Using Visual Scene Memory Accuracy as a Predictor of Spatial Navigation Performance

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Abstract

Spatial navigation is a fundamental cognitive function essential for daily life. Navigation skill assessment predominantly relies on self-reports, with varying accounts regarding their validity. The current study aimed to determine whether performance on an objective visual scene memory recognition ability task, could serve as a valid predictor of wayfinding navigation performance. A standardized sense of direction scale was used to compare the predictiveness of self-report with the visual recognition test for objective navigation performance. Results from multiple regression analyses indicated that better performance on the visual, but not the verbal memory task significantly predicted wayfinding ability. Visual memory performance was also a better predictor of navigation performance than participants' self-reported sense of direction. This study therefore suggests that the assessment of visual scene memory is a promising and ecologically valid way to predict everyday practical navigation ability – in addition to *or* instead of via the use of self-reports.

***Keywords**:* Navigation Ability, Visual Memory, Verbal Memory, Wayfinding, Sense of Direction

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Introduction

Navigation refers to the acquisition, encoding and storage of information to maintain a course or trajectory within the environment (Eichenbaum, 2017). Navigation strategies are often conceptualized as egocentric or allocentric. Egocentric navigation involves using a spatial reference frame that represents object in space relative to the navigator, while allocentric navigation relies on an externally centered reference frame whereby object locations are encoded relative to other objects (Chrastil, 2013; Eichenbaum, 2017; Wahlheim & Zacks, 2018; Zhang et al., 2014). According to the model by Siegel and White (1975), there are also three levels of spatial environmental knowledge: 1) landmark knowledge (information regarding navigationally relevant objects), 2) route knowledge (egocentric information about the spatiotemporal sequence of landmarks), and 3) survey knowledge (a mental map of the environment based on an allocentric frame of reference). Given that everyday wayfinding ability requires multiple forms of allocentric and egocentric spatial-environmental knowledge processing, it tends to vary considerably according to individual differences (Shelton et al., 2014; Taillade et al., 2015; Wolbers & Hegarty, 2010). Interindividual differences in spatial navigation have been found to be influenced by several factors including, age (van der Ham, et al., 2020), sex/gender (Bosco, et al., 2004; Wolbers & Hegarty, 2010), spatial abilities (Kozhevnikov et al., 2006; Nori et al., 2009; Wolbers & Hegarty, 2010), experience (Maguire et al., 2000), cognitive styles/strategies (Baumann et al., 2010, 2011; Boccia, et al., 2016, 2017), and even personality (Pazzaglia et al., 2018).

Whilst clinical assessment of everyday navigation abilities relies predominantly on self-reports, evidence continues to question their validity and reliability (Meade et al., 2019; Munion et al., 2019; Ventura et al., 2013). For instance, it has been found that males consistently over-estimate their navigation ability despite performing similarly to females on many objective route-tracking tasks (Castelli et al., 2008; Coluccia & Louse, 2004; Torres-

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Guijarro & Bengoechea, 2016; Ulrich et al., 2019). Furthermore, van der Ham et al.'s (2021) comparison of self-reported versus objective navigation abilities revealed systemic gender *and* age biases – with increasing ability overestimation as a function of age. Evidence from neuro-psychological patients also suggests that there is very little correlation between commonly administered self-reports and actual navigation ability (van der Ham et al., 2013). Weisberg et al. (2014) also noted that self-reported sense of direction (SOD) is typically regarded as a stable trait and is therefore insensitive to change in practical navigational ability tasks, overtime.

Whilst several extant studies suggest that both verbal and visual-spatial memory subsystems are involved in wayfinding ability (Baumann et al., 2011; Garden et al., 2002; Grzeschik et al., 2019; Meilinger et al., 2008), it seems that visual-spatial memory abilities *may* be most important for, and predictive of, effective navigation (Baumann et al., 2011; Nori et al, 2009; Nys et al., 2018; Tamura et al., 2007; Zhang et al., 2021). Previous research has further highlighted that interindividual differences regarding both spatial and visual landmark-related abilities affect representations of environments. More specifically, it has been found that individuals with high visual-spatial abilities – as measured by mental rotation tasks – were more likely to form survey-type environmental representations; indicated by their ability to draw 3-D sketch maps of a learned environment. In contrast, individuals with lower visual-spatial skills, generally demonstrated an affinity for 2-D or 1-D sketch-maps (Blajenkova, et al., 2005). The study by Blajenkova and colleagues (2005) also revealed, however, that higher visual-spatial ability and the ability to form survey-type representation, are not necessarily always better markers of enhanced wayfinding performance. That is, individuals with lower visual-spatial abilities but sufficiently high performance in landmark recognition ability tasks can exhibit comparable wayfinding performance – by resorting to landmark-based route strategies. The idea of separate subsystems for the processing of spatial (i.e., layout-based) information, and visual landmark-based information is also supported by human cognitive neuroscience research; implicating the hippocampus for the former and the parahippocampal gyrus and retrosplenial cortex for the latter (Chan et al., 2012; Epstein, et al., 2017). Considering this, in conjunction with the uncertain effectiveness of self-reports for measuring navigation ability, the current study aimed to investigate whether a brief test of visual scene recognition accuracy is an effective and efficient means to predict navigation performance.

Method

Participants

The sample size estimate for the current study was determined using an a-prior power analysis via the G* Power (version 3.1.9.4) software. A fixed linear multiple regression model (R^2 increase; F tests) was assumed, including five predictor variables. It was determined that a sample of 40 participants would have adequate power (.80) for detecting a large (.35) effect of mnemonic ability, self-reported navigation ability, gender, and age (as a control variables) on navigation ability, with the alpha level of significance set at .05. Given that the aim of the current study was to identify predictors of navigation ability that could be potentially used for diagnostic purposes in individual patients, our study design was developed to identify large (i.e., $f_2 = .35$) statistical effects. Our sample comprised 41 subjects (20 females, 21 males; aged 18 to 27, $M = 20.63$, $SD = 2.37$) from the university's student community. Psychology undergraduate students, recruited via the university's Research Participant Pool, received course credit for participating. Inclusion criteria stipulated subjects must be at least 18 years of age, with no significant head injury or cognitive impairment influencing their vision or memory (i.e., stroke). All participants reported that the navigation task driving route was unfamiliar to them.

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Materials

Demographic Questionnaire and Health Status Form

A three-item demographic questionnaire and health status form was developed and utilized to gather information pertaining to participants' gender, age, and current health status – assessing for the presence of any serious health condition(s) influencing their vision and/or memory functionality.

The Navigation Task

The navigation task is a novel virtual route-retracing test created to objectively, and with high ecological validity, determine participants' wayfinding navigation abilities. The task was designed to capture an everyday situation that places high demand upon individuals' navigation ability. Route retracing, navigating a recently travelled route from an endpoint to a starting point, is a crucial navigational ability (Miller & Eilam, 2011; Wiener et al., 2012). Wiener and colleagues (2012) have shown that participants make significantly more directional errors when retracing routes, compared to repeating routes, indicating that route retracing places greater demand on spatial representation ability. The performance reduction is even more pronounced among older adults (Allison & Head, 2017; Wiener et al., 2012) – plausibly suggesting that this task has higher sensitivity for predicting everyday navigational deficits. During the task's learning phase, participants observe – from the driver's perspective – a real car driving on a 4:08 minute route from point A (start) to point B (goal) around a typical Australian suburb. Participants are instructed to use any mental strategy to remember the journey – for the purpose of being able to reverse the route in a test phase. During the immediate and subsequent test phase, participants watch the car drive from point B (goal) back to point A (start). During this phase, the video is halted at 14 decision points (i.e., intersections) and participants are prompted to verbally respond to route-knowledge questions using a forced choice question format (e.g., should the car turn left or right). All decision points were T-junctions requiring dichotomous choices (i.e., left or right; left or straight, or straight or right). Navigation task responses focused solely on accuracy; response times were not measured. The navigation test phase took approximately six minutes, with slight variations due to interindividual differences in response times.

The driving simulation is presented using Windows Movie Maker. Auditory information was included to accurately mimic a real-world driving experience – contributing to the task's ecological validity. Indicators were not used throughout the route to avoid auditory feedback influencing participants' navigational decision making. Several neutral landmark objects were dispersed throughout the route (i.e., cars, signs, trees). Figure 1 presents a fishbone diagram of the navigation task components. A percentage accuracy score for the wayfinding criterion variable is calculated by dividing the number of correct answers by the number of questions. Possible accuracy scores range from zero to 100%.

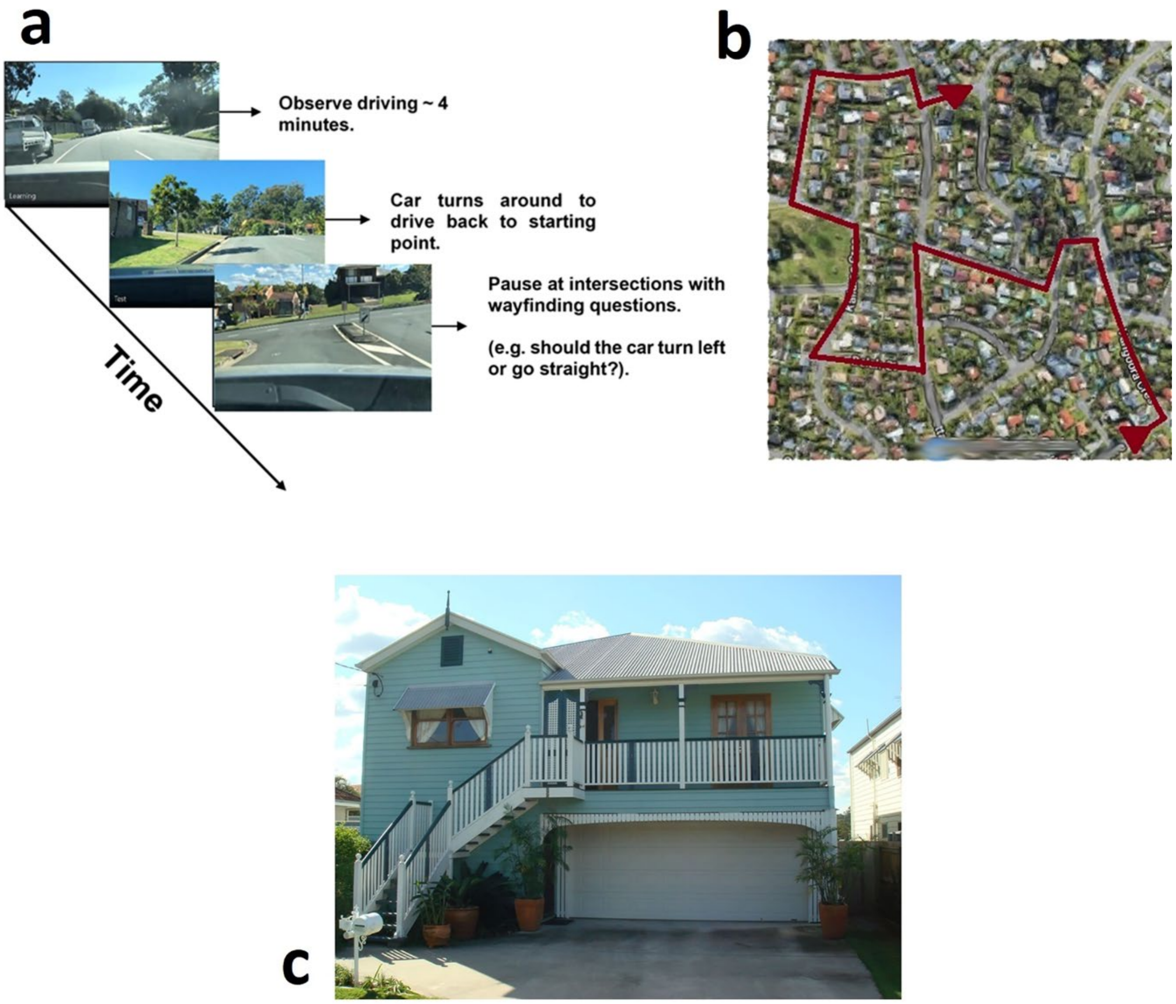

Figure 1

Schematics of the virtual driving task. (a) Sequence of events in the driving task. (b) Aerial perspective of the driving route. (c) Example stimulus from the Visual Memory Task

Visual Scene Recognition Task

The visual scene recognition task was designed to measure participants' ability to encode and retrieve typical suburban landmarks. More specifically, the task requires participants to memorize images of houses that are highly similar in architectural style. It therefore also simulates real-life large-scale (sub)urban navigation situations in which

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similar-looking buildings are the predominant landmark type. The use of houses also directly relates to the employed navigational task, in which similar residential buildings are the predominant type of information available to the participants for wayfinding. This task is similar to that described by Nori and Giusberti (2006) – which also tested memory recognition for buildings. A key difference, however, is that only seven trials were incorporated in Nori and Giusberti's study (leading to an accuracy rate of 98%). For our task, however, 40 recognition trials were administered – which according to pilot testing would preclude bottom and ceiling effects, thus capturing a wider range of performance that more reliably reflects the underpinning population's performance.

The Visual Scene Recognition Task was developed and administered via Presentation software (Neurobehavioral Systems, version 21.1.) using a 13'' laptop placed at a comfortable viewing distance. During the initial learning phase, participants are exposed to a set of 20 color-images of typical Queenslander architecture houses (See Figure 1[C]). Each image is displayed for three seconds, with a one second time interval separating the presentation of each image. Participants are instructed to encode the houses for the purpose of later recognition. In the immediate and subsequent test phase, participants are presented with the 20 learning phase images intermingled with 20 novel images and are instructed to differentiate scenes from the learning phase (old scenes), from those unique to the test phase (new scenes) via keyboard press.

Under the signal detection theory framework (Green & Swets, 1966), correctly recognizing an old name constitutes a hit, while incorrect identification constitutes a false alarm. The ratio of hits and false alarms for this task are used to calculate the sensitivity measure *d'*; a determinant of memory accuracy (Grider & Malmberg, 2008). Higher *d'* scores indicate better discrimination between hits and false alarms, and thus better visual memory. It is important to note that the use of several exemplars from the same category (Queenslander

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architecture houses) purposively limits participants' ability to employ verbal codes, making it a purer and more specific measure of visual memory. This also heightens the test's complexity, subsequently reducing any threat that potential ceiling effects may exert on the study's internal validity (Baumann et al., 2019).

Verbal Memory Task

This task was designed as a control task to capture participants' mnemonic ability for material by which verbal labels, in contrast to the visual task, can be readily employed. Importantly, this task was not designed to be matched in difficulty, but merely to capture inter-individual mnemonic ability in a task that employs an identical number of items and temporal profile. The verbal memory task was also administered via the Presentation software. During the initial learning phase, participants are visually presented (Black font on White background) with 20 first-names (each displayed for three seconds) with a one second time interval separating the presentation of each name. The names were chosen from a list of the most common English first names – to avoid large differences in memorability due to varying degrees of familiarity. Participants are instructed to encode the names for the purpose of later recognization. In the immediate and subsequent test phase, participants are presented with the 20 names from the learning phase intermingled with 20 novel names and are required to differentiate (via keyboard press) between names from the learning phase (old names), and those unique to the test phase (new names). As for the visual memory task, the proportions of hits and false alarms are used to calculate *d'*, as a measure of memory accuracy. Higher *d'* scores indicate better discrimination between hits and false alarms, and thus better verbal memory.

The Santa Barbara Sense of Direction Scale (SBSODS; Hegarty et al., 2002)

The SBSODS is a 15-item standardized self-report scale measuring 'large-scale' (Hegarty et al., 2002) environmental spatial ability (deemed: 'sense of direction;' SOD). An

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individual's SOD typically refers to their ability to track the direction in which they are heading, relative to their environmental reference frame (Hegarty et al., 2002). Responses are provided on a 7-point Likert scale – ranging from *strongly agree* (1), to *strongly disagree* (7). Eight items are phrased negatively (and subsequently reverse scored). An example of a positively worded item is: "I am very good at giving directions," and an example of a negatively worded item is: "I very easily get lost in a new city." All items are summed and divided by 15 (the number of items) to obtain a mean SOD rating score for each participant. Higher mean ratings indicate better SOD, with possible scores ranging from 1 to 7. Hegarty et al. (2002) showed that this scale has good internal consistency ($\alpha = .88$), excellent temporal consistency ($r = .91$), and moderate external validity ($r = -.40$; with mean pointing error in a real-world pointing task).

Procedure

Ethical approval for data collection was obtained from Bond University's Human Research Ethics Committee in accordance with the principles of the Declaration of Helsinki. Prior to commencing the experimental tasks, participants read an explanatory statement outlining the study's purpose, requirements, and their rights (i.e., to withdraw, to confidentiality, to privacy). Proceeding the provision of informed written consent, subjects were assigned a unique participant identifier to ensure data anonymity and completed paper-based versions of the demographic survey and the SBSODS, respectively. Following this, participants completed the three experimental tasks; the verbal memory task, the visual memory task, and the navigation task – with no specified delay in between each task. Counterbalancing of the tasks was employed to reduce the influence of potential practice effects associated with task familiarity and technology habituation (Harvey, 2012). Counterbalancing was also incorporated based on Heth et al.'s (2002) evidence suggesting that self-reported SOD may be skewed by a small number of recent events. Specifically, this study identified that self-reported SOD was *only* significantly correlated with navigation performance on a route-reversal task (akin to the current study's driving task) when administered following the practical task, and not prior. At the conclusion of the approximate 35-minute experimental session, participants were thanked for their time and given the chance to debrief and ask relevant questions. Students were assigned course credit following participation.

Results

Data was collated in Microsoft Excel, then exported into the IBM Statistical Package for the Social Sciences (SPSS) version 26.

Overall Test Performance

Performance in the visual scene recognition task (*M* = 72.41%, *SD* = 21.30%), verbal memory task (*M* = 83.05%, *SD* = 20.57%), and wayfinding task (*M* = 71.44%, *SD* = 10.47%) indicated that they were not prone to bottom and ceiling effects, and therefore allowed for an effective assessment of predictive relationships.

Assumption Checks

A missing value analysis revealed no missing data. Histograms assessing normality revealed some positive skew for the visual memory variable. The violation, however, was not major. Scatterplot graphs of standardized predicted residuals (zpred) against standardized residuals (zresid) for the navigation (wayfinding) outcome variable indicated residuals that were linear, normally distributed, and homoscedastic. An examination of Durbin Watson statistics indicated that the assumption of independence of errors was met, with all values close to two. An examination of Mahalanobis distance values indicated an absence of multivariate outliers, with $df = 5$, $\alpha = .001$. Pearson's correlation coefficients between the predictor and outcome variables did not exceed .70, indicating that multicollinearity was not

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a threat to the stability of the analyses. Means, standard deviations and intercorrelations for the data can be seen in Table 1.

Hierarchical Multiple Regression Analyses

A repeated-measures design was employed, comprising a series of standard and hierarchical multiple regression (HMR) analyses to determine the extent to which memory aptitude (verbal and visual) and self-reported SOD predicted wayfinding ability, whilst controlling for the influence of age and gender. The alpha level for all statistical tests was set at .05. The data met the assumptions for performing multiple regression analysis.

Table 1

Descriptive statistics and intercorrelations for age, gender, verbal memory sensitivity (d'), visual memory sensitivity (d'), self-reported sense of direction (SBSOD), and spatial navigation (% correct).

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*M*	*SD*
1. Age	–							20.63	2.37
2. Gender	.09	–						–	–
3. Verbal Memory	.18	- .26	–					2.55	1.47
4. Visual Memory	-.01	- .26	.38*	–				1.30	1.23
5. SBSODS	.01	- .45**	.22	.10	–			3.63	1.07
6. Navigation	- .12	.07	-.08	.41*	- .27	–		71.44	10.47

Note. N = 41. * $p < .05$. ** $p < .01$. Given the descriptive nature of the data, coefficients are not corrected for multiple comparisons.

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Visual Scene Recognition Accuracy Predicts Wayfinding Performance

A four-step HMR was conducted to examine the relationship between memory recognition (visual and verbal memory sensitivity), self-reported sense of direction (SBSOD) and objective navigation (wayfinding) performance, whilst controlling for age and gender. Studies indicate that with increasing age, humans exhibit deficits in the acquisition and retrieval of spatial environmental information (Jansen et al., 2010; Lopez, et al., 2021; Tangen et al., 2015; Techentin et al., 2014), recognizing scenes, recalling object associations (Bates & Wolbers, 2014) and wayfinding (Cushman et al., 2008). There is also considerable evidence supporting a relationship between gender and navigation ability – although existing findings are largely inconsistent (Munion et al., 2019; van der Ham et al., 2021). Thus, age and gender (*males* = 0, *females* = 1) were entered at step one. Sensitivity scores (*d'*) for the verbal memory task were added at step two of the regression model. At step three, Sensitivity scores (*d'*) for the visual memory recognition task were added. Given that self-reports are the most frequently used measure of navigation ability in clinical and professional settings (van der Ham et al., 2021), the SBSOD self-report navigation ability scores were entered into the fourth and final step of the regression model. Wayfinding percentage accuracy scores on the virtual driving navigation task were entered as the outcome variable.

At step one, there was no evidence to support a significant association between age, gender, and wayfinding, F (2, 38) = 0.38, p = .688. At step two, verbal memory task sensitivity was entered into the model, whilst controlling for age and gender. Verbal memory recognition scores failed to account for any statistically significant proportion of the variance in navigation ability, ΔF (1, 37) = 0.07, p = .799. The overarching model, including gender, age and verbal memory sensitivity, did not significantly predict wayfinding ability, F (3, 37) = 0.27, p = .849. At step three, visual memory sensitivity was added to the model and accounted for 24% of the variance in wayfinding, whilst controlling for age, gender, and

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verbal memory sensitivity, ΔF (1, 36) = 11.51, p = .002. Better performance on the visual memory task independently predicted significantly better navigation task performance, (β = .54, p = .002). The overall model containing age, gender, verbal memory, and visual memory sensitivity explained 26% of the total variance in wayfinding, F (4, 36) = 3.13, p = .026. Self-reported SOD scores were entered at step four of the model, however, failed to account for any significant additional variance in wayfinding performance, ΔF (1, 35) = 2.65, p = .113. Participants' SBSOD mean ratings were not significantly independently associated with wayfinding performance, (β = - .26, p = .113). The final model containing all five variables was found to significantly predict navigation accuracy on the virtual driving task, F (5, 35) = 3.15, p = .019. This model explained 31% of the variance in wayfinding ability. Considering all five predictors, visual memory sensitivity remained the *only* significant independent predictor of navigation ability, (β = .53, p = .002). A summary of this HMR analysis, including unstandardized regression coefficients and their associated 95% confidence intervals and standard errors, as well as standardized regression coefficients, R^2 and ΔR^2 can be seen in Table 2.

Table 2

Hierarchical multiple regression summary: predictors of wayfinding navigation ability

Variable	R	R^2	ΔR^2	β	*B*	*SE B*	95% CI
Step 1.	.14	.02	–				
Constant					81.90	14.72	[52.10, 111.69]
Age				-.12	-0.54	0.71	[-1.98, 0.90]
Gender				.08	1.60	3.34	[-5.16, 8.35]
Step 2.	.15	.02	.00				
Constant					82.02	14.91	[51.81, 112.23]
Age				-.12	-0.51	0.74	[-2.00, 0.99]
Gender				.07	1.34	3.55	[-5.80, 8.48]
Verbal Memory				-.04	-.32	1.23	[-2.91, 2.18]
Step 3.	.51	.26*	.24**				
Constant					75.64	13.29	[48.68, 102.60]
Age				-.08	-0.37	0.65	[-1.69, 0.95]
Gender				.16	3.21	3.16	[-3.20, 9.62]
Verbal Memory				-.23	-1.62	1.15	[-3.95, 0.72]
Visual Memory				.53**	4.56	1.35	[1.84, 7.23]
Step 4.	.56	.31*	.05				
Constant					85.08	14.23	[56.19, 113.98]
Age				-.08	-0.34	0.64	[-1.64, 0.95]
Gender				.04	0.89	3.40	[-6.02, 7.80]
Verbal Memory				-.19	-1.38	1.14	[-3.69, 0.93]

Visual Memory		4.42**	1.32	[1.74, 7.09]
SBSODS	.52**	-2.53	1.56	[-5.70, 0.63]
	-.26			

Note. *N* = 41. 95% CI = Confidence interval for *B*. **p* < .05. ** *p* < .01.

Gender Effects in Navigation Ability

A standard multiple regression analysis (SMR) was conducted to determine if males in the current study estimated their navigation ability to be significantly higher than females. Gender was entered into the model as a predictor variable, with SBSODS *mean* scores as the outcome variable. Results highlighted that gender significantly accounted for 20% of the variance in self-reported SOD, *F* (1, 39) = 9.82, *p* = .003. Specifically, males (*M* = 4.10, *SD* = 1.04) reported significantly higher average SOD (β = - .45, *p* = .003) than their female counterparts (*M* = 3.15, *SD* = 0.88; see Figure 2). To determine whether this gender differentiation corresponded with objective wayfinding ability, an additional SMR analysis was conducted. Gender was entered into the model as a predictor variable, with *mean* wayfinding percentage accuracy scores entered as the outcome. No significant association between gender and average wayfinding accuracy was found, *F* (1, 39) = 0.17, *p* = .682. Male (*M* = 70.78, *SD* = 9.82), and female (*M* = 72.14, *SD* = 11.33) participants demonstrated similar navigation performance, (β = .07, *p* = .682; see Figure 3). To compare the susceptibility of the visual memory task versus participants' self-reported SOD via the SBSOD, a SMR was conducted employing gender as the predictor variable and visual memory as the outcome. Visual memory task performance did not significantly vary as a function of gender, *F* (1, 39) = 2.90, *p* = .096.

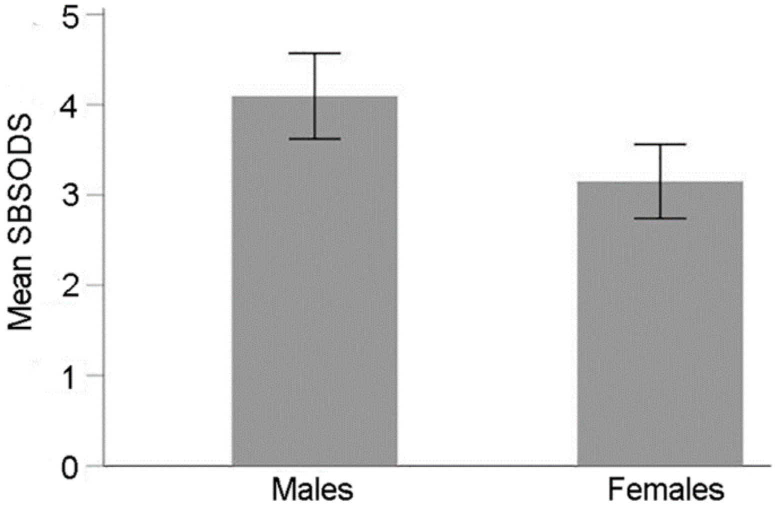

Figure 2. ***Mean self-reported sense of direction as a function of gender***

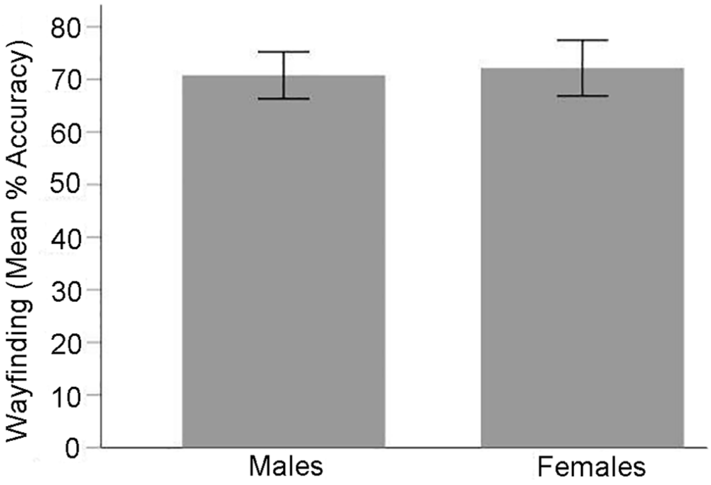

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Figure 3. ***Mean objective wayfinding accuracy as a function of gender***

Discussion

The aim of the current study was to assess the extent to which visual and verbal recognition memory, as well as self-reported SOD predicted objective performance on a novel wayfinding navigation task in a sample of adults. More specifically, we used a series of standard and hierarchical multiple regression analyses to determine the extent to which verbal and visual scene-based memory aptitude and self-reported SOD predicted wayfinding ability, whilst controlling for the influence of age and gender. Using this approach, we found visual scene memory – for distinctive buildings – to be the only significant predictor of wayfinding navigation. Our results suggest that the learning, maintenance, and retrieval of wayfinding information in unfamiliar environments is, to a considerable extent, based on the integration of visual scene memories; corroborating with extant evidence (Epstein et al., 2007, 2017). Neurocognitive evidence suggest that visual landmark information is processed by the parahippocampal cortex, which are integrated with directional information from the retrosplenial cortex into allocentric spatial maps encoded in the hippocampus (Epstein, et al., 2017). Accordingly, visual scene memory is a necessary, however insufficient, capacity underpinning viewpoint-independent navigation performance (Chan et al., 2012).

These findings suggest that visual scene recognition ability appears to be an appropriate proxy for determining wayfinding navigational deficits. This is highly relevant for clinical settings, since visual scene memory recognition can be measured in a concise and clinically feasible manner (i.e., the visual memory test can be administered in less than three minutes using a smartphone or even by using laminated picture cards). Also, given that our task shows no tendency for bottom or ceiling effects, this renders it a promising candidate for reliably measuring individuals with a large range of cognitive abilities.

Our study further determined that verbal memory accuracy was a non-significant predictor of wayfinding performance; endorsing previous findings suggesting that verbal mnemonic abilities are inaccurate measures of true navigation (Borella et al., 2014; de Beni et al., 2006; Taillade et al., 2012; Taillade et al., 2015). It may be that visual memory is the pre-dominant subsystem implicated in navigation ability and thus, methods of assessment based on verbalized episodic memories should be avoided as mainstay assessments in clinical settings. As suggested by Baumann et al. (2011), it could also be the case that individuals may actively and strategically, refrain from using verbal code when the environment has minimal symbolic visual information not readily encoded into a verbal format. Conceptual replication studies employing navigational assessments with varying richness of visual information (e.g., objects, landmarks) may be useful for determining if verbal memory is implicated when the navigational environment includes information that can be readily verbally encoded and retained.

The current study also provides support for an indirect dissociation between verbal and visual memory for predicting wayfinding ability. Further investigation using brain imaging technology such as voxel-based morphometry may enrich the current study. Correlations between performance on visual, verbal, and spatial navigation tasks with grey matter density could be examined to determine if specific memory task performance is related to partially overlapping brain regions (Schinazi et al., 2013). Considering the findings from neuropsychological case studies (Aminoff et al., 2013; Gazova et al., 2012; Labate et al., 2014), visual memory and navigation performance may correlate with grey matter density in the parahippocampus and right hippocampus, whilst verbal memory performance may correlate with grey matter density in the left hippocampus and language areas. Evidence indicating the neural basis of differential or overlapping memory and navigation performance deficits in clinical populations would support the use of such assessments for early detection of subtle neurodegeneration, where insensitive episodic memory tests are inadequate (Mistridis et al., 2015; Ponds et al., 2000).

Dissimilar to the findings from Burte and Montello (2017), results failed to uncover a significant positive association between self-reported SOD and wayfinding navigation ability (Hegarty et al., 2006; Ishikawa & Montello, 2006). Although the measure was designed to correlate with allocentric heading (Hegarty et al., 2002), it may be the case that the SBSODS measures cognitive processes insufficiently related to the navigational abilities implicated in 'real-world' wayfinding (Weisberg et al., 2014). In accordance with the hypothesis and previous literature, gender bias on the SBSODS was also identified. Males appraised their SOD (on average) significantly higher than their female counterparts (Castelli et al., 2008), despite non-significant navigation task performance differences across genders (Coluccia & Louse, 2004; Nori & Picardi, 2015; Picucci, et al., 2011; Torres-Guijarro & Bengoechea, 2016; Ulrich et al., 2019). Nori and Picardi (2015) speculated that the underestimation of spatial abilities in females might stem from the fact that they typically require a longer learning time than males (Piccardi et al., 2008; Nori et al., 2018). Another factor could be that women have been found to report higher levels of spatial anxiety (Lawton, 1994). Moreover, Boone and colleagues (2018) showed that whilst males and females significantly differed in self-reported navigation strategies (i.e., inclinations to use short-cuts versus following learned routes), strategy choices were only weakly correlated with objectives measures of strategy use. Overall, several lines of evidence suggest that large aspects of gender-based differences in spatial performance could be attributable to sociocultural stereotyping (Lawton, 2010).

Systematic gender biases in self-reports of navigation ability – like the SBSODS – further highlight that these types of measures are typically heavily affected by expectancy effects and stereotypes; adding to the extant base of literature questioning their construct validity and reliability (Meade et al., 2019; Ventura et al., 2013). Whilst it is plausible to suggest that with

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a larger sample size the SBSODS may have greater utility and reliability for predicting wayfinding, it is more likely that the individual differences associated with spatial navigation – a multi-dimensional construct (Weisberg et al., 2014) – extend beyond that which self-reports, like the SBSODS, are able to determine (Davies et al., 2017; Weisberg et al., 2014). Undeniably, traditional standardized self-report measures of SOD have been invaluable – particularly for use as research tools (Iwanowska & Voyer, 2013; Kozlowski & Bryant, 1977; Mitolo et al., 2015), and within clinical settings where the administration of more cumbersome experimental or experiential tasks remains infeasible (de Rooij, et al., 2019). The usefulness of self-reports is further reflected within assessment contexts involving patients that are visually impaired (Balata et al., 2015).

Our study employed a first-person route-retracing task to quantify navigation ability. While route repetition can be achieved by relying solely on egocentric representations of the environment, route retracing requires a viewpoint independent representation (Allison & Head, 2017; Wiener et al., 2012). It was therefore predicted that visual scene recognition ability would be a stronger and better predictor of performance in route repetition tasks, allowing for successful navigation via the retrieval of stimulus-response associations from an egocentric perspective. It has also been found that route retracing is more demanding and requires a more flexible mental representation of the environment compared to simpler tasks involving repeating a route in the same direction (Wiener et al., 2012). This indicates that route retracting is arguably more sensitive for identifying deficits (especially age-related deficits), in navigation ability (Allison & Head, 2017). It is important to note that although our navigation task realistically simulates car-based navigation within a suburban environment, it is un-representative of *all* possible situations that require goal-directed locomotion. For instance, the current study's findings should not be extrapolated to indoor navigation tasks, nor situations with limited visual input (e.g., navigation in the dark).

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Nevertheless, the novel navigation task has a high degree of ecological validity in that it captures an everyday situation that carries considerable risk of becoming lost. The development and preliminary validation of the novel route-reversal task also gives rise to further research opportunities of larger scope – with recommended aims being 1) to expand and advance the navigation task; incorporating additional spatial-navigational skill testing, and 2) to uncover additional, distinct, and measurable cognitive processes to explain the remaining variance (70%) in wayfinding task performance (Wiener et al., 2009). Earlier research has indicated that tests tapping into visual-spatial working memory abilities, such as those measured by Corsi Block and Mental Rotation Task for instance, are promising candidates to capture further variance in navigation performance unexplained by landmark recognition ability (Hegarty et al., 2006; Nori et al., 2009).

Ultimately, this study indicates that a brief assessment of scene-based mnemonic abilities provides more predictive value for determining real-world navigation than self-reports. In addition, visual-memory assessment is likely to carry fewer verbal, educational, and gender-based biases (Coughlan et al., 2018; Lawton, 2010) – reflected by the current study's non-significant visual memory performance differences across genders, whilst SBSODS ratings significantly varied as a function of gender. Finally, given evidence suggests that performance involving the maintenance of visual-*spatial layout* information, versus visual-*featural* information remains somewhat more stable over the lifespan (Picucci, et al., 2009) the current study's landmark recognition task has potential to be suitable for use in detecting more subtle age-related declines in navigation. Whilst there is a clear link between aging and comprised navigation ability, navigation tests are typically not included within most cognitive ageing test batteries (Moffat, 2009). Considering the high clinical utility of navigational assessment for the early detection of pathological ageing; Klencklen et al., 2011; Lester et al., 2017), the current study's development and preliminary validation of an effective and more efficient visual scene memory recognition task proxy provides a meaningful contribution to the field.

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