locomotion: tour of a linear route in an unfamiliar hospital	Landmark recognition	Y = O
Evans (1984)	Y = 72(26-45); O = 47(60-80)	Pre-existing memories of hometown	Landmark free recall	Y > O

Y = Young adults group; **M** = Middle-aged adults group; **O** = Older adults group; **N**=total sample size; **Sd** = Standard deviation; **=** = no significant differences between the groups on task performance; **>** = *better performance* on task than; **<** = *poorer performance* on task than; **NOTE**: **>** and **<** signs indicate better/poorer *performance* on the task (e.g., Y>O for 'path length to target' means that younger adults had *smaller* path lengths than older adult). It does not necessarily relate to the direction of the measure.

Discussion

The only consistent evidence in the topographical memory literature of a sex effect was a male advantage for heading orientation within newly-learned real-world environments. Though there is consistent evidence that males and females perform equally on tasks of heading orientation in familiar environments when required to perform the task in-vivo, this finding is largely reliant on studies with relatively small sample sizes and thus should be considered tentative. Studies examining sex differences using other measures of environmental configuration memory of either newly-learned or familiar environments were inconsistent. In the context of studies that examined sex differences in route memory of newly-learned environments, the literature is consistent in showing no differences between males and females in all measures of this facet of topographical memory. Currently, there are too few studies that have looked for sex differences in landmark memory of a newly-learned environment and, more broadly, there are too few studies that have examined sex differences in route and landmark memory using familiar environments, for it to be possible to draw conclusions at this time.

In the case of newly-learned environments, the literature suggests that some facets of topographical memory are age sensitive. This was apparent in all measures of route memory examined in the review, and on one measure of environmental configuration memory (i.e., landmark map localisation), where younger adults outperformed older adults. Studies that investigated age differences on other measures of environmental configuration memory of newly-learned environments are currently insufficient in number. Studies that examined age differences in landmark memory of newly-learned environments are inconsistent or currently too few in number, and too few studies have examined age differences in any of the three facets of topographical memory utilising familiar environments for it to be possible to draw conclusions.

The finding of a sex difference in favour of males for heading orientation in newly-learned real-world environments suggests that, compared to females, males may have superior memory of spatial configurations of large environments. This is in line with fMRI evidence, which shows greater recruitment of structures critical for spatial memory (i.e., the hippocampus) in males, relative to females, when solving a virtual maze task (Gron et al., 2000). On the other hand, the review found inconsistent evidence of a sex difference on another measure of environmental configuration memory of newly-learned environments, namely landmark map localisation. It is possible that heading orientation tasks are of greater difficultly than landmark map localisation tasks, and therefore only the former may be sensitive enough to consistently detect sex differences. Given the task demands for heading orientation (i.e., orienting and pointing to a landmark), it is possible that such tasks more directly tap into an individual's memory of the spatial relations of landmarks within an environment compared to the more 2D pictorial format of landmark map localisation tasks. It is notable that the consistent male advantage in heading orientation does not extend to virtual-world studies. That a consistent sex difference in heading orientation is observed in studies that utilised newly-learned real-world environments, but not in those that utilised newly-learned virtual environments, may be the result of important differences between the two methodologies. Given that self-motion and proprioception are important components that can assist with the acquisition of spatial representations (Lovden et al., 2005; Waller, Loomis, & Haun, 2004), the lack of such cues in virtual studies could potentially have diminished any male advantage in heading orientation. As the use of virtual environments may not adequately tap into the processes involved in determining heading orientation in real-world navigation, the use of real-world environments may therefore be a more ecologically valid approach for future research in this area.

The lack of sex differences on all measures of route memory that were examined in the review indicates that males and females perform similarly in some areas of topographical memory. This is consistent with the notion that the ability to represent the spatial relations of object relative to the self (i.e., egocentric ability), may be less reliant on structures that differ between the sexes, such the hippocampus, and, instead, may have an important parietal involvement (Aguirre & D'Esposito, 1999).

The tendency for studies to demonstrate age-related decline in some measures of environmental configuration memory and, more consistently, across all measures of route memory, in the context of newly-learned environments, is in line with the behavioural findings from animal studies (Begega et al., 2001; Winocur & Moscovitch, 1990). Age-related deterioration in hippocampal functioning likely accounts for this decline in environmental configuration memory of newly-learned environments across the adult lifespan (Moffat et al., 2006). On the other hand, the age decline in route memory of newly-learned environments may be better explained by age-related decline in extra-hippocampal structures, possibly adjacent areas of the temporal lobe or parietal regions (Xu et al., 2000). While the review supports the notion of age-related decline in both environmental configuration and route memory of newly-learned environments, due to the general paucity of studies that utilised middle-aged adults a detailed understanding of the precise nature of the trajectory of this decline is currently unavailable. It is, for example, unclear whether environmental configuration memory and route memory declines linearly across the adult lifespan. It is conceivable that topographical memory of highly familiar environments may follow a curvilinear trajectory across the adult lifespan, similar to other domains of cognition that involve the slow accumulation of knowledge over time, at least until the 60s (i.e., vocabulary knowledge, Salthouse, 2010; 2009). On the other hand, the ability to remember newly-learned environments may decline in a linear fashion across the adult lifespan, as is seen in the case of memory for recently-learned visual and verbal information (Salthouse, 2010; 2009). Additional research examining age differences in facets of topographical memory that utilise the entire adult age range is therefore needed to clarify the gap in current knowledge.

A number of basic cognitive abilities that decline with age and differ between males and females may also account for the age and sex differences consistently seen in some measures of topographical memory of newly-learned environments. For example, mental rotation, which tends to be stronger in males (Galea & Kimura, 1993), may underlie the male advantage in heading orientation. Similarly, age-related deterioration in route memory and some aspects of configuration knowledge (i.e. landmark map localisation), may be due to age-related decline in information processing speed, mental rotation and spatial memory (Salthouse, 1994; Herman & Coyne, 1980). The deterioration of these cognitive processes across the age span may be attributed to age-related atrophy in extra-hippocampal regions, such as the frontal lobes (Xu et al., 2000).

It is commonly viewed that tasks of configuration memory are solved using allocentric, 'map-like,' representations of an environment, whereas tasks of route recall are solved using linear and sequential, egocentric, memories pertaining to the specific route (e.g., O'Keefe & Nadel, 1978; Begega et al., 2001). While the current review adopts this approach to some degree by distinguishing between measures of configuration and route memory, it is important to note that such a view does not account for findings of individual differences in the use of egocentric and allocentric spatial strategies when learning to navigate an environment (Bohbot, Iaria, & Petrides, 2004). The view is further complicated by developmental accounts of topographical memory, which propose that environments may initially be represented as a collection of specific routes, however with increased familiarity knowledge of specific routes become integrated into a coherent and organised allocentric representation (Siegel & White, 1975). Thus, while newly-learned routes may reliably be solved using egocentric spatial strategies, it is conceivable that highly familiar routes may be solved using allocentric spatial strategies, or via a combination of egocentric and allocentric spatial strategies.

As the present review limited itself to published papers, the possibility of a publication bias cannot be excluded. Studies that find significant age or sex differences may be more likely to be published and therefore be more represented in the current review than studies that fail to find significant differences

This review highlights three important limitations of the current research that examines sex and age differences in topographical memory that need to be addressed in future research. Firstly, and as previously noted, most studies compare only young and older adult groups. There is little literature pertaining to middle-aged adults' topographical memory ability relative to young and older adults, and therefore a more fine-grained understanding of the nature of the trajectory of topographical memory across the adult lifespan, is currently unavailable. A second limitation of the current research concerns the paucity of studies that examine sex and age differences in landmark memory. Furthermore, all studies that examined landmark memory of newly-learned environments in the review tested participants' memory of scenes and environmental stimuli that had been seen while navigating the environment, with no study specifically examining memory of salient landmarks of high way-finding value.

This is a potential gap in the literature given that memory of navigationally-important landmarks and memory of incidental environmental stimuli may be mediated by different cognitive processes. It is notable that, while insufficient in number, when sex differences were found in the few studies that examined landmark memory of newly-learned environments, these tended to be in favour of females. This is consistent with evidence that females have superior visual memory of objects and arrays relative to males (Eals & Silverman, 1994). Given there are currently few studies, more research into this potential female advantage in landmark memory is required. A third limitation of the topographical memory literature is that too few studies that explore sex and age differences in topographical memory have utilised environments that are familiar to participants, and those that explore this tend to do so in the context of campus-style environments using university students who have had only a few years of experience with the environment. Moreover, few studies examine the possibility that age or sex differences observed in highly familiar environments might be accounted by differences in navigation experience of the target environment between males and females or between young and older adults. Ultimately, given the paucity of such studies, it is currently not possible to determine whether the level of familiarity with an environment mediates any observed sex or age differences in topographical memory. Further research that utilises environments that have been known by participants for many years therefore is required.

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Age and Sex Effects on Facets of Topographical Memory: A Study Utilising a Highly Familiar Environment

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Abstract

Topographical memory (memory for environments, including landmarks and routes) is a multifaceted construct that has been researched less frequently than other domains of memory. Evidence from the literature indicates that memory for newly-learned and familiar environments may be mediated by separable neural substrates. Factors such as age and sex have also been shown to influence some aspects of topographical memory. However, the majority of existing studies have investigated age and sex effects for newly-learned environments only, and, as such, it is currently unclear as to whether age and sex are important mediators of topographical memory for familiar environments. The current study set out to address this gap in the literature. Sixty-three healthy adult participants familiar to the Sydney region, ranging between 20 and 79 years of age, completed the Sydney City Test of Topographical Memory (SCTTM; Hepner, 2006). The relationships between performance on the SCTTM and specific spatial and verbal cognitive skills were also explored. The study found no significant age or sex effects on the ability to name well-known Sydney landmarks from photographs, localise well-known landmarks on a map of Sydney, or describe how to get from one Sydney landmark to another. A curvilinear relationship was found for males on tasks of heading orientation (determining cardinal directions and directions of landmarks not visible from a vantage point), with highest performance at middle-age. In contrast, for female subjects, a linear decline was found between age and performance on one task of heading direction (determining directions of landmarks), while no relationship was found between age and performance on the other task (determining cardinal directions). Mental rotation and object naming ability were found to correlate with performance on some SCCTM tasks. The findings indicate that age and sex have an impact on memory for direction but not on other facets of topographical memory of familiar environments.

Implications of the current findings and future directions for topographical memory research are discussed.

Introduction

Topographical memory is a multi-faceted construct that includes memory for landmarks, routes and the spatial relationships. While the number of studies that have explored topographical memory has grown steadily in recent years (e.g., Aguirre & D'Esposito, 1999; Maguire, Nannery, & Spiers, 2006; Hepner, Mohamed, Fulham, & Miller, 2007), topographical memory continues to be researched far less frequently than other domains of memory. This is perhaps due, at least in part, to the methodological difficulties associated with quantifying and standardising largely personalised knowledge of familiar places and locations. Indeed, few standardised tests of topographical memory exist, and those that do tend to examine memory of environments that had never been navigated or personally experienced by the test-taker (e.g., recognition of photographs depicting scenes of an unfamiliar environment, Warrington, 1996).

The literature pertaining to topographical memory literature tends to emphasise route memory and environmental configuration memory (Siegel & White, 1975; O'Keefe & Nadel, 1978). Route memory refers to linear and sequential memory of routes, which are learned via an egocentric (i.e., body-centred) representation that incorporates associations between specific sequences of body-movements and cues in the environment. Environmental configuration memory, on the other hand, refers to an allocentric (i.e., world-centred) representation of an environment that incorporates the spatial relations between landmarks. A third facet of topographical memory relates to memory of landmarks. Given that environmental landmarks serve as important points of decision in which all spatial activity is organised (Herman, Kail, & Siegel, 1979), the ability to recognise landmarks is of fundamental importance for successful navigation.

Given the general paucity of studies that examine topographical memory, further research in this area is warranted. The current study was conducted in order to examine age and sex differences in topographical memory in the context of a highly familiar environment using a test that examines this at the level of the three facets delineated in the literature (environmental configuration, route and landmark memory).

Age Effects on Topographical Memory

The effect of ageing on memory has been the focus of much investigation (e.g., Nilsson, 2003; Einstein & McDaniel, 1990; Rapp & Heindel, 1994; Parkin, Walter, & Hunkin, 1995). Findings have demonstrated a differential effect of ageing on episodic memory (memory concerning personal experiences and recollection of past events and thought to be relatively dependent on the hippocampus) and semantic memory (memory of facts and general knowledge not requiring recollection of an event and not dependent on the hippocampus) (Nilsson, 2003). The decline in episodic memory with ageing has been thought to be linked to changes in hippocampal volume (Moffat, Kennedy, Rodrigue, & Raz, 2007; Golomb et al., 1996). With reference to topographical memory, some findings (e.g., Rosenbaum et al., 2000) suggest that representations of environments that are very personally familiar, coarse or schematic may become partially akin to semantic memory and are therefore insulated from hippocampal deterioration, whereas memory for detailed or vivid topographical representations are thought to be more episodic-like, and hence, more susceptible to hippocampal damage. Some researchers, on the other hand, emphasise the importance of the hippocampus in mediating the imaginary experiences involved in mental navigation and constructing coherent spatial representations, and view the structure as remaining critical for all but the most basic spatial representations of an environment, regardless of how familiar it may be

(Maguire et al., 2006; Hassabis & Maguire, 2009). Maguire et al. (2006), using a virtual simulation of London, found that an ex-taxi driver who sustained bilateral hippocampal damage due to limbic encephalitis was able to navigate along major routes he had learned 40 years previously as successfully as a control group of taxi drivers. However, the subject performed poorly when it came to more fine-grained navigation along non-major roads. Similarly, Rosenbaum et al. (2000) reported that a patient with bilateral hippocampal lesions following a traumatic brain injury was able to accurately sketch a map of his neighbourhood depicting the spatial relations of landmarks and was accurate at recognising navigationally-important landmarks (e.g., a school and shopping centre). However, he was very poor at recognising non-salient landmarks (e.g., houses) in his neighbourhood. In a longitudinal study using functional magnetic resonance imaging (fMRI), Hirshhorn, Grady, Rosenbaum, Winocur, and Moscovitch (in press) explored changes in brain activation that occurred when individuals from the normal population performed tasks of topographical memory of their home city, initially within a few months of moving into the city and then after a year of living in the environment. In the study, participants performed tasks that required coarse memories of landmark distances. In addition, participants completed a task where they were asked to imagine walking from one landmark to another using the most efficient route while avoiding a particular major road that was blocked. Performance on the latter task was assessed by asking participants to determine whether a particular street would be passed along the detour. The study found that the right hippocampus was significantly activated in the first session but not in the second session. Moreover, in the second session activation was found in the lateral temporal cortex, in addition to increased activation in the right posterior parahippocampal gyrus, lingual gyrus and posterior retrosplenial cortex. Together, these preliminary findings are consistent with the suggestion that the hippocampus is initially involved in memory for large-scale environments. However, as the environment becomes well-learned, hippocampal involvement diminishes for topographical memories that are schematic and coarse in nature, and such memories subsequently become semantic-like and are transferred, either partially or fully, to extra-hippocampal regions. Hence, schematic, semantic-like, topographical memories would be predicted to be less vulnerable to the effects of hippocampal changes associated with ageing compared with vivid, episodic-like topographical memories.

In a recent systematic review (Campbell, Hepner, Batchelor, Porter, & Miller, 2012 – see first paper of this thesis) we found that for *newly-learned* environments, the literature indicates that younger adults outperform older adults on several facets of topographical memory, including the ability to recall specific routes (Wilkniss, Jones, Korol, Gold, & Manning, 1997; Barrash, 1994), and determine spatial relationships between landmarks (Head & Isom, 2010; Kirasic, 2000).

To date, few studies have explored the effect of healthy individuals' age on facets of topographical memory for *highly familiar* environments. Using the Sydney City Test of Topographical Memory (SCTTM), Hepner (2006) found no effects of age on any component of topographical memory explored in the study (i.e., recall and recognition of landmark names, determining the directions of landmarks, recalling a route, and localising landmarks on a map). However, a fairly restricted age-range was used in the study, with participants being primarily aged in their 50s and 60s. In a study that compared young adults (less than 45 years of age) with elderly adults (over 65 years of age), Evans, Brennan, Skorpanich, and Held (1984) found that the younger group was more accurate than the older group at arranging highly familiar hometown landmarks in the correct spatial arrangement on a blank grid. On the other hand, in one of the few topographical memory studies that utilised the entire adult age range, Kirasic (1989) found no differences between their young, middle-aged and elderly adult age groups in the ability of subjects to determine the direction of a landmark in their hometown when imagining facing another landmark. In another study, Kirasic (1991) explored differences between college-aged and elderly women in their memory of a large, familiar supermarket and a large, newly-learned supermarket. The author found that, in the case of the newly-learned supermarket, elderly adults were poorer at determining the distance of items in the store in relation to a single starting point. In contrast, no differences in landmark distance estimates between the two groups were found in the case of the familiar supermarket. Together, the findings suggest that age has less of an effect on memory for the topographical details of a familiar environment (compared to a newly learned one), but the paucity of studies makes it difficult to know to what extent this is the case across different facets of topographical memory.

Sex Differences in Topographical Memory

Some researchers (e.g., Kimura, 2000; Galea & Kimura, 1993) posit that sex differences may exist in some facets of topographical skills due to different evolutionary pressures in early human societies. For example, in early societies human males may have been more likely than females to routinely navigate across large distances, for such activities as hunting. This would place a greater demand on the use of cues more helpful for large-scale navigation, such as distance and cardinal point information (Kimura, 2000; Galea & Kimura, 1993). On the other hand, female members of early societies may have been more likely than males to undertake short-range navigation in familiar territory for caregiving and gathering food. This would place a greater demand for effective perceptual discrimination and allow greater opportunity to use distinct and familiar landmarks as references (Kimura, 2000; Galea

& Kimura, 1993). Such a notion would predict that females are more likely to encode landmark information and males are more likely to encode distance and cardinal direction information when navigating environments.

There is some evidence that men and women use different brain regions to perform tasks of navigation. Using functional MRI, Gron, Wunderlich, Spitzer, Tomczak, and Riepe (2000) found sex differences in a group of young adults in hippocampal activation during navigation of a complex three-dimensional virtual reality maze. In their study, all walls in the virtual maze were composed of the same colour except at crossing points, where the walls were coloured differently to serve as landmarks. Participants were instructed to find their way out of the unfamiliar maze. While increased left hippocampal activity was found in males, increased right frontal and right parietal lobe activity was found in females. The authors argued that these sex differences in brain activation might reflect differences in strategies, such that the greater recruitment of frontal regions in women reflected the greater working memory demands of keeping track of the landmarks, while the greater left hippocampal recruitment in men might be consistent with processing geometrical relationships (Gron et al. 2000).

When sex differences in topographical memory abilities were investigated with a systematic review (Campbell et al., 2012– see the first paper of this thesis), we again found it useful to divide the findings according to whether the environments were newly-learned or highly familiar to the subject. For newly-learned environments, the literature indicates sex differences (in favour of males) on tasks of heading orientation in real-world environments (Ishikawa, & Montello, 2006; Silverman et al., 2000). On the other hand, the literature suggests that tasks of route memory of newly-learned environments are performed equally well by men and women (Castelli, Corazzini, & Geminiani, 2008; Barrash, 1994).

Few studies have explored sex differences in memory of *familiar* environments and the majority of those that have been conducted tend to investigate this in the context of relatively small-scale environments, such as university campuses, using undergraduates participants who have only had months or, at most, a couple of years of experience with the environment (Zinser, Palmer, & Miller, 2004; Prestopnik & Roskos-Ewoldsen, 2000; Waller, 2000; Holding, 1992; Kirasic, Allen, & Siegel, 1984; Richardson, Powers, & Bousquet, 2011). Moreover, the studies are generally either inconsistent or too few in number across the various facets of topographical memory investigated for it to be possible to draw firm conclusions. The only consistent finding in the previous systematic review concerns that of heading orientation within highly familiar environments, where studies tend to find no differences between males and females, though this is apparent only when the task is undertaken in vivo (i.e. from the actual vantage point and not from an imagined position, Bell & Saucier, 2004; Richardson et al., 2011). For her sample of 50-60 year-olds who lived in Sydney, Hepner (2006) found sex differences in some, but not all, components of the SCTTM. Specifically, males performed better than females at determining the cardinal direction when shown pictures of familiar landmarks and in determining the direction of one landmark relative to another. No sex differences were found in naming landmarks, recalling a route or localising landmarks on a map.

Overall, the literature regarding sex differences in topographical memory of newly-learned environments tend to support the predictions made that males will have superior spatial memory of environments, with females possibly showing an advantage for memory for landmarks. However, given the sparse research and inconsistent results to date, it is currently unclear whether these sex differences exist in the case of memory of highly familiar large-scale environments.

Age and Sex Effects and Topographical Memory: Possible Cognitive Mediators

A number of age-sensitive cognitive skills may potentially account for observed differences in topographical memory ability across the adult lifespan. There is consistent evidence of age-related decline in the ability to mentally rotate three-dimensional figures (Dror & Kosslyn, 1994; Dror, Schmitz-Williams, & Smith, 2005; Maylor et al., 2007). Furthermore, elderly adults (in their 60s and 70s) have been found to be less able to mentally rotate their surroundings relative to younger counterparts (in their 20s) (Herman & Coyne, 1980). Mental rotation abilities are likely to be important for tasks of topographical memory that require generating and manipulating stored mental spatial representations of the environment, such as determining directional information between two familiar landmarks or mental navigation. Indeed, successfully navigating a newly-learned virtual (Moffat, Hampson, & Hatzipantelis, 1998; Castelli et al., 2008) or real-world (Silverman et al., 2000) environment has been found to be related to mental rotation ability. Other age-sensitive cognitive skills, namely information processing speed and spatial working memory (the capacity to hold and manipulate information in mind; Salthouse, 1994), have also been shown to be related to performance on tasks of topographical memory of newly-learned environments (Castelli et al., 2008; Nori, Grandicelli, & Giusberti, 2009).

Some tasks of topographical memory involve the retrieval of landmark names and other environmental features (e.g., street names). There is evidence from both cross-sectional and longitudinal studies that the ability to retrieve the names of objects from memory declines after approximately 60 years of age (Borod, Goodglass, & Kaplan, 1980; Strauss, Sherman, & Spreen, 2006). In addition, verbal fluency skills begin to decline after middle adulthood (see Strauss et al., 2006, for a review; Brickman et al., 2005). Consequently, any age-related decline in the ability to recall the names of topographically-relevant landmarks or describing specific routes might alternatively be explained by a general decline in object naming ability or verbal fluency.

Few studies that have investigated sex differences in topographical memory have controlled for cognitive abilities that are known to differ between males and females. The observed tendency for females to make reference to more landmarks and street names than males when giving directions (Lawton, 2001; Ward, Newcombe, & Overton, 1986), for example, may be partially based on sex differences between verbal fluency or object naming ability, a skill which some studies indicate is more developed in females (e.g., Strauss et al., 2006). Indeed, it is possible that any observed sex differences in the type of topographical information recalled may merely reflect stylistic differences between the sexes in communicating topographical information rather than differences in memory per se (Ward et al., 1986). In addition to certain verbal abilities, reliable sex differences have also been found on tasks of three-dimensional mental rotation, with males consistently outperforming females (Galea & Kimura, 1993; Lewin, Wolgers, & Herlitz, 2001) and, as previously noted, mental rotation ability has been found to be related to performance on tasks of memory of newly-learned environments (Moffat et al., 1998; Silverman et al., 2000).

In summary, certain spatial and verbal cognitive abilities that differ between young and elderly adults and between males and females may explain age and sex differences observed on certain topographical memory tasks. Determining the influence of these cognitive skills when investigating the effect of age and sex on topographical memory is therefore warranted.

Aims

The aim of the current study was to determine any age and sex differences (and possible interactions) in facets of topographical memory in the context of an environment that was well known to participants as a result of exposure over years. Relationships between facets of topographical memory and several potential underlying cognitive skills were explored in order to determine whether any age or sex differences in topographical memory could be explained by differences in these cognitive abilities. Finally, given the lack of standardised tests of topographical memory, the study also aimed to provide group data on the SCTTM.

Based on the findings from previous studies (e.g., Maguire et al., 2006), it was hypothesised that an age effect (in favour of younger adults) would be observed for components of topographical memory that likely require the most highly detailed of spatial representations of the environment (i.e., tasks of heading orientation), which may remain dependent, at least partially, on the hippocampus. In contrast, no age effects were predicted for semantic components of topographical memory (i.e., landmark naming). It was also hypothesised that males would perform better on facets of topographical memory that involve determining spatial relationships between landmarks, while females would be more accurate in facets of topographical memory pertaining to landmark naming.

Methods

Participants

Sixty-three individuals (33 males, 30 females) between the ages of 20 and 79 years (inclusive) participated in the current study. The sample was balanced, such that each decade of the 60 year age range (i.e., 20-29 years, 30-39 years, and so on) contained approximately five males and five females. All participants fulfilled three minimum requirements that were set by the experimenter regarding level of familiarity with the Sydney area. These were: 1) participants were required to have lived in the Sydney region for at least eight years; 2) participants had to have visited the Sydney central business district at least once in the past ten years; and 3) participants were required to have rated themselves at least five out of ten on the Subjective Familiarity Scale.[2] Individuals with any current or past significant psychiatric or neurological condition were excluded from the study. All elderly participants lived independently at the time of testing. Potential participants contacted the experimenter in response to an advertisement of the study published in a Sydney newspaper as well as flyers and announcements of the study posted on public billboards located at a university, church community centre and a retirement village in the Sydney region. The study was approved by the Macquarie University Human Ethics committee. Participants provided informed consent prior to commencing the session and were paid $50 AUD at the completion of the session.

Materials

Sydney City Test of Topographical Memory

The Sydney City Test of Topographical Memory (SCTTM; Hepner, 2006) was used to examine memory of the Sydney region and central business district. The SCTTM was designed with the purpose of assessing the various facets of topographical memory that research suggests can be differentially impaired following brain injury (i.e., Aguirre &

[2] This involved asking participants: *How familiar would you say you are with the Sydney central business district on a scale between 1 to 10, where 1 is not familiar at all and 10 is very familiar with the Sydney central business district?*

D'Esposito, 1999). The test took 60-90 minutes to complete and six measures were obtained.

Landmark Name Recall and Recognition. Participants were first required to recall the names of 50 famous Sydney landmarks displayed on 21 x 15 cm photographs (a measure of *Landmark Name Recall*). For each incorrect response, participants were shown a card, consisting of the name of the landmark along with the names of three other Sydney landmarks, and asked to choose the correct name from amongst the distracters. Items correctly recognised (along with items that had been correctly recalled) contributed to a second measure (*Landmark Name Recognition*).

Heading Orientation (Perspective and Cardinal Direction).Fifteen of the items in the Landmark Name Recall/Recognition tasks were used to assess two measures of heading orientation. First, a measure of *Perspective* was obtained. Participants looked at pictures of the 15 landmarks, and were given the name of the landmark if necessary. They were asked to imagine they were standing in the same position as the photographer and to provide the direction of the Queen Victoria Building, a very well known Sydney landmark, in relation to where they were standing. There were eight options (in front of me, behind me, to my left, to my right, to the front and right, to the front and left, behind and right, behind and left). Two responses were scored as correct for each item. For example, 'behind' or 'behind and right' were acceptable in instances where the Queen Victoria Building was located between 135 and 180 degrees from the photographer's position facing the first landmark. Secondly, a measure of *Cardinal Direction* was obtained. Participants were asked to provide the cardinal direction they would have been facing if they had taken the picture of the landmark (North, South, East or West). The 15 landmarks were chosen for these two heading tasks based on earlier pilot work (see Hepner, 2006), which indicated these landmarks were amongst the most frequently correctly recalled and recognised in the pilot sample.

Route Recall. Participants were then required to provide directions from one Sydney landmark to another (*Route Recall*). This component of the SCTTM involved eight pairs of well-known Sydney landmarks that served as start and end points. For each item, participants were shown photographs of both landmarks and given the name if necessary (see Figure 1). In any instance where a participant did not know a landmark, a pre-determined alternative landmark, close in proximity to the original, was used. Participants were first given the opportunity to freely recall the route from start to finish. The experimenter would then clarify each step, providing general non-leading prompts to guide the participant's responses if necessary (e.g., "what would be the first step to take"... "What would you do next?"). Responses were recorded on an mp3 audio recorder to be later transcribed verbatim and scored. Responses were scored according to the provision of correct landmarks and correct turning information. Correct landmark information included street names (e.g., "College Street") or other unique environmental landmarks (e.g., "St Mary's Cathedral"). Turning information included egocentric coordinates or cardinal directions (e.g., "turn left at..." "turn right at..." "turn to the North along..."). The score for each item was converted to the percentage correct and the total route recall score was the average of these. All route recall transcripts were scored by the primary author (JC). Fifteen route recall transcripts were randomly selected and independently scored by the second author (IH). Inter-rater reliability was found to be very high (single measures intra-class correlation = 0.96, $p < 0.001$). Further details regarding Route Recall administration and scoring procedures is presented in Appendix I and II.

Landmark Map Localisation. The final task (*Landmark Map Localisation*) involved participants being shown a map of the Sydney Central Business District and asked to label the map with the location of 16 landmarks (when given the landmark name). The photographs of all sixteen landmarks had been shown previously in the Landmark Recall/Recognition section, though they were not shown again during this task. The error score was the distance (in centimetres) between the participant's placement and the true location. The total score was the sum of these error measurements. To avoid the possibility that large errors on a single item would unduly impact participants' total error score, up to a maximum of five centimetres error per item contributed to the total error score in this study.

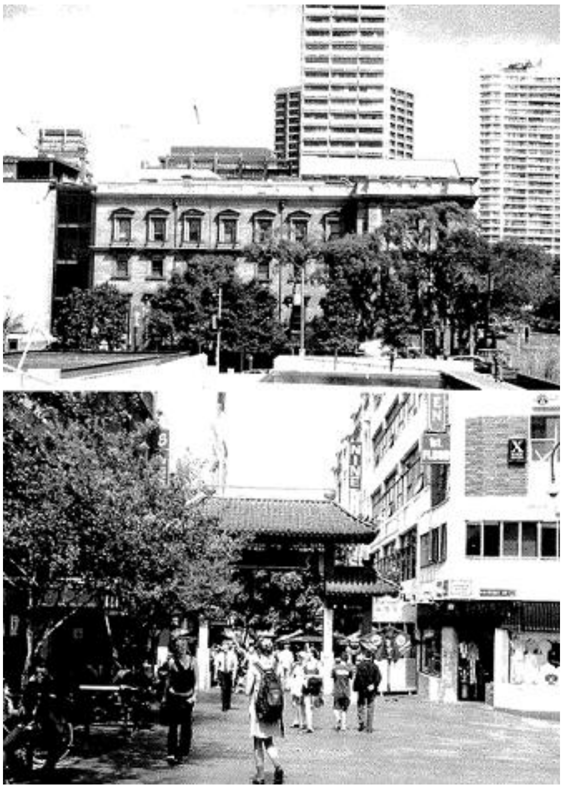

Figure 1

An Item from the Sydney City Test of Topographical Memory: Route Recall Subtest (Hepner, 2006; reproduced with permission). Participants Were Required to Provide Directions from One Landmark to Another.

While a participant may not be able to recall landmarks, he or she may nevertheless be able to recognise the landmark's name. Similarly, a participant who is poor at recognising landmark names may still have knowledge concerning its location (thus making it valid to pursue the heading orientation, route recall and landmark map localisation tasks). With this rationale, there is no discontinue rule in the SCTTM and participants completed all subtests regardless of their performance.

Verbal and Spatial Cognitive Tasks

Revised Vandenberg and Kuse Mental Rotations Test. The Revised Vandenberg and Kuse Mental Rotations Test: Version A (Peters et al., 1995) was used as a measure of mental rotation ability. The Revised Vandenberg and Kuse Mental Rotations Test is a pencil and paper task composed of two sets of twelve items each. Each item consists of a target figure made up of cubes on the left side of the page and four sample figures on the right. Two of the four sample figures are identical to the target figure except they are rotated in depth, while the other two figures cannot be made to match the target figure regardless of rotation. For each item, participants were required to identify and mark the two rotated versions of the target figure. A three-minute time limit was given for participants to complete as many items as they could in each set. A four minute break was given in between the two sets. To allow the stimuli to be more easily perceived for older participants, the original A4 size test stimuli were scaled to A3 size for all participants. Participants scored 1 point per item if and only if they marked off both correct figures. The maximum score was 24.

Wechsler Test of Adult Reading. The Wechsler Test of Adult Reading (WTAR; Wechsler, 2001), was used to obtain an education-adjusted estimate of participants' intellectual functioning. In this task, participants were shown a list of 50 irregular words and asked to pronounce each word aloud.

Boston Naming Test. The Boston Naming Test (Kaplan, Goodglass, & Weintraub, 2001) was used to assess object naming ability. In this test, participants were shown and asked to name 60 line drawings of objects, which progressively increase in naming difficulty. Items that were correctly named spontaneously or after a semantic stimulus cue were given credit.

Verbal Fluency (Letter and Category [Animal] Fluency).Two verbal fluency tasks (Thurstone, 1938; see Strauss et al., 2006) were used to measure spontaneous verbal production under restricted criteria. In *Letter Fluency*, participants were given three letters (F, A, S), one at a time, and asked to generate as many different words as possible that began with the specified letter, given a one-minute time limit. The final score for this measure was the raw total number of words generated (excluding repetitions and rule breaks). In *Category (Animal) Fluency*, participants were asked to produce the names of as many different types of animals as possible in one-minute. The final score for this measure was the raw total number of different names of animals generated within the specified time limit.

Digit Symbol-Coding. Digit Symbol-Coding from the WAIS-III (Wechsler, 1997a) was used in the current study as a measure of speed of information processing. Participants were first shown a key on a sheet of paper showing the digits 1 though 9, each paired with a simple and unique symbol. They were then shown a list of digits and were required to write down as many corresponding symbols as possible in a two minute time limit. The final score was the raw number of symbols correctly written down within the time limit.

Spatial Span. Spatial Span from the WMS-III (Wechsler, 1997b) was used to measure capacity to hold spatial information in mind. The task consists of two components. In *Spatial Span Forward*, the experimenter tapped a series of identical blocks haphazardly arranged on a board, and participants were required to tap the blocks in the same order without error. In *Spatial Span Backward*, the experimenter similarly tapped a series of blocks, however this time participants were required to tap the blocks in the reverse order without error. The raw scores from both Spatial Span Forward and Backward were added together to form a Spatial Span (Total) composite score.

Sydney Familiarity Measures

Participants were asked questions regarding their recent exposure to the Sydney central business district. Namely, they were asked how many times they had visited the Sydney central business district in the past five years and how many different places in the Sydney central business district they had visited in the past five years. Their responses to the latter question (*Places 5 Years*), which likely best reflects the quality and depth of recent experience with the target environment, would be used as a potential covariate. In addition, participants were also asked to clarify the number of months it had been since they had last visited the Sydney central business district (*Months Since Last Visit*), which would also be examined as a potential covariate for recent familiarity.[3]

Procedure

Eligibility to participate in the study was assessed by phone or email before the arrangement of a session. During this screening period, participants were asked to specify their age and were screened as to whether they fulfilled three minimum requirements regarding their familiarity with Sydney and the Sydney central business district. Table 1 summarises the level of familiarity that participants had with the target environment. On the day of the session, participants were tested individually in either a designated room at the Psychology Laboratory at Macquarie University or in a quiet room at the participant's own home. After reading and signing the information and consent form, participants were asked about their familiarity with the Sydney region. Participants also provided their education level. Following this, the six cognitive tasks were administered. Test order was kept consistent across all participants in the order outlined above. After the completion of the cognitive tests, participants completed the SCTTM. The session took a total of two-and-a-half to three hours to complete.

[3] The number of years of residence in the Sydney region, which was information obtained during screening, was also initially considered as a potential familiarity covariate, however as the vast majority of participants in the study had lived in Sydney their whole life, controlling this variable would likely have the effect of removing any variance related to age.

Table 1

Participants' Familiarity Level with the Target Environment

	Mean (sd)	Range
Number of years lived in Sydney region	35.59 (21.46)	8-78
Last time visited Sydney CBD (months)	1.44 (3.49)	0-18
Subjective Familiarity of Sydney CBD	7.5 (1.35)	5-10

CBD = Central Business District; sd = standard deviation

Statistical Analysis

Tests of Normality

Inspection of Kolmogorov-Smirnov goodness of fit tests and quantile-quantile plots for each topographical memory measures indicated that the distributions for Landmark Name Recognition and Landmark Map Localisation were negatively skewed and positively skewed, respectively. Consequently, logarithmic transformation was performed for both variables (the Landmark Name Recognition scores were first reflected before logarithmic transformation was undertaken). Places 5 Years, Months Since Last Visit, and mental rotation were positively skewed. Consequently, these variables were transformed using the logarithmic function. Logarithmic transformation (after reflecting the scores) was undertaken for the Boston Naming Test variable as the distribution of this variable was found to be negatively skewed.

Correlations and Analysis of Variance

One-way Pearson product-moment correlational analyses were conducted to explore the relationships between the topographical memory measures and demographic variables (years of education and estimated premorbid full scale intelligence quotient (FSIQ)), and between the topographical memory measures and potential familiarity covariates

(Places 5 Years and Months Since Last Visit). Bonferroni correction was undertaken according to the number of correlations made within each demographic and familiarity variable (i.e., alpha was set at 0.05/6 = .008).

A two-way analysis of variance, with age group (6 levels) and sex as fixed factors, was conducted to explore possible age and sex effects in the two familiarity covariates. These results, along with the above correlations, would assist in determining the most appropriate covariate. A two-way analysis of variance was also conducted to explore possible age and sex effects for each verbal and spatial cognitive task.

Correlations between the topographical memory measures and the verbal and spatial cognitive tasks were also examined. Bonferroni correction was undertaken according to the number of correlations examined within each verbal and spatial cognitive task, and only correlations that made theoretical sense were examined. Namely, correlations were only conducted between tasks thought to be related to spatial ability (including processing speed), and also only between tasks thought to rely on naming and language ability.

GLM Statistical Analyses

Sex and age differences on the six topographical memory outcome measures were examined using General Linear Model (GLM) analyses, with age as a continuous numeric variable and sex as a categorical independent variable. An age by age (age-squared) term was included in the model to allow non-linear (i.e., quadratic) relationships between age and measures of topographical memory to be examined (Cohen, Cohen, West, & Aiken, 2003). A sex by age by age (sex by age-squared) term was included to determine any complex non-linear interaction between sex and age. As any age or sex differences found on performance on topographical memory tasks could potentially be explained by differences in recent experience with the target environment, the familiarity variable (Places 5 Years or Months Since Last Visit) that was most related to age or sex and the topographical memory measures was introduced to the analyses as a covariate. In addition, any demographic variable (i.e., estimated premorbid FSIQ or education) that was found to be related to age or sex and the topographical memory measure, was added as a covariate. Multiple comparisons were adjusted using Bonferroni correction and p-values were adjusted according to how many comparisons were made. As a p-value cannot exceed one, a p-value of 1.0 is provided when the multiplied p-value exceeds one (e.g., p-value = 0.4 x 3 comparisons will be reported as p = 1.0).

Results

The Places 5 Years and demographic variables stratified by age group and sex can be seen in Table 2. In terms of the Months Since Last Visit variable, 75% of participants in the study had visited the Sydney central business district within the last month.

The two-way analysis of variance, with age group (6 levels) and sex as fixed factors, revealed no sex effects for any of the demographic or familiarity variables, and a main effect of age group was found only for Years of Education ($F(5, 51) = 3.35$, $p = 0.01$). No other age group or sex main effects, or sex by age group interactions were found for any of the other demographic or familiarity variables. Hence, neither age nor gender appeared to be related to the potential familiarity covariates or estimated premorbid FSIQ.

However, neither of the demographic variables (Years of Education and estimated premorbid FSIQ) correlated with any of the six topographical memory measures or with the familiarity measures. Of the two familiarity variables (Places 5 Years and Months Since Last Visit), only Places 5 Years was found to correlate with any of the topographical memory measures (Perspective, $r(61) = .38$, $p = 0.002$). Hence, though not appearing to be related to age or sex, as Places 5 Years was the only variable that was related to any of the topographical memory measures, it was considered the most appropriate variable to use as a covariate.

Two-way analysis of variance, with age group (6 levels) and sex as fixed factors, revealed a main effect of age group for Mental Rotation ($F(5, 51) = 3.91$, $p = 0.004$), Animal Fluency ($F(5, 51) = 2.90$, $p = 0.02$), Digit Symbol-Coding ($F(5, 51) = 8.61$, $p > 0.001$) and Spatial Span ($F(5, 51) = 4.09$, $p = 0.003$). A main effect of sex was found for Mental Rotation ($F(1, 51) = 11.67$, $p = 0.001$). No sex or age group main effects were found for Letter Fluency or the Boston Naming Test. No sex by age interaction was found for any of the verbal or spatial cognitive tasks. Tables 3 and 4 summarise group performance on these tasks.

Correlations between the six topographical memory measures and the verbal and spatial cognitive tasks can be seen in Table 5. Object naming was found to be weakly correlated with both the Landmark Name Recall and Landmark Name Recognition subtests. Mental Rotation was weakly associated with the Perspective subtest, but was unrelated to the Cardinal Direction subtest. Object naming, but not any of the spatial measures, correlated with Route Recall. Finally, none of the spatial measures were found to be related to Landmark Map Localisation.

Table 2

Demographic and Recent Familiarity Variables Stratified by Age Group and Sex

Age	Education (Years)				WTAR estimated premorbid FSIQ				Places 5Years			
	Males		Females		Males		Females		Males		Females	
	Mean	sd	Mean	sd	Mean	Sd	Mean	sd	Mean	Sd	Mean	Sd
20-29	13.6	2.0	15.1	2.1	109.5	7.0	111.6	7.5	54.0	34.3	50.0	15.8
30-39	15.6	1.8	14.2	1.8	115.0	3.8	110.4	5.7	76.0	32.1	42.4	34.5
40-49	14.7	1.5	15.0	2.2	112.2	5.6	110.4	4.7	63.3	42.2	67.0*	43.62
50-59	13.4	2.3	12.0	1.4	111.2	4.8	106.4	5.1	82.0	123.2	37.2	39.0
60-69	12.3	2.0	13.2	2.6	107.8	6.9	111.0	5.6	59.2	71.0	32.4	38.8
70-79	12.4	2.3	12.4	2.2	106.4	12.1	107.8	5.5	44.4	41.0	36.0	39.0

sd = standard deviation; WTAR = Wechsler Test of Adult Reading; FSIQ = Education-adjusted estimated premorbid Full Scale Intelligence Quotient; CBD = (Sydney) central business district. NOTE: cell size = 5-6 subjects; * one outlier was excluded (participant's score was over four times higher than any other participants' score in the group)

Table 3

Verbal and Spatial Cognitive Task Performance stratified by Age Group

Age	Animal Fluency		Digit Symbol-Coding		Spatial Span	
	Mean	sd	Mean	sd	Mean	Sd
20-29	24.5	6.3	88.8	10.4	18.4	2.5
30-39	24.3	6.1	82.4	15.2	15.7	1.8
40-49	24.2	5.0	80.4	14.2	16.7	2.7
50-59	20.9	3.0	73.9	17.8	15.2	3.0
60-69	19.2	2.6	59.5	13.6	14.2	2.3
70-79	19.6	4.8	57.5	14.0	14.2	3.3

sd = standard deviation. NOTE: cell size = 10-11 subjects

Table 4

Mental Rotation Performance Stratified by Age Group and Sex

Age	Males		Females	
	Mean	sd	Mean	sd
20-29	11.8	6.9	6.8	2.2
30-39	7.8	4.2	5.6	3.6
40-49	9.2	4.2	4.8	1.6
50-59	6.6	1.1	3.2	1.6
60-69	5.8	2.0	2.8	3.3
70-79	3.8	3.0	4.0	2.5

sd = standard deviation. NOTE: cell size = 5-6 subjects

Table 5

Correlations Between Topographical Memory Measures and Cognitive Tasks

	Letter Fluency	Animal Fluency	Boston Naming Test	Digit Symbol-Coding	Spatial Span	Mental Rotation
Landmark Name Recall	ns	ns	.38**	-	-	-
Landmark Name Recognition	ns	ns	.34*	-	-	-
Cardinal Direction	-	-	-	ns	ns	ns
Perspective	-	-	-	ns	ns	.35*
Route Recall	ns	ns	.32*	ns	ns	ns
Landmark Map Localisation	-	-	-	ns	ns	ns

* $p < 0.05$ ** $p < 0.01$; ns = non-significant after correcting for multiple correlations. NOTE: significance levels adjusted using Bonferroni correction according to the number of correlations examined within each cognitive task. Only correlations that made theoretical sense were examined.

Age and Sex Effects on Topographical Memory (No Covariates)

No sex, age, sex by age, age-squared, or sex by age-squared effects were found for the Landmark Name Recall, Landmark Name Recognition, Landmark Map Localisation or Route Recall measures. Consequently, these four topographical memory measures were not explored in further analyses.

There was a significant interaction between sex and age-squared for both the Perspective (β = -.005, $t(57) = -2.01$, $p = .05$) and Cardinal Direction (β = -.008, $t(57) = -2.39$, $p = .02$) subtests, indicating that the curvilinear relationship between age and these dependant variables differed for males and females. Consequently, the slope relationship at each level of sex was examined. For males, a significant negative quadratic relationship was found between age and Perspective, as indicated by a significant age-squared term (β = -.004, $t(57) = -2.56$, $p = .03$). For females, a significant negative linear relationship between age and Perspective score was found (β = -.074, $t(59) = -2.91$, $p = .01$) (see Figure 2). Similarly, a significant negative quadratic relationship was found between age and Cardinal Direction (β = -.008, $t(57) = -3.40$, $p = .01$) for males. For females, no quadratic (β < 001, $t(57) = .10$, $p = 1.0$) or linear relationship (β = -.031, $t(59) = -.76$, $p = .90$) was found between age and Cardinal Direction score (see Figure 3).

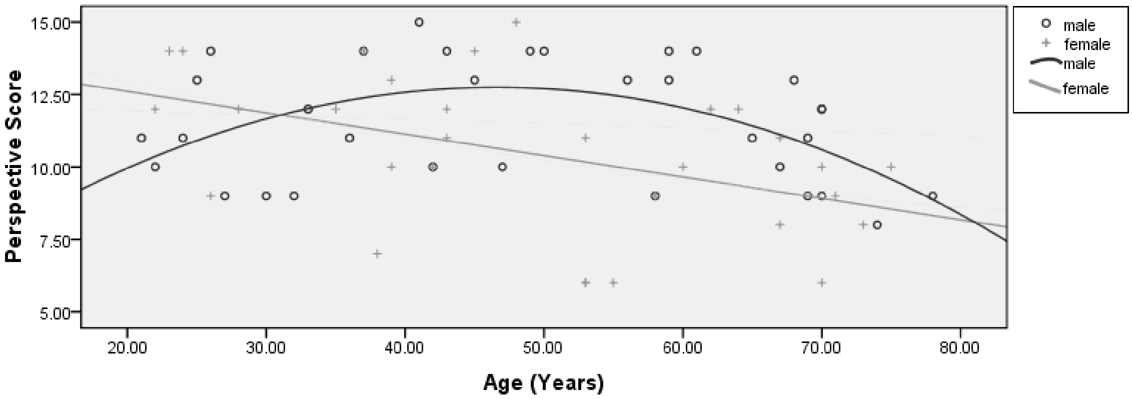

Figure 2

Scatterplot of Age and Perspective Performance for Male and Female Subjects (No Covariates)

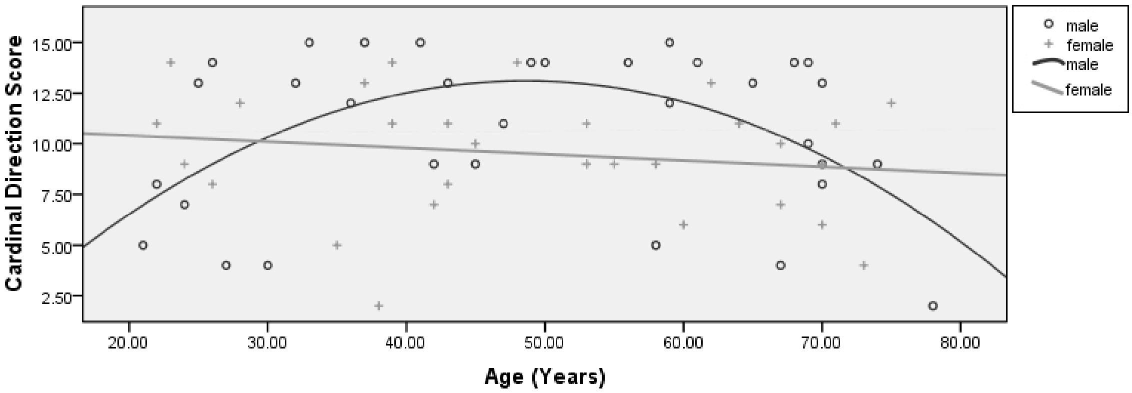

Figure 3

Scatterplot of Age and Cardinal Direction Performance for Male and Female Subjects (No Covariates)

Age and Sex Effects on Topographical Memory (Familiarity Covariate)

The Places 5 Years variable was added as a covariate to control for recent familiarity with the environment of interest. The sex by age-squared interaction remained significant for both the Perspective (β = -.004, $t(56)$ = -2.01, p = .05) and Cardinal Direction (β = -.008, $t(56)$ = -2.38, p = .02) subtests. The negative quadratic relationship between age and Perspective remained (marginally) significant for males (β = -.003, $t(56)$ = -2.30, p = .05) once recent familiarity was controlled, as did the significant negative linear relationship between age and Perspective for females (β = -.060, $t(58)$ =

-2.40, *p* = .04). The negative quadratic relationship between age and Cardinal Direction for males also remained significant (*β* = -.007, *t*(56) = -3.17, *p* = .01) once Places 5 Years was added as a covariate. There continued to be no significant quadratic (*β* = .001, *t*(56) = .28, *p* = 1.0) or linear effect (*β* = -.012, *t*(58) = -.29, *p* = 1.0) for age and Cardinal Direction in the case of females.

Sex Differences (Familiarity Covariate)

Sex differences on the Perspective and Cardinal Direction measures (with Places 5 Years controlled) were explored at three points of the models fitted using GLM: at the mean age (49 years), one standard deviation below the mean age (32 years), and one standard deviation above the mean age (66 years) (i.e. the *pick-a-point* approach, Hayes & Matthes, 2009). At the mean age, males outperformed females on the Perspective subtest (*β* = -2.228, *t*(56) = -2.73, *p* = .03). At one standard deviation above the mean age, this sex difference in favour of males approached significance (*β* = -1.788, *t*(56) = -2.37, *p* = 0.06). No sex differences were found at one standard deviation below the mean on Perspective performance (*β* = -.090, *t*(56) = -0.12, *p* = 1.0). At the mean age, males outperformed females on the Cardinal Direction subtest (*β* = -3.41, *t*(56) = -2.67, *p* = .03). No sex difference were found on Cardinal Direction performance at one standard deviation below or above the mean age (*β* = -.738, *t*(56) = -0.62, *p* = 1.0; *β* = -1.357, *t*(56) = -1.15, *p* = .76, respectively).

Sex and Age Differences for Perspective (Controlling for Mental Rotation)

Given that both age and sex differences were found in performance on Mental Rotation, and Mental Rotation correlated with Perspective, it was of interest to examine whether the age and sex effects for Perspective remained once mental rotation ability was controlled. Once Mental Rotation was added as a covariate (in addition to the Places 5 Years variable), the sex by age-squared interaction was no longer significant for Perspective (β = -.004, $t(55)$ = -1.71, p = .09). The age-squared term was also non-significant and there were no age or sex main effects.

Data for the six topographical memory measures are provided in Tables 6-9, stratified by age group and sex when appropriate. As both the Landmark Name Recognition and Landmark Map Localisation distributions strayed from normality, the group data for these two measures are expressed as percentiles.

Table 6

Age Group-and-Sex-Stratified Data For The Perspective Subtest

	Males (n = 33)	Females (n = 30)
Age Group	Mean (sd)	Mean (sd)
20-39	11.18 (1.89)	11.70 (2.36)
40-59	12.64 (2.01)	10.00 (3.27)
60-79	10.73 (1.90)	9.60 (1.90)

sd = standard deviation; n = sample size (10-11 per cell)

Table 7

Age Group-and-Sex-Stratified Data For The Cardinal Direction Subtest

	Males (n = 33)	Females (n = 30)
Age Group	Mean (sd)	Mean (sd)
20-39	10.00 (4.45)	9.90 (3.96)
40-59	11.91 (3.14)	9.70 (1.95)
60-79	10.00 (4.15)	8.90 (3.00)

sd = standard deviation; n = sample size (10-11 per cell)

Table 8

Data for the Landmark Name Recall and Route Recall Subtests

Subtest	Mean (sd)
Landmark Name Recall (raw score)	37.33 (7.10)
Route Recall (% correct)	79.16 (10.86)

sd = standard deviation

Table 9

Data Expressed As Percentiles for The Landmark Name Recognition and Landmark Map Localisation Subtests

Percentile	Landmark Name Recognition (no. correct)	Landmark Map Localisation (displacement in cm)
5	37	29.1
10	39	23.2
25	42	17.8
50	45	12.7
75	47	6.7
90	49	2.4
95	50	1.7

Discussion

The present study examined the effects of age and sex on memory for an environment that was well known to participants. The relationship between facets of topographical memory and several cognitive skills, which were thought to potentially subserve performance on many topographical memory tasks, was also explored. The results revealed that age and sex were related to some, but not all, facets of topographical memory for familiar environments, and weak correlations were found between some measures of basic cognitive ability and performance on topographical memory tasks. The study provided data for the SCTTM, stratified by age and sex when appropriate.

Utilising familiar environments, the current study found no evidence of age-related deterioration or sex differences in the ability to recall a route or localise landmarks on a map. These findings are in line with past research that had examined the influence of age (for subjects aged 50-60) on these two measures using the SCTTM (Hepner et al., 2006), though the findings are somewhat inconsistent with results of a study conducted by Evans et al. (1984), where younger adults performed better than elderly adults at arranging home-town landmarks on a grid matrix. As the current study utilised a map that contained basic geographical information (e.g., roads, bridges and coastlines), as opposed to a grid matrix devoid of such information, it could be argued that our landmark map localisation task was less spatially demanding than that used in the Evan et al. (1984) study. This difference on task difficulty may explain the absence of age effects in the current study. The lack of a sex effect for both route recall and landmark map localisation in the current study is consistent with previous research on memory of highly familiar large-scale environments (i.e., participants' hometowns; Hepner et al., 2006; Evans et al., 1984).

The current findings are in contrast to research on topographical memory of *newly-learned* environments, which demonstrates evidence of age-related decline on both tasks of route recall and landmark map localisation (e.g., Head & Isom, 2010; Kirasic, 2000). One possible explanation of this apparent discrepancy between past studies that employed newly-learned environments and the current study which used a familiar environment is that localising landmarks on a map (as was done here) requires only very coarse and schematic representations of the environment, which have the potential of becoming semanticised with increasing familiarity. Though initially dependent on the age-sensitive hippocampus, such memories may be subsequently transferred to a more widely distributed and age-resistant extra-hippocampal neural system, a notion consistent with evidence from neuroimaging (Hirshhorn et al., in press) and single-case (Maguire et al., 2006; Rosenbaum et al., 2000) studies. The finding that recalling a route in a highly familiar environment did not deteriorate with age also raises the possibility that route memory, which does not appear to be mediated by the hippocampus, nevertheless may also be transferred to more age-resistant brain regions and possibly become akin to semantic knowledge over time. It is important to note, however, that as the current study does not provide a direct test regarding the semanticisation or schematisation of the underlying representations, these interpretations are ultimately tentative.

In contrast to the findings of studies that employed newly-learned environments (Castelli et al., 2008; Silverman et al., 2000), none of the spatial cognitive skills examined in the current study, namely mental rotation and spatial working memory, correlated with either the ability to recall routes or the ability to localise landmarks on a map of a familiar environment, supporting the notion that these topographical memory abilities become independent of age-sensitive spatial processes once the environment is well-learnt. In the context of highly familiar environments, memories of routes and the ability to localise landmarks on a map may require minimal spatial cognitive skills as representations of familiar environments might be more in-grained into long-term memory and mental manipulation of the representations may therefore be less effortful. It is also possible that recalling a route and localising landmarks on a map of a familiar environment may also have the advantage of being assisted by the individual's accumulated background knowledge of the environment. This may include historical knowledge of the environment and landmarks, which may provide information as to the spatial layout of the positions of specific landmarks, and past exposure and use of a map of the target environment. Such background knowledge is not available in the case of a newly-learned environment, and participants are, instead, required to retrieve memories of their short experience with the environment. These memories would be contextually-bound and may therefore be akin to episodic (i.e., age-sensitive) memories.

Nevertheless, the current study suggests that not all facets of topographical memory that are spatial in nature have the same potential to become resistant to the effect of ageing, as shown by the finding of age differences on both tasks of heading orientation. Estimating cardinal directions was found to increase in males up until late middle-age, followed by a decline thereafter, while no relationship between cardinal direction estimates and age was found for females. The results also revealed a similar curvilinear relationship for males between age and Perspective (i.e., determining the direction of a second landmark from a vantage point depicted in a photograph), while a linear, negative relationship was found between age and Perspective for females. Importantly, these relationships could not be explained by differences in the quality of recent exposure to the target environment (i.e. the number of different places in the Sydney central business district participants had visited in the past five years) as the relationships remained once this variable was controlled. In addition, and consistent with past research that utilised the SCTTM (i.e., Hepner et al., 2006), males performed better than females at both tasks of heading orientation in the current study, though this was only seen in middle-aged adults. While previous evidence has shown that males are more likely than females to use cardinal directions when freely giving directions (Ward et al. 1986; Lawton, 2001), stylistic differences between the sexes in communicating topographical information rather than differences in actual memories of cardinal directions could not be ruled out from such findings. Using measures that are likely to more directly tap into memory processes, the current study demonstrated evidence of differences in memories of cardinal directions between middle-aged males and females.

Male superiority on tasks of heading orientation, at least in middle age, may be explained by sex differences brought about by evolutionary pressures to navigate large-scale environments (Kimura, 2000; Galea & Kimura, 1993). Males may tend to encode and represent environments utilising a co-ordinate system that incorporates elements likely beneficial to large-scale navigation, such as knowledge of landmark directions and cardinal directions, and develop this knowledge until late middle-age. Given the decline of heading orientation ability after middle-age in males, this facet of topographical memory may not have the same potential to become semanticised in the way that appears to be the case for memories of routes and landmark locations on maps, and may remain dependent on the age-sensitive hippocampus. In addition, heading orientation may also remain critically dependent on particular age-sensitive spatial cognitive abilities. The ability to determine directions of landmarks was found to correlate with mental rotation ability, and indeed the relationship between age and perspective was no longer significant once mental rotation ability was controlled, suggesting that decline in this topographical memory skill may be explained by age-related deterioration in mental rotation ability. In contrast, the other age-sensitive spatial measure used in the current study, spatial working memory, was not found to be related to any of the heading orientation tasks. Females, on the other hand, may not represent environments in a way that incorporates cardinal direction information or memories of landmark directions, at least to the extent of males, as indicated by the finding that these topographical memory skills remain either unchanged across the age span or decline linearly across the age span, respectively, for females. The differential age effect between the sexes on both measures of heading orientation is partially consistent with the finding that men predominantly rely on the hippocampus for tasks of navigation while women tend to utilise extra-hippocampal regions of the brain (Gron et al., 2000). These tasks of topographical memory would be predicted to decline with advancing age for males but not necessarily for females.

The current study found no sex or age differences on the ability to recall or recognise the names of familiar landmarks when provided photographs of the landmarks. This is consistent with the findings of a previous study that utilised the SCTTM (Hepner, 2006), though the current study extended this by utilising a much wider age range and a larger sample. The present findings are, however, not consistent with two studies (e.g., Head & Isom, 2010; Evans et al., 1984), which found that younger adults were better at recalling names of landmarks relative to elderly adults. One important difference between past research and the current study is that previous studies required participants to freely recall the names of as many different landmarks that had been seen in the target environment from memory, while the present study only required participants to recall the names of specific and highly-distinct landmarks depicted in photographs. Overall, the current study would indicate that the ability to name familiar landmarks depicted in photographs is resistant to the effect of age and may potentially be akin to semantic memory. A positive relationship was found between the two landmark naming tasks and object naming. While this may indicate that the object naming and landmark naming involve common cognitive processes, it is important to note that the relationships found were weak.

Given that the SCTTM took 60 to 90 minutes to complete, it is possible that older adults may have fatigued to a greater extent than younger adults, potentially confounding performance. Unfortunately, counterbalancing the order of tasks, which ordinarily would address such a confound, was not possible in the case of the SCTTM, as particular subtests would be invalidated if administered in a different order (e.g., recognition tasks before recall tasks).

The current study did not find evidence of age or sex effects for the majority of tasks of topographical memory. Given our sample size of 64 participants, it could be argued that the study involved a relatively small sample size and differences may have been detected with greater participant numbers. Future research with a larger sample size is therefore needed to address this limitation. Future research is also needed to investigate the neural substrates that underlie topographical memory for familiar environments to clarify the role of the hippocampus in explaining the age and sex differences observed on tasks of heading orientation. Though the current study focused on topographical memory of highly familiar environments, the inclusion of a test that measured topographical memory of a new environment may also have assisted in differentiating between younger and older adults, given evidence that such memory tends to decline with age (e.g., Head & Isom, 2010; Kirasic, 2000), and have provided further insight into hippocampal function. Furthermore, while the current study considered several measures related to participants' exposure to the target environment, a more precise measure concerning the extent that participant's may have resided away from the Sydney region during their lifespan may have been a useful covariate when examining SCTTM performance. Finally, while all older adults in the current study lived independently at the time of testing and appeared physically and cognitively healthy, we did not undertake any cognitive screening (e.g., MMSE) to formally confirm their current cognitive status. Thus, it cannot be confirmed that all older adults in our sample had completely normal cognition. Despite these limitations, the current study's method of examining age differences in memory of an environment that had been learned gradually within a natural setting is likely to be more ecologically valid than the more common approach used in past research of utilising newly-learned environments, which involve rapid and artificial learning.

In conclusion, the current study found that, in the context of familiar environments, the trajectory of heading orientation across the adult age span is complex and differs between males and females. In contrast to studies that examine memory of newly-learned environments, no evidence of age or sex differences was detected on any other facet of topographical memory investigated in the current study. Together, this would indicate that familiarity with an environment plays an important role in reducing or eliminating sex and age differences in topographical memory, at least in the case of facets of topographical memory that require only coarse and schematic representations.

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Appendix I: SCTTM: Route Recall General Scoring Procedure

1.1- Information should be broken down into steps, with each step consisting of <u>landmark and directional information</u>. Landmark information includes street names and/or any distinctive landmark that is passed (or is at the point of a turn). Directional information generally consists of "left" "right" and "forward/continuous" statements, but can also be "diagonal left, diagonal right etc" statements. **See Appendix Section 4.1.**

1.2-<u>The first step:</u> The first step should always consist of both directional (D) and landmark (L) information [e.g., "*Walk West (D) along Park Street (L)"* OR "*Turn right (D) and go down Park Street (L)"*]. Sometimes participants will start with just landmark information, without giving explicit directional information and then give directional and landmark information onwards [e.g., *"so I'm walking through Park Street (L); turn right (D) on George Street (L)..."*]. In such cases, the following rules should be applied:

> 1.2.1-If both the directional and landmark information on the second step is correct, then it should be assumed that the missing directional information in the first step is correct [e.g., "*so I'm walking through Park Street (1) [1-direction implied from next step]/ turn right (1) on George Street (1)*"]
>
> 1.2.2-If the participant gets the second step wrong, then score 0 for the first (missing) directional information.

1.3-<u>Straight roads that change names:</u> In cases where the participant has described going down a straight street and has not acknowledged that the street name changes, the examiner will prompt the participant. [e.g., *"Go straight down William Street and turn right on George Street" [Examiner: does William Street directly connect to George Street?] yes"*]. The participant would get (0) for Park Street but still get (1) for "turns into" (because they have remembered the road being straight, even though they did not remember the name change). Such an example would indicate a failure at acknowledging landmark information rather than a directional error. **See Appendix Section 4.2.**

1.4-<u>Going Through Parks/Paved Areas:</u> Significant paved areas should be treated as a separate step (requiring landmark and directional information) [e.g., *"turn right (1) onto King Street (1) through (1) the paved law court area (1) at the end of King Street, and turn left (1) on Macquarie Street (1)*].

1.5-<u>The final step:</u> The final step consists of isolated directional information regarding where the destination landmark is in relation to their previous step [e.g., *"turn right (1) and walk down art gallery road (1)/ and the art gallery is on your right (1)"*]. Note, unlike all other steps, this final step lacks landmark information (no point is awarded for the destination landmark 'art gallery'). **See Appendix 4.3.**

1.6-Because of this scoring method, an item is nearly always <u>out of an odd number</u>. [e.g., *"Walk West (direction) along Park street (landmark)/ turn right (direction) on George Street (landmark)/……/…../ Circular Quay is to your left (Final Step – Direction of the landmark)"*]. An exception to this is when it is necessary to give the additional prompt for item 5, which would make the item out of an even number (**see Section 3.1.2**).

2.1-Non-verbal information: If the participant correctly indicates the street by pointing at the photo, give landmark/street name credit. (Transcription will note hand gestures – for example: *points to George Street*). Similarly, if the participant correctly indicates directional information by pointing at the photo, give directional credit. (Transcription will note hand gestures – for example *points leftward*).

2.2-Clarifying/summarising Route: The tester will often clarify/summarise a participant's provided route. Information on the transcript given in "[ ]" marks reflects what the tester has said to the participant. If the participant changes/clarifies their answer following a tester's prompt, marks should be awarded.

2.3-Conflicting information: In the rare case where the participant gives an incorrect street/road name but gives very good description of the actual street, then the participant should be given landmark credit. In the rare instance that the participant gives conflicting directional and cardinal point statements [e.g., *"turn left on George Street, so you are now walking West up George Street"*], the scorer should place more focus on whether the body-centred left/right statements are correct, rather than N/S/E/W statements.

2.4-If the participant begins by describing steps within the starting point landmark (i.e., "Driver Ave" in Fox studios) the participant is not interrupted, however marking should only start once the participant has described leaving the landmark [for example: "turn right onto Lang Road"]. Participants should not lose marks for incorrect information they provide before exiting the landmark.

2.5-<u>The participant does not need to give the most direct route</u>: All information should be considered in the scoring, even if the provided route is longer than necessary. Scoring should be done in a way that <u>utilises all the information the participant has given</u>, as much as possible and in a way that minimises their error rate. **See Appendix section 4.4.**

3.1-<u>Item-specific scoring procedure [Item 5 and Item 8].</u>

3.1.1-<u>Item 5:</u> If a participant enters onto Macquarie Street from Martin Place, or a street further south, and states that the conservatorium is to the right, the additional prompt “will it be just there or would you have to walk further down?” is used. If the participant acknowledges that they have to walk past a further landmark (e.g., State Library/Botanical Gardens) or provides a reasonable distance estimate (“you have to walk down ¾ of Macquarie Street”) they will be given an additional 1 point. If they do not acknowledge having to pass anything further, they will be given 0 for this prompt, but will still be given 1 point for their correct final (directional) step.

3.1.2-<u>Item 8:</u> If a participant is unable to name the highways near the Harbour Bridge, but acknowledges that it is continuous from the Gore Hill Freeway (or there about, such as after a turnoff in the inner city/north Sydney or describes a continuous highway around Lane Cove, Artamon etc), then they should be given credit for the ‘continuous’ directional information [e.g., “which turns into (1-implied) Warringah Freeway (0), which turns into (1-implied) the Bradfield Freeway (0), onto the bridge (1)”]. If the participant is particularly hazy and does not acknowledge any turn offs after the pacific highway near North Sydney, then 0’s should be given for the ‘continuous’ highway information.

Appendix II: SCTTM: Route Recall General Scoring Procedure [Extended Notes]

4.1. Landmark and directional information

Acceptable landmarks/features often provided by participants instead of the street name:

Park Street: Street that cuts through Hyde Park; You see Hyde Park on your right/left.

Druitt Street: Street that passes Town Hall/Queen Victoria Building on your left/right.

William Street: Street that passes Australian Museum.

Hay Street: Street with Paddy's Market; Street that follows the tramline.

Alfred Street: Street parallel to the overhead bridge/Cahill Express.

Phillip Street: On the left is the AMP building.

Lang Road: Street that has Centennial Park on left/SCG/Football stadium on right.

Military Road: The road begins after a large (four-way) roundabout. [NOTE: Mossman Shops/Shopping Centre is not given credit, unless the participant can name a particular shop they would pass].

Dixon Street (Area between Liverpool Street and Chinatown entrance): A quiet/isolated road with few shops and mainly apartments; road that veers along to the left and slopes, with the monorail system in the distance.

An important note about Hyde Park: When describing the "S" shape around Hyde Park (i.e., Elizabeth Street to Macquarie Street or College Street to Macquarie Street), participants need to describe a landmark that they are veering rightward/leftward around before veering leftward/rightward into Macquarie Street (i.e., directional information should always be coupled with landmark information and vice versa). As there are few landmarks around this area, and the most prominent landmark is Hyde

Park itself, participants can use Hyde Park as a landmark, even if they had already used this feature in a previous step. For example:

> *"Turn right (1) onto the street with Hyde Park on the right (1-i.e., Elizabeth Street). Hugging it [i.e., Hyde Park (1)] around and heading in an easterly direction (1), and turn left (1) onto Macquarie Street (1)."*

4.2. Straight Roads That Change Names

Some straight streets that are commonly not acknowledged as changing names:

William Street/Park Street [or which cuts through Hyde Park]/Druitt Street

Gore Hill Freeway/Warringah Freeway/Bradfield Freeway

Elizabeth Street/Phillip Street

ANZAC Parade/Flinders Street

Pitt Street/Pitt Street Mall/Pitt Street

4.3. The Final Step

The final step should be "which direction is the *landmark.* If the participant stops short of a route but gives the correct final direction of the landmark from their final position, then mark their final step as correct but score 0 for the remaining steps. For example:

> *"Turn right on the road after you pass the library and walk down for a while and the* ***art gallery is to your right."***

In this example, the participant stopped short of the route and failed to mention that they also had to turn right onto art gallery Road. However, from the point they finished at, the art gallery is on their right. So their final directional information is marked as correct (1), but they are given 0 for the missing section: "turn diagonally rightward (0) into the domain (0)." The participant is given a point for "the art gallery is on your right" even though the art gallery is actually in front if the participant followed through with the rest of the route.

Another example of a participant finishing short of the route:

> *"turn right onto Liverpool Street, go down, and the Chinatown entrance is a few blocks down on your left."*

In this case, the entrance is on the left from the end point, however it is not immediately on the left, but rather the participant had to walk through a street (part of Dixon Street) before approaching the entrance. So the participant will have missed: "turn left (0) onto Dixon Street (0)", but should be given credit for the final directional information (i.e., that the entrance is on the left), even though when the missing step is added, the entrance would now be in front.

4.4. Utilise all the information the participant has given

Sometimes participants may add an entirely incorrect and unnecessary step in between two correct steps. For example:

[Item 2] You come out onto ***Lang Road and then you turn right****, and then you walk all the way until you get to ANZAC Parade,* ***you turn right on ANZAC Parade*** *and head towards the city. And then you* ***turn left in Cleveland Street….***

In this case, the most direct route is from Lang Street directly into Cleveland Street with ANZAC Parade intersecting the two roads. Errors of this nature should be dealt with in a way that utilises all the information the participant gives as much as possible, in a way that minimises their error rate. How this is done is highly dependent on the context. In this case, ANZAC Parade and Cleveland Street can be connected by walking through Moore Park:

You come out onto ***Lang Road (1) and then you turn right (1)/****, and then you walk all the way until you get to ANZAC Parade,* ***you turn right (1) on ANZAC Parade (1)/*** *and head towards the city. And then you* ***[missed: turn left (0) and walk through Moore Park (0)]/ turn left (0-should be straight) in Cleveland Street (1)….***

Appendix III: Study Macquarie University Ethics Approval

MACQUARIE UNIVERSITY

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19 November 2009

Mr Jamie Ian Campbell
23 Paul Street
Dundas
NSW 2117

Reference: HSHE30OCT2009-D00040

Dear Mr Campbell,

FINAL APPROVAL

Title of Project: Exploring age and sex effects on facets of Topographical Memory

Thank you for your recent correspondence. Your responses have addressed the issues raised by The Faculty of Human Sciences Sub-Committee of the Ethics Review Committee (Human Research). Approval of the above application is granted, effective 18th November 2009, and you may now proceed with your research.

Please note the following standard requirements of approval:

1. The approval of this project is **conditional** upon your continuing compliance with the *National Statement on Ethical Conduct in Human Research (2007)*.

2. Approval will be for a period of five (5 years) subject to the provision of annual reports. **Your first progress report is due on 1st November 2010.**

If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. If the project has been discontinued or not commenced for any reason, you are also required to submit a Final Report on the project.

Progress Reports and Final Reports are available at the following website:
http://www.research.mq.edu.au/researchers/ethics/human_ethics/forms

3. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report and submit a new application for the project. (The five year limit on renewal of approvals allows the Sub-Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).

4. Please notify the Sub-Committee of any amendment to the project.

5. Please notify the Sub-Committee immediately in the event of any adverse effects on participants or of any unforeseen events that might affect continued ethical acceptability of the project.

ABN 90 952 801 237 | CRICOS Provider No 00002J

www.mq.edu.au

6. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by the University. This information is available at: http://www.research.mq.edu.au/policy .

If you will be applying for or have applied for internal or external funding for the above project it is your responsibility to provide Macquarie University's Research Grants Officer with a copy of this letter as soon as possible. The Research Grants Officer will not inform external funding agencies that you have final approval for your project and funds will not be released until the Research Grants Officer has received a copy of this final approval letter.

Yours sincerely,

P.P.

Dr Peter Roger
Chair
Faculty of Human Sciences Ethics Review Sub-Committee
Ethics Review Committee (Human Research)

CC: Dr Jenny Batchelor, Department of Psychology
Dr Melanie Porter, Department of Psychology

Topographical Memory in a Left Temporal Lobectomy Patient: A Single-case Study Utilising the Sydney City Test of Topographical Memory

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Abstract

The current study examined the utility of the Sydney City Test of Topographical Memory (SCCTM, Hepner, 2006) in detecting impairments in memory of familiar environments and routes in a patient who had undergone a temporal lobectomy. Case TA was a 38 year-old, right-handed man, who reported topographical memory problems following left anterior temporal lobectomy, but in whom traditional memory tests revealed few post-operative changes. Utilising the SCCTM, TA's memory of environmental configurations, routes and landmarks was compared to that of a group of 10 control subjects matched for sex, age and educational level as well as compared to the newly developed large-group data. TA's ability to recall and recognise the names of famous Sydney landmarks, remember spatial relationships between Sydney landmarks, localise Sydney landmarks on a map, and recall routes within the Sydney area was significantly lower than the control group. TA's performance on all SCCTM subtests was also poor when examined against the large-group data. The findings highlight the value of the SCCTM in detecting impairments on facets of topographical memory after unilateral temporal lobectomy and supplement past research concerning the utility of this test in clinical samples.

Introduction

Memory of familiar environments and routes (i.e., topographical memory) following unilateral temporal lobectomy has been researched far less frequently than other domains of memory in this population. Topographical memory is multi-faceted in nature and includes both spatial aspects, such as knowledge of the spatial relations between landmarks, and non-spatial aspects, such as knowledge of the names of environmental landmarks. To date, of the few studies that have examined the effect of unilateral temporal lobectomy on topographical memory, most have principally explored this in the context of recently learned environments as opposed to environments that have been learned over many years. Studies suggest that unilateral temporal lobectomy leads to reductions in memory of recently learned environments regardless of the side of resection (Maguire, Burke, Phillips, & Staunton, 1996; Astur, Taylor, Mamelak, Philpott, & Sutherland, 2002; Glikmann-Johnston et al., 2008; Spiers et al., 2001). Individuals who have undergone either left or right temporal lobectomy have been shown to be impaired at recognising newly-learned landmarks and scenes (Spiers et al., 2001; Maguire et al., 1996), drawing plans showing the spatial relations between such landmarks (Spiers et al., 2001; Gilkmann-Johnson et al., 2008; Maguire et al., 1996) and judging distances between them (Maguire et al., 1996). Hence, the literature suggests that both spatial and landmark memory of recently learned environments involves both the left and right temporal lobes.

There has been no investigation regarding the impact of unilateral temporal lobectomy on topographical memory of highly familiar environments. This is an important limitation with the current literature, given evidence that different neural substrates may mediate recently-learned and old-established memories of environments (Epstein, De Yoe, Press, Rosen, & Kanwisher, 2001; Rosenbaum, Ziegler, Winocur, Grady, & Moscovitch, 2004; Teng & Squire, 1999). Specifically, while the hippocampus may be critical for acquisition, on-line navigation and short-term storage of a newly-learned environment (Burgess, Maguire, & O'Keefe, 2002; Gron, Wunderlich, Spitzer, Tomczak, & Riepe, 2000), some authors have posited that, after a prolonged period of time, such memories are transferred and maintained in a more distributed system involving the lateral temporal, posterior parietal and retrosplenial cortices (Rosenbaum, Gao, Richards, Black, & Moscovitch, 2005; Hirshhorn, Grady, Rosenbaum, Winocur, & Moscovitch, in press), many of the latter areas often surviving the unilateral temporal lobectomy procedure. Limited evidence concerns that of the bilateral temporal lobectomy patient, H.M., who was able to draw the floor plan of a house he had lived in for several years following his surgery (Corkin, 2002). This indicates that, even following bilateral mesial lesions, at least one aspect of topographical memory for a highly familiar environment is spared.

Given the paucity of studies that have investigated topographical memory in the context of a highly familiar environment following temporal lobectomy, further research in this area is warranted. One important limitation in this line of research concerns the lack of standardised tests that allows a detailed assessment of memories of personally familiar places and locations. The recently-developed group data of the Sydney City Test of Topographical Memory (SCCTM) provides a means to overcome this barrier. The SCCTM has previously been found to be sufficiently sensitive to detect impairments in landmark naming and determining the direction of landmarks in SG, a patient with bilateral mesial temporal and retrosplenial infarction (relative to a normal control group, Hepner, Mohamed, Fulham, & Miller, 2007). However, the SCCTM's utility in profiling topographical memory in a patient with temporal lobectomy has not yet been examined. Thus, the current study aimed to examine the effectiveness of the

SCCTM in detecting any deficits in topographical memory of a familiar environment in TA, a 38 year-old right-handed male left temporal lobectomy patient who began noticing topographical memory problems post surgery. The study aimed to assess TA's performance on the SCCTM relative to 1) 10 normal controls and 2) the large group SCCTM data (see tables 6-9 of previous paper).

Case Description

At the time of the study, TA was a 38 year-old right-handed male with 12 years of education. He had undergone a left anterior temporal lobectomy 15 months beforehand, in June 2009, as a result of treatment for pharmacologically intractable epilepsy. He had first experienced complex partial seizures at the age of 25, and trials of medications, including Levetiracetam, Carbamazepine and Phenytoin, failed to alleviate these seizures. Initially occurring approximately once every six months, TA's seizures gradually became more frequent, until by the age of 36 he would often experience several seizures a week and as many as five seizures in a single day. Besides sustaining several sports-related concussions in his early-twenties, TA had no risk factors associated with epilepsy, and he had no known premorbid neurological or psychiatric conditions. In terms of his familiarity with the target environment, TA had lived in the Sydney region all of his life, and for 10 years he worked fulltime in a retail store located in the Sydney central business district.

Presurgical Evaluation

Neuropsychological assessment

TA underwent neuropsychological assessment eight months prior to surgery. His preoperative performance is shown in column 1 of Table 1. Unlike the usual pattern seen in a right-handed individual with left mesial pathology, where relative weaknesses in verbal memory are expected, preoperative neuropsychological assessment found TA performed broadly within normal limits on tasks of verbal memory, but below expectation on tasks of visual memory. Specifically, his ability to recall short stories, word pairs and word lists immediately after presentation and after a delay generally fell in the average range, while his memory of newly-presented visual material (i.e., faces and doors) and a complex geometric figure (ROCFT) all fell $\leq 10^{th}$ percentile. This was in the context of an estimated average premorbid intelligence, and general average information processing speed, immediate verbal attention, object naming, and verbal and non-verbal problem-solving abilities. Prior to surgery, TA was noted to have mild symptoms of depression and anxiety, and moderate symptoms of stress on the Depression Anxiety Stress Scale.

Imaging

Magnetic resonance imaging (MRI), taken 10 months before surgery, revealed that TA's left hippocampus was small (relative to his right hippocampus) and slightly hyperintense, compatible with left hippocampal sclerosis. Evidence of abnormality circumscribed to the left hippocampal area was also supported by positron emission tomography (PET) scans taken during the same month, which revealed glucose hypometabolism in the left mesial temporal lobe region.

Wada testing

Subsequent findings using injection of sodium amobarbital into the internal carotid arteries (i.e., the Wada test) indicated bilateral language representation. During left-sided injection, TA correctly named only 4/9 verbalisable memory items. In addition, he made several reading errors (e.g., he read *instead* as *interested*), could only generate one word during a test of verbal fluency, and was dysarthric when attempting to repeat a phrase. However, he was able to follow commands, and he made no mistakes on a formal comprehension test. Of the 12 memory items, TA recalled two and recognised a further eight items, giving him a total of 10/12 correct, which was similar to his baseline performance. During right-sided injection, TA correctly named all verbalisable memory items except one, and he was able to generate 11 words during a task of verbal fluency, which was similar to his baseline performance. In contrast, he failed to respond to several commands (e.g., when asked to stop counting and to repeat a phrase), though he made no errors on a formal comprehension test. TA was unable to recall any of the memory items he had been shown, and only recognised 4/12 (which was at chance level). Overall, the procedure revealed that TA's expressive language function was mostly represented in the left hemisphere, while his verbal comprehension was represented, at least in part, in the right hemisphere. On the other hand, only the right hemisphere was shown to be capable of sustaining visual recognition memory.

Surgery

Surgical resection of the left anterior temporal lobe involved the removal of 3.5 cm of the superior temporal gyrus, 4.0 cm of the middle temporal gyrus and 5.0 cm of the inferior temporal gyrus, as well as underlying medial structures, namely the amygdala, uncus and all of the hippocampus. Pathology revealed a small cortical ganglioglioma as well as focal hippocampal sclerosis (see Figure 1).

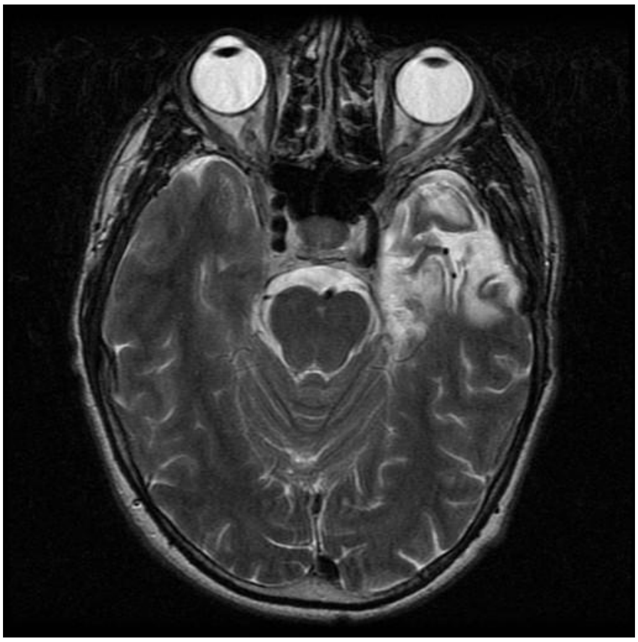

Figure 1

MRI Axial Image Showing the Removal of Left Anterior Temporal Region

Post Surgical Evaluation

Neuropsychological assessment

There were no post-operative complications and TA had not experienced a single seizure since the surgery. He remained medicated on 100mg of Keppra per day. Neuropsychological assessment conducted at three and nine months following the surgery found little evidence of change on most measures except for a modest decline in verbal memory and learning, and object naming ability (see Table 1). In terms of his mood, however, increased symptoms of depression and anxiety were noted and he was commenced on anti-depressant treatment following the second post-operative assessment.

Current topographical memory difficulties

At the time of the current study, 15 months following the left temporal lobectomy, TA reported experiencing episodes of topographical disorientation, which he believed had only become apparent after the surgery. Specifically, TA reported several occasions where he had forgotten how to get to an otherwise familiar place in his neighbourhood by foot. In at least one instance, he reported unintentionally walking to the wrong final destination (e.g., walking with the intention of going to the aquarium but ending up at the sports store instead). TA also reported sometimes forgetting the location of things in the environment (e.g., finding his friend's table at a pub when returning from the restroom), though he did not make any specific reference to having difficulties in navigating new environments. Despite these problems, TA reported no difficulties in recognising buildings and other environmental landmarks.

Normal Controls

TA's performance on the SCCTM subtests was compared with that of 10 males, who were approximate matches for age, estimated premorbid Full Scale Intelligence Quotient (FSIQ), years of education and familiarity with the environment of interest (see Table 2). All individuals in the control group had either worked in the Sydney central business district or had frequented the area regularly (i.e., at least once a week on average).

Materials

The Sydney City Test of Topographical Memory (SCTTM; Hepner, 2006) was used to examine knowledge of the Sydney region and central business district. The SCCTM is comprised of six subtests: Landmark Name Recall, Landmark Name Recognition, Perspective, Cardinal Direction, Route Recall and Landmark Map Localisation. Six verbal and spatial cognitive tasks were also administered: The Revised Vandenberg and Kuse Mental Rotation Test (Peters et al., 1995), The Wechsler Test of Adult Reading

(Wechsler, 2001), The Boston Naming Test (Kaplan, Goodglass, & Weintraub, 2001), Verbal Fluency (composed of Letter [FAS] and Category [Animal] fluency; see Strauss, Sherman, & Spreen, 2006), Digit Symbol-Coding (Wechsler, 1997a), and Spatial Span (Wechsler, 1997b).[4] TA's performance on the cognitive tasks has been included in column three of Table 1.

Table 1

Summary of TA's Cognitive Performance

	8 months pre-surgery		3 months post-surgery		9-15 months post-surgery	
Test	SCORE	Percentile	SCORE	Percentile	SCORE	Percentile
WAIS-III Digit Symbol-Coding	73	50-62	72	37-49	69	37-49
WAIS-III Similarities	22	37-49	15	5-8		
WAIS-III Block Design	26	16-24	33	37-49		
WAIS-III Digit-Span (Longest Forward)	9	97	9	97		
WAIS-III Digit-Span (Longest Backward)	5	52	8	98		
WAIS-III Digit-Span (Total)	21	84-90	25	95-98		
WMS-III Logical Memory I	32	25-36	31	25-36		
WMS-III Logical Memory II	14	16-24	7	2-4		
WMS-III Verbal Paired Associates I	14	25-36	3	2-4		
WMS-III Verbal Paired Associates II	4	25-36	2	9-15		
WMS-III Mental Control	29	63-74	25	37-49		
WMS-III Auditory Recognition Delay	47	25-36	48	25-36		
WMS-III Auditory Immediate (Index)	89	23	77	6		
WMS-III Auditory Delay (Index)	86	18	71	3		
WMS-III Spatial Span					13	25-36
Doors and People Memory Test (Doors)	16	10	13	1-5		
Recognition Memory Test – Words	43	10-2	44	10-25		
Recognition Memory Test – Faces	34	<5	44	50-75		
RAVLT – Total Learning	50	54			35	10

[4] See the 'Materials' section in the second paper of this thesis for a full description of the tests.

Table 1 (Continued)

Test	8 months pre-surgery		3 months post-surgery		9-15 months post-surgery	
	SCORE	Percentile	SCORE	Percentile	SCORE	Percentile
RAVLT – Delayed Recall List A	7	21			0	<1
ROCFT – Copy Time	152	>16	119	>16	72	>16
ROCFT – Copy Score	31	<1	35	>16	33	11-16
ROCFT – Immediate Recall	12.5	1	13	2	10	<1
ROCFT – 30-Minute Delay					9	<1
Boston Naming Test	55	25-50	49	<10	55	25-50
COWAT – Letter Fluency	22	5	20	4	27*	16
COWAT – Category Fluency	22	50-75	16	10-25	17	25
WCST – Categories	6	>16	6	>16		
WCST – Perseverative Errors	8	82	6	84		
WCST – Failure to Maintain Set	2	11-16	0	>16		
Trail-Making Test – Part A					38	10-20
Trail-Making Test – Part B					86	10-20
RVK-Mental Rotation					6	28

WAIS-III = Wechsler Adult Intelligence Scale – Third Edition (1997a); WMS-III = Wechsler Memory Scale – Third Edition (1997b); Doors and People (Baddeley, Emslie & Nimmo-Smith, 1994); Recognition Memory Test (Warrington, 1984); COWAT = Controlled Oral Word Association Test (letter fluency, Ruff, Light, Parker & Levin, 1996; category fluency, Tombaugh, Kozak & Rees, 1999); WCST = Wisconsin Card Sorting Test (Heaton, Chelung, Talley, Kay, & Kurtis, 1993); Boston Naming Test (Tombaugh & Hubley, 1997); RAVLT = Rey Auditory Verbal Learning Test (Geffen norms, In Strauss, Sherman & Spreen, 2006); ROCFT = Rey-Osterrieth Complex Figure Test (Meyers & Meyers, 1995); Trail-Making Test (Tombaugh, 2004). RVK-Mental Rotation = The Revised Vandenberg and Kuse Mental Rotation Test (Percentile derived from TA’s performance relative to the 10 normal controls).

Table 2

TA and Normal-Control Demographic and CBD Familiarity Variables

	TA	Normal Controls		
		Mean	Sd	Range
Age (Years)	38	38.7	10.24	(22-50)
Education (Years)	12	13.75	1.84	(10-16)
WTAR Estimated premorbid FSIQ	109	109.5	5.02	(98-115)
Estimated number CBD visits in past 5 years	938	600.5	473.15	(38-1200)
Estimated CBD visits in 5 years (Unique Places)	70	60.9	36.34	(12-100)
Estimated CBD visits in past year	25	106.6	97.27	(8-240)
Estimated CBD visits in past year (Unique Places)	2	35.3	29.11	(4-100)
Residence in Sydney region (Years)	38	21.4	10.27	(11-47)
Years of Work in CBD*	10	7.93	7.02	(0.3-18)

sd = standard deviation; WTAR = Wechsler Test of Adult Reading; FSIQ = Education-adjusted estimated premorbid Full Scale Intelligence Quotient; CBD = (Sydney) Central Business District * The Two NC's who never worked in the Sydney CBD were not included in this statistic.

Procedure

Participants (including TA) provided informed consent prior to commencing the session. TA was tested in a quiet room in his own home, while the normal controls were tested individually in either a designated room at the Psychology Laboratory at Macquarie University or in a quiet room at their own home. The same procedure was followed for TA and each of the 10 normal controls. After obtaining the demographic and familiarity variables, the six spatial and verbal cognitive tasks were administered in the order outlined above, followed by the SCCTM. The session took each participant approximately two-and-a-half to three hours to complete (TA took approximately three hours). The study was approved by the Macquarie University Human Ethics Committee and Ethics Review Committee of the Sydney South West Area Health Service.

Statistical Analyses

For each SCTTM measure, modified t-test analyses were conducted using the Crawford, Garthwaite and Porter (2010) ‘singlims_ES’ program. Treating the six SCCTM measures as a single set, multiple comparisons were controlled for using Holm’s (1979) sequential rejective Bonferroni correction procedure. One-tailed p-values were derived using the ‘Singlims_ES’ program. TA’s performance on the SCCTM subtests relative to the newly-developed large-group data developed was also examined.[5]

Results

There were no significant differences between TA and the normal controls on any of the demographic and CBD familiarity variables (p’s > 0.05). Also, as can be seen in the last column of Table 1, TA’s scores fell within normal limits on all of the control tests of verbal and spatial cognitive ability, namely that of object naming, verbal fluency, spatial working memory, mental rotation and processing speed. However, on the SCTTM, TA was found to perform significantly poorer than the control group on all six subtests after Bonferroni correction (see Table 3).

[5] The data is taken from Tables 6-9 in the second paper of this thesis.

Table 3

Sydney City Test of Topographical Memory Results

Subtest	TA	Matched-Control Group				Large Group [2]
	Score	Mean	sd	*t*-value	*p*-value	Percentile
Landmark Name Recall	17	34.8	5.75	-2.95	0.008*	< 1
Landmark Name Recognition	31	42.8	2.94	-3.83	0.002*	< 5
Perspective	7	11.7	1.95	-2.30	0.024*	1-2
Cardinal Direction	4	11.3	2.87	-2.43	0.019*	9
Route Recall (Total)	38.34	82.5	7.47	-5.64	< 0.001*	< 1
Landmark Map Localisation[1]	49.7	18	8.61	3.51	0.003*	< 5

sd = standard deviation; * = significantly different from the control group (after correction). The above (uncorrected) one-tailed probability p-values were derived using the Crawford, Garthwaite and Porter (2010) 'singlims_ES' program. Significance levels for the six comparisons were determined using Holm's (1979) sequential rejective Bonferroni correction procedure. [1] Displacement in cm. [2] Percentiles derived from information in Tables 6-9 in the second paper of this thesis.

TA's scores on the SCCTM subtests were also compared to the large-group SCTTM data (see last column of Table 3). As can be seen, on all but one subtest (*Cardinal Direction*), TA's scores fall below the 5th percentile with respect to the large-group SCTTM data.

Discussion

This study examined the utility of the SCCTM in detecting impairments in memory of a familiar environment in patient TA, a 38-year old male who had undergone a left anterior temporal lobectomy 15 months prior to testing. TA had noticed topographical memory problems following the temporal lobectomy, however aside from a reduction in his verbal memory since his surgery, no significant changes had been apparent in his visual memory and most other areas of his cognition remained intact. TA was found to perform significantly worse than a matched control group on all subtests of the SCCTM. His performance was also poor relative to the newly-developed large-group SCCTM data.

Consistent with past findings of reduced memory for the names of landmarks within highly familiar environments following mesial temporal damage (Hepner et al., 2007), TA's recall and recognition of landmarks names on the SCCTM were both found to be poor. The findings extend those from previous single case-study research by demonstrating that resection of the left temporal region alone, as opposed to bilateral mesial temporal damage, is sufficient to result in a reduction in the ability to name familiar landmarks. It is important to note that TA performed within normal limits on a task of object naming (i.e., the Boston Naming Test). Therefore, it is unlikely that his poor SCCTM landmark recall is based on a general naming deficit.

TA's performance on subtests of the SCCTM that relate to spatial topographical knowledge of the Sydney central business district was also found to be poor. TA's normal performance on the control tasks, namely processing speed, mental rotation and spatial span capacity rules out these more basic processes as being likely mediating factors for the differences observed. Though more detailed assessment of executive ability and attention may have assisted in determining a more precise cause of TA's topographical memory impairments, his broadly normal performance on neuropsychological tests of divided attention and non-verbal problem-solving abilities suggests that the underlying cause of his topographical memory impairments is unlikely to be attributable to difficulties with these areas of higher-order cognition. When provided with a photograph of a Sydney landmark and asked to imagine himself standing in the photographer's position, TA had difficulties with determining both the direction of a second landmark and the cardinal direction he was facing. It could be argued that TA's poor performance on these two SCCTM tasks may have been due to more fundamental difficulties with recognising the landmark rather than a difficulty in deriving directional information from the landmark per se. TA initially failed to recognise 5 of the 15 landmarks used for the *Perspective* and *Cardinal Direction* subtests. However, once given the names of the landmarks, TA stated that he was familiar with all but two of the landmarks and proceeded to correctly determine the direction of the second landmark for four of the five he had failed to initially recognise. Consequently, it is unlikely TA's poor performance on these tasks was based on underlying difficulties with recognising the 15 landmarks.

Similarly, TA demonstrated that his knowledge of the 16 landmarks used in the *Landmark Map Localisation* task was as good as the controls from his earlier responses to the items during the *Landmark Name Recognition* subtest. TA had recognised the names of 12 out of the 16 landmarks that were later used in the *Landmark Map Localisation* task (and he provided accurate location information for three of the four landmarks that he had previously failed to recognise). Consequently, his poor *Landmark Map Localisation* performance is unlikely to be due to poorer knowledge of the actual landmarks but rather more likely reflect a failure to recall a map-like (allocentric) representation of the environment. This finding is consistent with evidence that localising landmarks or drawing maps of a recently-learned environment is impaired following (left or right) unilateral temporal lobectomy (Maguire et al 1996; Spiers et al. 2001). On the other hand, this is inconsistent with the previous case-study that found intact *Landmark Map Localisation* performance on the SCCTM in an individual with more extensive bilateral lesions in the context of highly familiar environments (Hepner et al. 2007). One possible reason for this inconsistency is the differences in aetiologies between the present and previous case study. In the previous single-case study, SG's atrophy of key mesial areas does not completely preclude the possibility that some of these structures remained viable to support function, at least to a minimal extent. If old memories are more widely distributed, or even simply more consolidated within the same structures that mediate recently-learned memories, then even partial sparing of mesial structures may be sufficient to result in relatively intact established topographical memories. On the other hand, mesial structures that are implicated in a temporal lobectomy, as was the case for TA, are removed and therefore can no longer be recruited. Indeed, TA's performance on all SCCTM subtests that relate to spatial topographical knowledge was poor, whereas the only SCCTM subtest that relates to spatial topographical knowledge that SG performed poorly on was determining the direction of a second landmark.

Despite working in the area for a decade, TA was also poor at describing routes around the Sydney central business district. This is partially consistent with a study by Maguire, Nannery, and Spiers (2006), which found poor navigational skills within a (virtually reconstructed) familiar environment in an ex-taxi driver with bilateral mesial lesions due to limbic encephalitis. On the other hand, Maguire et al.'s (2006) study found no differences if the route consisted of main artery roads. In the present study, TA had great difficulty with recalling routes that involved even the most major of roads/landmarks in the Sydney central business district. Importantly, his poor performance could not be based on differences with knowledge of the actual landmarks. Moreover, he stated that he had often personally travelled one of the routes many times while working, despite getting a relatively poor score on that item (TA = 40% NC: M = 90.5%; [SD=13.0%]). One potential reason for the inconsistency with Maguire et al.'s (2006) findings is a methodological difference. Whereas their study involved navigating a virtual reconstruction of the environment, the SCCTM *Route Recall* subtest required TA to mentally navigate the environment, which may be a more difficult task.

As far as the authors are aware, this is the first detailed investigation of topographical memory of a highly familiar environment following left temporal lobectomy. Consistent with new-learning topographical memory research (Maguire et al. 1996; Spiers et al. 2001) the present findings suggest that resection of the left temporal lobe is sufficient to impact topographical memory. This study extends previous findings by showing that this also holds for memories of environments learned over years and decades.

The current study indicates that the SCCTM is sensitive in detecting impairments in several facets of topographical memory of familiar environments in the case of a left temporal lobectomy patient. Of course, it is important to note that the study is limited in its generalisability, given that it has investigated one case. In addition, this case was unusual in that TA's language representation was atypical. Wada testing demonstrated that his expressive language was mostly represented in his left hemisphere, while his verbal comprehension was, at least in part, represented in the right hemisphere. Research indicates that atypical cortical language representation is not a protective factor for sparing of verbal memory following left temporal lobectomy (Helmstaedter, Brosch, Kurthen, & Elger, 2004). Moreover, in the case of males, while individuals with typical cortical language representation tend to have spared non-verbal memory following left temporal lobectomy, individuals with atypical cortical language representation tend to also have a reduction in non-verbal memory (Helmstaedter et al., 2004). Because of this double reduction of both verbal and non-verbal memory in atypical cortical language representation cases, it is possible that TA's topographical memory skills are impaired to a greater extent than what would typically be seen following left temporal lobectomy. Indeed, if TA's poor SCCTM performance is typical it would be expected that complaints of poor topographical memory would be prevalent in unilateral temporal lobectomy patients. In contrast, topographical memory complaints are not known to be amongst the most commonly reported problems in such patients, though this may simply be due to a general failure to routinely investigate topographical memory in such individuals. Future research should explore the impact of unilateral temporal lobectomy on established topographical memory using the SCCTM in groups of individuals with typical cortical language representation to clarify whether such impairments are more commonplace in more typical cases. It would also be of interest to examine whether the profile of SCCTM subtest performance differs between individuals with left or right temporal lobectomy.

TA appeared motivated and was in good spirit when tested. Nevertheless his poorer performance on the SCCTM could be argued to be the result of his recent moderate symptoms of depression. Depression has been found to result in reductions in memory in the context of tasks that are effortful in nature, namely free recall, with performance on verbal or visual tasks of recognition remaining relatively intact (Egeland et al., 2003). Thus, at the very least it is unlikely that any existing mood problems could explain TA's poor *recognition* of landmark names. It is notable that TA performed within normal limits on a number of verbal and spatial measures, several of which (i.e., digit-symbol coding, object naming and verbal fluency) have been shown to be sensitive to depression (Henry & Crawford, 2005; Hoof, Jogems-Kosterman, Sabbe, Zitman, & Hulstijn, 1998). Consequently, while it cannot be ruled out, it is unlikely that, if present, mood dysfunction was of such severity to account for the observed poor performance on the SCCTM.

TA's frequency and quality (i.e., the number of different places in the Sydney central business district visited) of visits to the Sydney central business district over the past five years was very similar to that of the controls. On the other hand, TA had visited the Sydney central business district in the past 12 months four times less frequently than the average of the controls' frequency of visits. His quality of visits was also very low during that time. Though these were not significantly different to the controls, this may have been due to the extreme range in the controls' scores on these variables. Moreover, TA had ceased driving many years ago while the majority of the control subjects (90%) had a driver's license at the time of the study. It could be argued that TA's relatively less frequent visits in the past 12 months may have contributed to his poorer performance across all SCCTM subtests, and that the test may have tapped more heavily on recent, rather than remote, memories of familiar environments. However, it is noteworthy that the two highest *Landmark Name Recall/Recognition* scores in the control group were from two individuals that had visited the Sydney central business district less than TA in the past 12 months (12 and 8 times) and their quality of visits were the lowest of the controls (four and five places, respectively). Performance of these two control participants on all the other topographical memory tasks was also amongst the highest in the group. Thus, a greater number of recent visits to the environment of interest offers no obvious advantage to SCCTM performance.

In conclusion, this study indicates that left temporal lobectomy is sufficient to impair various aspects of topographical memory of familiar environments, and the SCCTM is a sensitive tool that captures such impairments.

Acknowledgements

We wish to thank Dr. Alan Taylor for his helpful statistical assistance and John Crawford for his helpful singlims_ES program.

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Appendix I: Study External Macquarie University Ethics Approval

Macquarie University Mail - External Approval Noted- Reference-5... https://mail.google.com/a/mq.edu.au/b/ethics.secretariat@mq.edu.au...

MACQUARIE UNIVERSITY

Ethics Secretariat <ethics.secretariat@mq.edu.au>

External Approval Noted- Reference-5201000832

Ethics Secretariat <ethics.secretariat@mq.edu.au> **Wed, Oct 6, 2010 at 12:56 PM**
To: Dr Jennifer Batchelor <batchelo@psy.mq.edu.au>
Cc: Dr Nora Breen <nora.breen@mq.edu.au>, Mr Jamie Campbell <jamie.campbell@mq.edu.au>

Dear Dr Batchelor

Re: "Topographical Memory in Temporal Lobectomy Patients"

The above application was considered by the Executive of the Human Research Ethics Committee. In accordance with section 5.5 of the National Statement on Ethical Conduct in Human Research (2007) the Executive noted the final approval from the Royal Prince Alfred Hospital and the University of Sydney and your right to proceed under their authority.

Please do not hesitate to contact the Ethics Secretariat if you have any questions or concerns.

Please do not hesitate to contact the Ethics Secretariat at the address below, if you require a hard copy letter of the above notification.

Please retain a copy of this email as this is your official notification of external approval being noted.

Yours sincerely

Dr Karolyn White
Director of Research Ethics
Chair, Human Research Ethics Committee

Appendix II: Study South West Area Health Service Ethics Approval

SYDNEY SOUTH WEST
AREA HEALTH SERVICE
NSW HEALTH

ADDRESS FOR ALL CORRESPONDENCE
RESEARCH DEVELOPMENT OFFICE
LEVEL 3, BUILDING 92
ROYAL PRINCE ALFRED HOSPITAL
CAMPERDOWN NSW 2050

TELEPHONE: (02) 9515 6766
FACSIMILE: (02) 9515 7176
EMAIL: lesley.townsend@email.cs.nsw.gov.au
REFERENCE: X09-0338 & HREC/09/RPAH/564

15 December 2009

Dr L Miller
Department of Neuropsychology
Level 8, Building 89
Royal Prince Alfred Hospital

Dear Dr Miller,

Re: Protocol No X09-0338 & HREC/09/RPAH/564 - "Neuropsychological functioning in people with and without neurological conditions"

The Executive of the Ethics Review Committee, at its meeting of 26 November 2009, considered your correspondence of 25 November 2009 and subsequently Dr N Breen's correspondence of 15 December 2009. In accordance with the decision made by the Ethics Review Committee, at its meeting of 11 November 2009, approval is now granted to proceed.

This approval includes the following:

- Information for Participants (Version 2, 25 November 2009)
- Participant Consent Form (Version 1, 26 October 2009)
- Information for Control Participants (Version 1, 25 November 2009)
- Control Participant Consent Form (Version 1, 25 November 2009)
- Medical Record Data Collection Form (Version 1, 15 December 2009)
- Wechsler Memory Scale – Third Edition (WMS-III) (Copyright © 1997 by The Psychological Corporation)

- Wechsler Adult Intelligence Scale – Third Edition (WAIS-III) (Copyright © 2003 by the Harcourt Assessment, Inc.)
- The Autobiographical Memory Interview (AMI) Manual (Thames Valley Test Company)
- National Adult Reading Test (NART) (No version, undated)
- The Visual Object and Space Perception Battery Scoring Sheet (Copyright © 1991 Elizabeth K Warrington, Merle James)
- Trail Making Part A (No version, undated)
- Trail Making Part B (No version, undated)
- Rey Complex Figure (No version, undated)
- RAVLT-C (No version, undated)
- Mental Rotation (No version, undated)
- CC Famous Faces Screen (No version, undated)
- Section 2: The Doors Test (No version, undated)
- Controlled Oral Word Association Test (No version, undated)
- Facial Recognition Test Record Form (Copyright © 1983 by Oxford University Press, Inc.)
- Wisconsin Card Sorting Test Scoring and Recording Form (No version, undated)
- Boston Naming Test (No version, undated)
- DASS21 (No version, undated)

You are asked to note the following:

- This approval is valid for four years, and the Committee requires that you furnish it with annual reports on the study's progress beginning in December 2010.
- You are responsible for the following:
    - arranging an identity pass for any researcher who is not employed by the Sydney South West Area Health Service. You should contact the Ethics Officer on 02 9515 7899 for advice on this matter, and

- if appropriate, informing the study sponsor that this human research ethics committee (HREC) has been accredited by the NSW Department of Health as a lead HREC under the model for single ethical and scientific review and is constituted and operates in accordance with the National Health and Medical Research Council's *National Statement on Ethical Conduct in Human Research* and the *CPMP/ICH Note for Guidance on Good Clinical Practice.*

- If you or any of your co-investigators are University of Sydney employees or have a conjoint appointment, you are responsible for informing the University's Risk Management Office of this approval, so that you can be appropriately indemnified.

- Where appropriate, the Committee recommends that you consult with your Medical Defence Union to ensure that you are adequately covered for the purposes of conducting this study.

Yours sincerely,

Lesley Townsend

Lesley Townsend
Executive Officer
Ethics Review Committee (RPAH Zone)

Research Governance Officer
SSWAHS (RPAH Zone)

HERC\EXCOR09-12

General Discussion

Topographical memory is a multi-faceted construct that includes memory of landmarks, routes and spatial relations between landmarks. Despite the functional importance of topographical memory and its relevance to clinical practice (e.g., Monacelli, Cushman, Kavcic, & Duffy, 2003; Maguire, Nannery, & Spiers, 2006), research in the area is sparse compared to other domains of memory. The research reported in the current thesis was designed to further the knowledge of topographical memory, and specifically, to determine whether age and sex differences exist in memories of highly familiar environments. A case study was also undertaken to demonstrate the application of new data collected for the Sydney City Test of Topographical Memory (SCCTM; Hepner, 2006), a test of topographical memory of highly familiar environments.

The first paper comprises a systematic review which revealed consistent evidence of age and sex differences in certain facets of topographical memory. It was found that those effects were often dependent on such factors as the type of task and outcome measure used, whether real-world or virtual-world environments were utilised, and whether the target environment had been newly-learned or highly familiar to the individual. Due to the paucity of studies, no conclusions could be drawn regarding age and sex effects in topographical memory of highly familiar environments. Studies concerning age and sex differences in topographical memory of newly-learned environments, on the other hand, were more numerous and the review outlined some key findings concerning this research. The finding that males outperform females on tasks of heading orientation in real-world newly-learned environments, but not on other, potentially less spatially-demanding, tasks of environmental configuration memory suggested that while there appear to be sex differences in this facet of topographical memory, such differences may only be detectable using tasks that are sufficiently difficult. The conclusions regarding environmental configuration memory were limited due to a paucity of studies, however on the one measure with a sufficient number of studies (landmark map localisation) an age effect, in favour of younger adults was found. The lack of differences between males and females on measures of route memory of newly-learned environments suggested that the sexes perform similarly in some facets of topographical memory that are spatial in nature. Nevertheless, even this facet was found to decline with advancing age. The finding of an age effect for environmental configurational memory and route memory suggest that facets of topographical memory that are spatial in nature are susceptible to the effect of ageing, at least in the context of memories of newly-learned environments. The findings support the notion that environmental configuration memory is mediated by structures that deteriorate with advancing age and that differ between males and females, such as the hippocampus, while route memory may be less reliant on structures that differ between the sexes, and may instead be reliant on extra-hippocampal structures within the temporal lobe or parietal regions, which are susceptible to the effect of ageing (Xu, Kobayashi, Yamaguchi, Iijima, Okada, & Yamashita, 2000).

The review found an insufficient number of studies that have examined landmark memory to permit conclusions regarding age and sex differences in this facet of topographical memory. The majority of studies included in the review compared only young (college-aged) adults with elderly adults. This highlighted an important gap regarding our knowledge of the trajectory of environmental configuration memory and route memory across the adult age span. Namely, it remains unclear whether these facets decline linearly or follow a non-linear trend. As was suggested in the review, highly-familiar environments may follow a curvilinear trajectory across the adult lifespan, as is the case for some domains of cognition that involve the slow accumulation of knowledge over time (i.e. vocabulary knowledge) (Salthouse, 2009). In contrast, memory for newly-learned environments may decline linearly across the adult lifespan, as in the case of memory of recently-learned visual and verbal information (Salthouse, 2009). Overall, the review highlighted the need for additional research examining i) age and sex differences in landmark memory, ii) age and sex differences in topographical memory of familiar environments, and iii) the trajectory of topographical memory across the adult lifespan, utilising middle-aged adults.

The findings from the empirical study reported in the second paper helped clarify the trajectory of topographical memory of highly-familiar environments across the adult-lifespan for both males and females. In contrast to studies employing newly-learned environments which tend to find age-related decline in environmental configuration memory and route memory (Head & Isom, 2010; Monacelli et al., 2003; Wilkniss, Jones, Korol, Gold, & Manning, 1997), age and sex differences in topographical memory of familiar environments were found to be limited to tasks of heading orientation. Altogether, the evidence was consistent with the hypothesis that coarse and schematic memories of highly-familiar environments (which may be sufficient for some tasks of topographical memory) may be transferred to age-resistant extra-hippocampal structures over time and become akin to semantic memory, while detailed memories of environments (necessary for heading orientation tasks) may remain critically dependent on the hippocampus (Maguire et al., 2006; Rosenbaum et al., 2000).

The finding that heading orientation changes in a curvilinear fashion across the age span for males and is stable or declines in females could be attributed to differences between the sexes in the extent that information such as cardinal directions and absolute directions of landmark is encoded and incorporated into representations of environments. Based on sex differences in evolutionary pressures (Kimura, 2000), males may tend to encode and represent environments using a coordinate system that incorporates elements that are beneficial to large-scale navigation, namely knowledge of cardinal directions and landmark directions and thus, such knowledge is accumulated until middle-age. Given the decline of these skills after middle-age in males, it appears that memories or other cognitive processes utilised during heading orientation tasks (such as mental rotation) remain dependent on age-sensitive brain regions. In contrast, the results suggested that females may not represent environments in a way that incorporates cardinal direction information or memories of landmark directions, at least to the extent that males do, as indicated by the finding that such knowledge does not accumulate across the age span but rather remain either unchanged or decline linearly, respectively, for females. Alternatively, when undertaking such tasks males may rely more heavily on brain regions/structures that deteriorate with age, such as the hippocampus, compared to females (Gron, Wunderlich, Spitzer, Tomcazk, & Riepe, 2000).

While not the focus of the paper, the findings from the empirical group study may inform development of the model proposed by Brunsdon, Nickels, and Coltheart (2007) in relation to topographical memory of familiar environments. While it appears that visuospatial working memory may underlie certain tasks of topographical memory of newly-learned environments such as route recall (Nori, Grandicelli, & Giusberti, 2009; Castelli, Corazzini, & Geminiani, 2008) and heading orientation (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006), the study did not find visuospatial working memory to be related to any task of topographical memory of familiar environments. Indeed, the only spatial cognitive skill found to be related to topographical memory of a familiar environment was mental rotation, which correlated with only one task of heading orientation. In contrast, mental rotation has been found to correlate with a large number of tasks of topographical memory of newly-learned environments, including tasks of route recall, heading orientation and map-labelling (Richardson, Powers, & Bousquet, 2011; Castelli et al., 2008; Palermo, Iaria, & Guariglia, 2008). Moreover, several other cognitive skills, namely verbal fluency and processing speed, also failed to correlate with any of the tasks of topographical memory of familiar environments examined in the study, despite evidence that such cognitive skills may underlie tasks of newly-learned topographical memory (Moffat, Kennedy, Rodrigue, & Raz, 2007; Monacelli et al., 2003).

It therefore appears that when the environment is highly familiar, the majority of topographical memory tasks do not require visuospatial working memory, or indeed any other spatial or verbal cognitive skill examined in the study. Instead, it is proposed that long-term memory, in interaction with a semantic system, may be sufficient to mediate most tasks of topographical memory of familiar environments. Future studies will need to explore the possible involvement of other cognitive skills not examined in the current study, particularly the role of executive functions. Based on the findings from the second study a basic model outlining the cognitive processes that mediate specific tasks of topographical memory of familiar environments is proposed (see Figure 1).

The findings from the third paper provided some insight into the impact of a left temporal lobectomy on facets of topographical memory of a highly familiar environment and demonstrated the utility of the SCTTM in providing objective measures of the patient's topographical memory complaints. The finding that TA performed poorly on all SCCTM tasks suggest that left temporal lobectomy is sufficient to impair topographical memory of familiar environments, including facets that are visual and spatial in nature. Importantly, given TA performed within normal limits on various spatial and verbal cognitive tasks, namely tasks of object-naming, processing speed, mental rotation and spatial span, his poor performance could not be attributed to differences in those areas of cognition. Ultimately, as the results of the case study may be atypical (given TA's bilateral language representation) future research using temporal lobectomy patients with typical language representation is necessary. Nevertheless, the case study demonstrates the application of the SCCTM in detecting impairments on facets of topographical memory in a left temporal lobectomy patient and together with the study by Hepner, Mohamed, Fulham, and Miller (2007) highlights the test's utility in assessing topographical memory in clinical samples.

In conclusion, the current thesis furthers the research concerning age and sex differences in facets of topographical memory in humans, specifically in the context of memories of highly familiar environments.

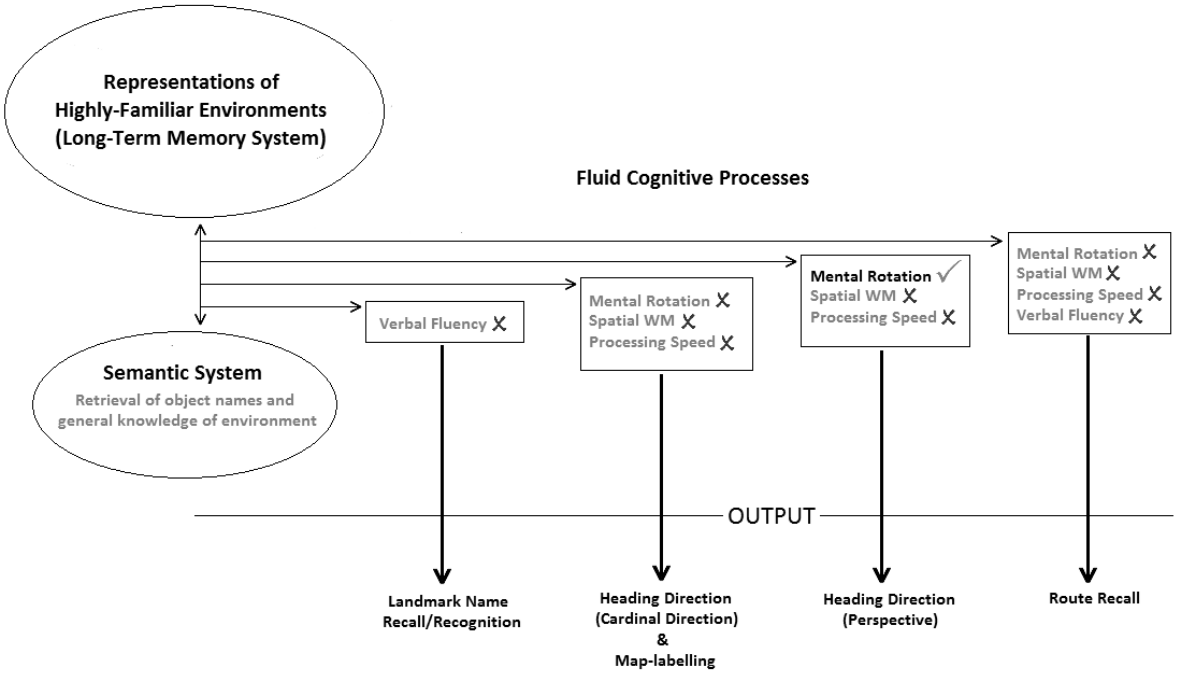

Figure 1

Proposed Model of Topographical Knowledge of Highly Familiar Environments (WM = working memory; X = not required; ✓ = required)

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