Interplay of Sex, Visuospatial Abilities, and Gaze Behavior in Egocentric and Allocentric Spatial Navigation

Psychology Honours Thesis Proposal

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**Part 1: Background literature summary**

Humans have been found to exhibit navigation preferences in maze-learning, biasing in either egocentric strategy, based on body-centred cues, or allocentric strategy, based on the configural relationship of landmarks, via dual-solution paradigm (DSP), where both strategies can solve the task (Ferguson et al., 2019; Furman et al., 2014; Marchette et al., 2011). Such preference is determined by the initial encoding of the environment, while the strategy applied in individual trials may differ depending on the environment, for example, availability of proximal and distal cues (Furman et al., 2014), warranting investigation into gaze pattern, indicating the locus of attention, during initial and subsequent navigation trials.

**Gaze Behaviour**

Recognition of a presented array is determined by the gaze chaining pattern during initial exposure (Hilton et al., 2020). As practice increases, attentional focus is observed to focus selectively on the most relevant cues that guide navigation (Geisen et al., 2021). At decision points (e.g., intersections), gaze tend to shift to the intended direction when the route is familiar, but gaze tend to focus on the previously encoded cue when the route is new, regardless of turning direction (e.g., starting from new position) (de Condappa & Wiener, 2016; Geisen et al., 2021). Also, in a simple goal search paradigm without route learning, allocentric knowledge is found to be dependent on a selected cue that is most predictive of the goal location (Negen et al., 2021), suggesting that allocentric navigation depends on several selected landmarks.

Though knowledge for the non-preferred strategy can be acquired (Boone et al., 2019; Furman et al., 2014), discrepancies between egocentric and allocentric knowledge have been observed as a function of other factors, such as gender, spatial abilities, and task-specific variables.

**Sex difference**

Males tend to outperform females in estimating target location with reference to other landmarks (indicative of allocentric knowledge) and re-tracing a learnt route (indicative of egocentric knowledge) (Nazareth et al., 2019). When given free choice, males and females perform equally accurate in estimating goal location, but males tend to be quicker and use shortcuts, while females tend to follow the learnt route (Boone et al., 2018; Nazareth et al., 2019).

These trends, however, are inconclusive to the summarise sex-specific spatial learning abilities and navigation preference, as task-specific variables can bias participants into adopting either egocentric or allocentric strategy. For example, smaller environment favours egocentric navigation, while larger environment favours allocentric navigation (Segula, 2017). Virtual Morris water maze (vMWM) also found larger male advantage in spatial learning compared to closed or open environments (Nazareth et al., 2019).

**Spatial abilities**

Spatial orientation (SO) refers to the ability to manipulate perspectives (Buckley et al., 2024). It is associated with the precision of maps constructed after exploring a virtual city (Keller & Sutton, 2022) and shortcutting performance (Meneghetti et al., 2021), suggesting its role in alternating 2D and 3D viewpoints, which supports the construction of configurational representation of the environment.

Visuospatial working memory (VSWM) refers to the capacity to store visual and spatial information simultaneously, and it is found to be better in males than females (Voyer et al., 2017). Less route tracing error, that is, following the trained route, is found among people with higher VSWM capacity, suggesting its role in remembering landmark sequence that supports egocentric navigation (Meneghetti et al., 2021).

**Part 2: Gap in literature**

Both spatial abilities may possibly support different types of spatial learning. Buckley et al. (2024) suggests that people are more likely to use route tracing rather than shortcutting after learning a complex route, whereas the opposite is true for simpler routes. Additionally, strong shortcutters do not necessarily excel in sequence or landmark following (Geisen et al., 2021). However, it remains unclear whether visual abilities influence navigation preferences or how gender factors into this relationship.

Keller & Sutton (2022) asked participants to explored a virtual city with a goal to construct the map, and found that eye fixation on landmarks did not differ between levels of SO. However, the explicit instruction of map construction may have encouraged more attention allocated towards the landmarks, masking one’s attention allocation pattern in normal navigation. Given the differences in spatial learning performance across gender and different spatial abilities, it is possible that gaze behaviour during navigation trials, which reflects the locus of attention, may differ between these variables. It is worth investigating whether gaze behaviour, particularly the cues selected to guide navigation, differ between navigation preferences in DSP and forced strategy trials.

Furthermore, previous studies have been conducted in different environments, such as environment scale, different maze types (vMWM or closed corridors maze) and cue type (intra-maze or extra-maze; proximal or distal) (see review: Nazareth et al., 2019). Spatial learning across these variables may differ, for example, corridors may still serve as navigation cues after the removal of prominent landmarks. Also, the navigation strategy selected may vary by the environment, affecting encoded representations, and thus, limiting the generalizability of performance outcomes and real-life navigation.

**Part 3: Research questions**

In DSP studies, females tend to adopt egocentric route following, while males tend to adopt allocentric shortcutting (Boone et al., 2018). In terms of spatial abilities, SO and VSWM has been suggested to respectively support allocentric and egocentric knowledge acquisition. Rather than gender, however, performance in spatial knowledge is determined by whether the task matches one’s navigation preference, which is vulnerable to task environment and instructions (Ferguson et al., 2019). This study will examine: (1) whether sex is associated with spatial abilities; (2) whether sex and spatial abilities, independently or interactively, influence participants’ navigation preference; and (3) whether sex and spatial abilities, independently or interactively, predict participants’ spatial knowledge (via forced strategy trials and series of egocentric and allocentric tasks)?

Provided that attentional locus and selected cues may determine one’s navigation strategy, this study will extend the mentioned hypotheses with eye tracking: (4) whether there are differences in gaze pattern and cues selected between navigation preferences in DSP and performance in navigation tasks targeting allocentric or egocentric knowledge; and (5) whether sex and spatial abilities, independently or interactively, influence gaze pattern.

This study will employ vMWM, which is a “gold standard” for human spatial research (Thornberry et al., 2021). Though it is less complex than real-life city layouts, it is efficient for participants to learn and allow good differentiation between allocentric and egocentric reference frames.

**Part 4: Research design and methods**

**Design**

This study would employ a within-subjects design. This study will be conducted in 2 phases: the first on flatscreen, the second on immersive VR. In the first phase, the independent variables are: sex and spatial abilities; the dependent variables are participants’ navigation preferences, allocentric task performance, and egocentric task performance. The second phase will employ the same variables as phase one, with the inclusion of gaze pattern, via eye tracking in immersive VR.

**Participants** Each phase require approximately 40 participants (estimated). They will be first- and second-year psychology students recruited via SONA pool, and will be rewarded with course credits.

**Materials**

**Spatial orientation test** (Hegarty et al., 2004) This test will examine participants’ spatial orientation and ability to manipulate perspectives.

**Corsi-block tapping test** This test determines participants’ VSWM capacity.

**vMWM** The vMWM will consist a circular pool of 50m diameter, where the participants navigate in, and extra-maze landmarks surrounding the maze from varying distance. The salience of landmarks will be controlled (Chan et al., 2012). Participants’ movement speed will be 140cm/s, matching the comfortable walking speed of young adults (Bohannon, 1997).

**Immersive VR headset** This will provide an immersive environment for participants to navigate in. Participants may move their heads or press the left/right/up/down button to change move their perspective in all directions.

**Procedure**

**Spatial abilities test** The mentioned SO and VSWM task will be administered on computer screen prior to the vMWM trials.

**Pre-training** Participants will familiarise themselves with manoeuvring with the keyboard keys and planks constraints in a virtual environment different from the vMWM.

**Training** After pre-training, participants are teleported to the vMWM environment. This is a dual-strategy maze with both allocentric and egocentric features (adopted from Thompson, 2019). Allocentric features include extra-maze landmarks. Egocentric features constraint participants to a specific path with several arms pointing towards different directions leading to the goal. Also, at each decision point (i.e., end of a path), new planks indicating other directions will appear, but participants cannot see if the path is leading to a dead-end. The planks in the pool will only appear when the participant step on it, and disappear once the participant move away. All trials start in a fixed position.

**Outcome tests** After training, participants will complete a series of tests to examine their allocentric and egocentric knowledge. The presentation of test sequence will be counterbalanced.

*Landmark recognition* Participants will judge whether the landmark presented is novel or presented during training. This task is incorporated as object recognition is a prerequisite to object-location binding, which supports subsequent configurational representation of the environment (Hilton et al., 2020).

*Judgement of relative direction (JRD)* Participants will point to an estimated position of a given landmark with reference to three available landmarks, which are present during training. Error in Euclidean distance and bearing will be recorded.

*Shortcutting* Participants are instructed to find a shortcut towards the goal. Participants are able to navigate freely without the constraints of planks. Navigation pattern, such as going straight towards the goal, or towards a particular cue first before turning straight towards the goal, will also be recorded (Piber et al., 2018).

Both JRD and shortcutting examine participants’ allocentric representation of the environment, but their discrepancies in within-subject measurements can detect if the participant is using a configurational map-like spatial representation (excel in both tests), or labelled graph knowledge that depend more on the landmarks’ characteristics (excel in shortcutting only) (He et al., 2023).

*Egocentric navigation* Participants will navigate in a maze where only egocentric features of the training maze are present.

In both shortcutting and egocentric navigation, participants will press “X” to indicate their estimated position of the goal. Total duration and total distance travelled, and error in Euclidean distance and bearing of the estimated position to the actual position will be recorded.

**Conflict test** (adopted from Segula, 2017). DSP maze is presented and participants will start in a different position to the training trials. Both egocentric and allocentric strategy will appear equally viable. Allocentric strategy, depending on the landmarks, will lead the participant to the real goal position, while egocentric strategy, depending on route-following, will demonstrate the same navigation pattern as in egocentric trial, leading to a “egocentric goal” position. This task categorises participants’ navigation preferences—egocentric or allocentric.

**Eye-tracking**Fixation duration and frequency on cues (landmarks or planks), and gaze chaining pattern, in terms of order of interest areas, throughout each arm and at decision points will be compared within subjects trial by trial. Systematic difference in gaze behaviour in training trials, outcome tests and conflict test will be examined between allocentric and egocentric navigators.

**Attention checks** Participants will read the corresponding instructions, then complete a multiple-choice question to confirm that they understand the task requirements before starting the next trial type (e.g., training, outcome tests),

**Statistical analyses**

**Regression analyses** Sex and both spatial abilities will be regressed against egocentric and allocentric navigators separately, to examine if there are any main effects and interaction effects on navigation preference. Similarly, sex and both spatial abilities are regressed against the test outcomes independently.

Gaze parameters mentioned above, and discrepancies in these parameters between final training trial and test trials, will be regressed against navigation preferences and each test outcomes.

**Part 5: Ethics**

Ethics application will be covered by supervisor. (Code: TBC)

**References**

Bohannon, R. W. (1997). Comfortable and maximum walking speed of adults aged 20-79 years: Reference values and determinants. *Age and Ageing*, 26(1), 14-19.

Boone, A. P., Gong, X., & Hegarty, M. (2018). Sex differences in navigation strategy and efficiency. *Memory & Cognition*, *46*(6), 909–922. <https://doi.org/10.3758/s13421-018-0811-y>

Boone, A. P., Maghen, B., & Hegarty, M. (2019). Instructions matter: Individual differences in navigation strategy and ability. *Memory & Cognition*, *47*(7), 1401–1414. <https://doi.org/10.3758/s13421-019-00941-5>

Buckley, M. G., Austen, J. M., & McGregor, A. (2024). The role of distal landmarks and individual differences in acquiring spatial representations that support flexible and automatic wayfinding. *Journal of Environmental Psychology*, *98*, 102391-. <https://doi.org/10.1016/j.jenvp.2024.102391>

Chan, E., Baumann, O., Bellgrove, M. A., & Mattingley, J. B. (2012). From objects to landmarks: the function of visual location information in spatial navigation. *Frontiers in Psychology*, *3*, 304–304. <https://doi.org/10.3389/fpsyg.2012.00304>

de Condappa, O., & Wiener, J. M. (2016). Human place and response learning: navigation strategy selection, pupil size and gaze behavior. *Psychological Research*, *80*(1), 82–93. <https://doi.org/10.1007/s00426-014-0642-9>

Ferguson, T. D., Livingstone-Lee, S. A., & Skelton, R. W. (2019). Incidental learning of allocentric and egocentric strategies by both men and women in a dual-strategy virtual Morris Water Maze. *Behavioural Brain Research*, *364*, 281–295. <https://doi.org/10.1016/j.bbr.2019.02.032>

Furman, A. J., Clements-Stephens, A. M., Marchette, S. A., & Shelton, A. L. (2014). Persistent and stable biases in spatial learning mechanisms predict navigational style. *Cognitive, Affective, & Behavioral Neuroscience*, *14*(4), 1375–1391. <https://doi.org/10.3758/s13415-014-0279-6>

Geisen, M., Kim, K., Klatt, S., & Bock, O. (2021). Effects of practice on visuo-spatial attention in a wayfinding task. *Psychological Research*, *85*(8), 2900–2910. <https://doi.org/10.1007/s00426-020-01463-5>

He, C., Boone, A. P., & Hegarty, M. (2023). Measuring configural spatial knowledge: Individual differences in correlations between pointing and shortcutting. *Psychonomic Bulletin & Review*, *30*(5), 1802–1813. <https://doi.org/10.3758/s13423-023-02266-6>

Hegarty, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-

taking spatial abilities. *Intelligence*, *32*, 175-191

Hilton, C., Muffato, V., Slattery, T. J., Miellet, S., & Wiener, J. (2020). Differences in Encoding Strategy as a Potential Explanation for Age-Related Decline in Place Recognition Ability. *Frontiers in Psychology*, *11*, 2182–2182. <https://doi.org/10.3389/fpsyg.2020.02182>

Keller, M., & Sutton, J. E. (2022). Individual Differences in the Allocation of Visual Attention During Navigation. *Canadian Journal of Experimental Psychology*, *76*(1), 10–21. <https://doi.org/10.1037/cep0000247>

Marchette, S. A., Bakker, A., & Shelton, A. L. (2011). Cognitive mappers to creatures of habit: differential engagement of place and response learning mechanisms predicts human navigational behavior. *The Journal of Neuroscience*, *31*(43), 15264–15268. <https://doi.org/10.1523/JNEUROSCI.3634-11.2011>

Meneghetti, C., Labate, E., Toffalini, E., & Pazzaglia, F. (2021). Successful navigation: the influence of task goals and working memory. *Psychological Research*, *85*(2), 634–648. <https://doi.org/10.1007/s00426-019-01270-7>

Meneghetti, C., Miola, L., Toffalini, E., Pastore, M., & Pazzaglia, F. (2021). Learning from navigation, and tasks assessing its accuracy: The role of visuospatial abilities and wayfinding inclinations. *Journal of Environmental Psychology*, *75*, 101614-. <https://doi.org/10.1016/j.jenvp.2021.101614>

Nazareth, A., Huang, X., Voyer, D., & Newcombe, N. (2019). A meta-analysis of sex differences in human navigation skills. *Psychonomic Bulletin & Review*, *26*(5), 1503–1528. <https://doi.org/10.3758/s13423-019-01633-6>

Negen, J., Bird, L.-A., & Nardini, M. (2021). An Adaptive Cue Selection Model of Allocentric Spatial Reorientation. *Journal of Experimental Psychology. Human Perception and Performance*, *47*(10), 1409–1429. <https://doi.org/10.1037/xhp0000950>

Piber, D., Nowacki, J., Mueller, S. C., Wingenfeld, K., & Otte, C. (2018). Sex effects on spatial learning but not on spatial memory retrieval in healthy young adults. *Behavioural Brain Research*, *336*, 44–50. <https://doi.org/10.1016/j.bbr.2017.08.034>

Segula, B. (2017). *Testing the acquisition and use of navigation strategies in humans using a virtual environment (Unpublished master’s thesis).* University of Sydney, Sydney, Australia.

Thompson, K. (2019). *Know Your Competition*: *Overshadowing between Allocentric and Egocentric Spatial Navigation Strategies* *(Unpublished honours thesis).* University of Sydney, Sydney, Australia.

Thornberry, C., Cimadevilla, J. M., & Commins, S. (2021). Virtual Morris water maze: opportunities and challenges. *Reviews in the Neurosciences*, *32*(8), 887–903. <https://doi.org/10.1515/revneuro-2020-0149>

Voyer, D., Voyer, S. D., & Saint-Aubin, J. (2017). Sex differences in visual-spatial working memory: A meta-analysis. *Psychonomic Bulletin & Review*, *24*(2), 307–334. <https://doi.org/10.3758/s13423-016-1085-7>