Exploring the Role of Sex, Spatial Abilities, and Gaze Behaviour in Navigation Preferences

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 (self-to-object reference frame), or allocentric strategy (configural relationship of landmarks), as revealed by the dual-solution paradigm (DSP), where both strategies can solve the task (Ferguson et al., 2019; Furman et al., 2014; Marchette et al., 2011). These preferences is determined by the initial encoding of the environment, though strategy applied in individual trials may shift depending on trial-specific factors, for example, availability of proximal and distal cues (Furman et al., 2014). This highlights the need to investigate 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). With practice, attentional focus selectively on the most relevant cues that guide navigation (Geisen et al., 2021). For instance, at decision points (e.g., intersections) on familiar routes, gaze tend to shift to the cues on the intended direction, while in unfamiliar routes, gaze tend to focus on the previously encoded cues, regardless of turning direction (de Condappa & Wiener, 2016; Geisen et al., 2021). In a simple goal-search paradigm without route learning, allocentric knowledge depended the most predictive cue (i.e., the nearest) (Negen et al., 2021), implying that allocentric navigation in longer distances may depend on multiple selected landmarks. As gaze-chaining patterns may relate to one’s navigation preference, this study aims to investigate the association between gaze behaviour across trials and navigation strategy.

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 linked to factors like gender, spatial abilities, and task-specific variables.

**Sex difference**

Previous studies found that 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 for summarizing sex-specific spatial learning abilities and navigation preference, as task-specific variables can bias strategy choice. 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 spatial abilities influence navigation preferences or how gender factors into this relationship.

Given gender and spatial ability differences in spatial learning, gaze behaviour—reflecting attention locus—may also vary across these factors. Keller & Sutton (2022) found no difference in landmark fixations across SO levels during a map-construction task, though the explicit goal may have influenced attention allocation. It remains unclear whether gaze patterns differ under more natural navigation conditions. Investigating gaze behaviour, especially cue selection in DSP and forced strategy trials, may offer deeper insights into spatial learning processes.

Furthermore, previous studies have used varied environments—differing in scale, maze type (vMWM or closed corridors maze) and cue type (intra-maze or extra-maze; proximal or distal) (see review: Nazareth et al., 2019). These differences can influence spatial learning, for instance, corridors may still serve as navigation cues after removing prominent landmarks. Also, the navigation strategy selected may vary with the environment, shaping encoded representations, and limiting the generalizability of findings into 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 suggested to be determined by whether the task matches one’s navigation preference, which largely depends on the task environment and instructions (Ferguson et al., 2019). This study examines: (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 extends above hypotheses with eye tracking to examine: (4) whether gaze-chaining pattern, cue selection (number of cues selected and average distance from the prior fixated cue) and the magnitude of practice effect throughout training trials vary across sex, spatial abilities and navigation preferences; and (5) whether these gaze parameters predict allocentric and egocentric knowledge.

This study employs 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.

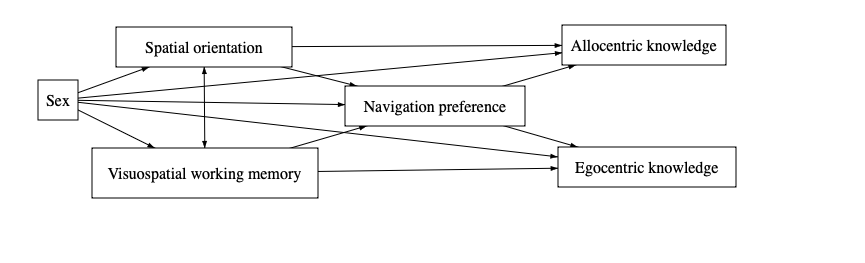
**Part 4: Research design and methods**

**Design**

This study is conducted in 2 phases: flatscreen (Phase 1), and immersive virtual-reality (VR) (Phase 2). In the Phase 1, the independent variables are: sex, VSWM and SO; the dependent variables are navigation preferences, allocentric, and egocentric task performance. Phase 2 uses the same variables as phase one, adding gaze pattern via eye-tracking in VR. The study examines consistency in task performances and gaze parameters across navigation preferences and other independent variables, followed by analysis of their interactions.

**Figure 1**

*Analysis Plan of Variables (created with Mai et al., 2023)*

*Note*. Allocentric and egocentric knowledge are test outcomes. Each test outcome is analysed independently.

Correlation analysis will be conducted to examine whether both spatial abilities (SO & VSWM) correlate. Regression analyses will be conducted to examine (1) whether sex predicts participants’ spatial abilities, (2) whether SO and VSWM independently and interactively predict navigation preference—allocentric or egocentric, (3) whether SO and VSWM independently and interactively predict level of allocentric and egocentric knowledge, (4) whether navigation preference predicts participants’ level of allocentric and egocentric knowledge. Path analyses will be conducted to examine how sex and spatial abilities interact and influence navigation preferences and level of allocentric and egocentric knowledge.

Within-subject comparisons examine participants’ navigation preference and test outcomes, while between-subject comparisons examine pattern in test outcomes across spatial abilities, sex and navigation preference (*Figure 1*).

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

**Materials**

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

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

**vMWM** The vMWM consists a circular pool with a diameter of 50 virtual metres, where the participants navigate in. Extra-maze landmarks, with controlled salience, surround the maze from varying distance (Chan et al., 2012). Participants’ movement speed is 140cm/s, matching the comfortable walking speed of young adults (Bohannon, 1997).

**Immersive VR headset** This provides an immersive environment for navigation. Participants may move their heads or use directional buttons to shift their perspectives freely.

**Outcome tests**

*Configuration recognition (configID)* Participants judge whether the landmark configuration presented is the same as the one during training. Landmarks are swapped with other landmarks either from opposite direction or adjacent to them (Negen et al., 2020). This task is incorporated to examine participants’ extent of object-location binding, which supports subsequent configurational representation of the environment (Hilton et al., 2020).

*Route recognition (routeID)* Participants are shown several pictures of a route on the vMWM without any landmarks in random sequence. They are asked to select the one which they navigated during the training trials. Other pictures of alternative routes are wrong.

*Judgement of relative direction (JRD)* Participants 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 are recorded.

*Shortcutting* The pool is filled of visible grids which participants can manoeuvre on. The original path they are trained to reach the goal is blocked, and they are asked to take the shortest path towards the goal (Boone et al., 2018) (*Figure 2*).

*Free-swim* Participants may navigate freely without the constraints of planks. They are instructed to swim towards the goal. Navigation patterns are also recorded (Piber et al., 2018) (*Figure 3*).

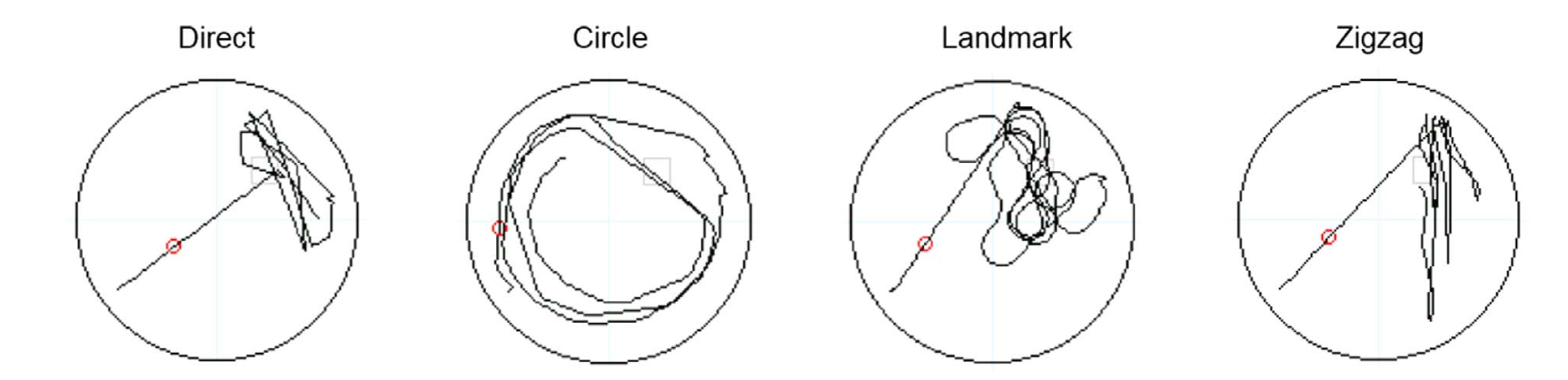
**Figure 2**

*Examples of Categories in Shortcutting from Boone et al. (2018)*

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| --- | --- | --- |
|  |  |  |

*Note*. Participants were allowed to navigate freely without explicit instruction to find a shortcut, nor roadblocks on the original learnt path. “(a) shortcut, (b) shortcut liberal, (c) learned, (d) learned liberal, (e) reversed learned, (f) wandering.”

**Figure 3**

*Example Free-swim Navigation Patterns from Piber et al. (2018)*

*Note.* Red circle on the lower-left quadrant represents the starting location. Grey square on the upper-right quadrant represents the goal location, which was invisible during the trials.

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

RouteID and egocentric navigation examine participants’ egocentric representation. JRD, free-swim, and shortcutting examine participants’ allocentric representation of the environment, but discrepancies in within-subject measurements can detect if the participant uses a configurational map-like spatial representation (excel in shortcutting and JRD), or labelled graph knowledge that depend more on the landmarks’ characteristics (excel in shortcutting only) (He et al., 2023). Free-swim pattern and the screen bearing throughout their navigation are compared to the bearing of the goal and training start position. This may inform the navigation strategy applied.

In shortcutting, free-swim and egocentric navigation, participants 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 are recorded.

**Procedure**

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

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

**Training** After pre-training, participants complete 15 training trials in the vMWM environment, which 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 only appear when the participant step on it, and disappear once the participant move away. All trials start in a fixed position.

**Outcome tests** As allocentric knowledge are acquired more readily than egocentric knowledge when both cues are present, ConfigID tests are presented after 5 training trials, and routeID tests are presented after 10 training trials (Thompson, 2019). After completing 15 training trials and the conflict test, they complete a series of outcome tests: configID and routeID that are different from the ones presented beforehand, shortcutting, free-swim, and egocentric navigation. These tests are presented in random and counterbalanced order between participants.

**Conflict test** (adopted from Segula, 2017). DSP maze is presented to categorise participants’ navigation preferences. Participants start in a different position to the training trials. Both egocentric and allocentric strategy appear equally viable (*Figure 2*).

**Eye-tracking**(only in VR, Phase 2) For each subject, fixation duration on each cue (landmarks or planks) is measured and form the gaze-chaining pattern, marking the order of interest areas, for each arm and decision points.

**Attention checks** Participants will read task instructions and complete a multiple-choice question to confirm their understanding before proceeding to the next trial type.

**Statistical analyses**

In both phases, all test outcomes are compared across sex, spatial abilities and navigation preferences with t-test. Main and interaction effects between variables are examined as in *Figure 1*.

In Phase 2, the average change in number of cues selected and fixation duration on each cue are measured. Practice effects in gaze behaviour, reflected by the slope of decreasing cues selected across trials—are also measured. These gaze parameters are compared across groups using t-tests. Regression analyses examine whether they predict test outcomes.

All test outcomes are compared across sex, spatial abilities and navigation preferences with t-test. Main and interaction effects between variables are examined as in *Figure 1*.

**Part 5: Ethics**

Ethics application will be covered by supervisor.

**Figure 4**

*A blue circle with white hexagons and different colored arrows

AI-generated content may be incorrect.Schematic survey view of conflict test environment* (Segula, 2017).

*Note*. Number of landmarks and landmark positions may differ in this study. Allo target represents the location that participants using an optimal allocentric strategy will reach. Ego target represents the location that participants using an optimal egocentric strategy will reach.

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Tests between training: allo obtained faster (maybe 5), ego at 15

* Allo test go earlier—e.g., recog scene (object location binding)
  + Near swap, vs across-direction swap
* Ego test at maybe 10
  + Show them a picture schematic of route, which is correct

Head bearing position x location (turn right, but face towards goal, OR face towards starting location?)