THREE TYPES OF ENVIRONMENTAL REPRESENTATIONS AND INDIVIDUAL DIFFERENCES IN SPATIAL NAVIGATION

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DECLARATION

I hereby declare that the thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.

ZHONG Yu Jimmy
14th October 2013

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Three Types of Environmental Representations and Individual Differences in Spatial Navigation

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Abstract

This study proposed the existence of two distinct types of environmental representations: “allocentric-survey” and “egocentric-survey”. The *allocentric-survey* representation is a third-person (top-down perspective) representation formed as a result of acquiring knowledge of landmarks, routes, and spatial relations between them. In contrast, the *egocentric–survey* representation is a first-person perspective survey representation formed through an engagement of *spatial updating*, which pertains to the automatic and continuous updating of transient self-to-object relations as one navigates in space. The results of study 1 suggest that egocentric-survey representations are qualitatively different from allocentric-survey representations since the former preserves information not only about spatial locations, but also about orientation. While both groups were relatively accurate in representing the spatial layout of the route, sketchers of egocentric-survey maps were significantly faster on orientation and navigational pointing judgments than sketchers of allocentric-survey maps. In Study 2, a *Navigational Strategy Questionnaire* was designed. It included a novel scale assessing a preference for spatial updating navigational strategy and two traditional scales assessing survey-based and procedural navigational strategies. Critically, the spatial updating scale exhibited predictive validity in relation to large-scale navigational performance and related spatial updating strategy use to the formation of egocentric-survey representations.

Keywords: Spatial updating, survey-based representations, egocentric and allocentric frames of reference, large-scale navigation

INTRODUCTION

The classical model that describes the development of spatial knowledge is the sequential/stage model, *Landmark, Route, Survey (LRS)*, first proposed by Siegal and White (1975) and subsequently elaborated by Thorndyke and Goldin (1983). In this model, the representational knowledge of a new environment is proposed to progress sequentially from a foundational level of landmark knowledge to an intermediate level of route/procedural knowledge and finally to an advanced level of survey knowledge. *Landmark knowledge* is the first to develop during an initial period of familiarization; it includes mental images of discrete objects and scenes which are salient and recognizable in the environment. *Route/procedural knowledge* links together important, salient landmarks in a sequence and associates specific actions with them (e.g., “turn left in front of the library and walk straight past the benches”). It constitutes a type of non-spatial representation with three main aspects: i) the information of travel is accessed sequentially as an ordered list of different locations; ii) the number of alternative paths branching out from one path is small; and iii) a first-person perspective is adopted to decide on where to go from a given location (Siegal & White, 1975; see also Werner, Krieg-Brückner, Mallot, Schweizer, & Freksa, 1997). With adequate familiarization or route exposure, representational knowledge acquired from traveling on different route segments gets integrated into *survey knowledge* (also termed as *configurational knowledge*) that pertains to a map-like network of objects/landmarks, termed as a *survey-based representation*. A survey-based representation is characterized by: i) spatial extent over a common coordinate or reference system; ii) abstract or symbolic mental representations of physical or geographical entities in the real world; and iii) metrically scaled information about distance and direction between environmental features (i.e., landmarks, routes, and districts) (Siegal & White, 1975; see also Berendt, Barkowsky, Ereksa, & Kelter, 1998). The survey-based representation, unlike route knowledge that is acquired though the sequential merging of segmented paths, is formed by the spatial integration of landmark configurations, and gives fast and route-independent access of locations.

Despite being a highly influential for decades, Siegal and White’s (1975) LRS model has not received convincing empirical support. A number of studies had shown that the route knowledge acquired early on after direct exposure to a new environment did not always become survey knowledge despite repeated exposures (e.g., Chase, 1983; Gärling, Böök, Lindberg, & Nilsson, 1981; Ishikawa & Montello, 2006; Herman, Blomquist, & Klein, 1987). For instance, Ishikawa & Montello (2006) showed that many participants consistently demonstrated poor estimations of directions, route and Euclidean distances after repeated exposure to two routes over ten weeks to a previously unfamiliar neighborhood in Santa Barbara, implicating a failure to acquire survey knowledge. At the same time, there were also several participants who consistently demonstrated highly accurate performance on direction and distance estimations, and drawing of sketch maps from the very first session. In addition, another problem with the Siegal and White's (1975) LRS model is that it cannot explain an accumulating amount of evidence suggesting that survey-based representations can be of two different types, represented by either a "field perspective" or an "observer perspective" (Blajenkova, Motes, & Kozhevnikov, 2005; Nigro & Neisser, 1983; Werner et al., 1997). While both survey-based representations may refer to the same spatial layout in the environment, the "field perspective" corresponds to a *first-person (egocentric)* perspective that is closely linked to one's visuo-perceptual experience (Herrmann, 1996) whereas the "observer perspective" corresponds to a *third-person (allocentric)* perspective that is closely linked to a bird's eye (top-down) view of a spatial layout (Cohen, 1989). The first-person perspective is defined by remembering a scene from one's own position by visualizing a body-centered field of view that was available in the original situation (Herrmann, 1996; Nigro & Neisser, 1983). In contrast, the third-person perspective is defined by remembering a scene from the position of an observer by visualizing a field of view from an external, disembodied vantage point (Nigro & Neisser, 1983).

In a previous study that suggested different types of survey representations, Blajenkova et al., (2005) asked each of their participants to draw a sketchmap after a one-time exposure to an unfamiliar route, and classified those sketchmaps into three categories: i) one-dimensional (1D) sketchmaps that represented landmarks and route knowledge; ii) two-dimensional (2D) sketchmaps that represented the configuration of the route from a top-down third-person perspective; and three-dimensional (3D) sketchmaps that represented route segments and topographical features from two levels of the building aligned along the vertical dimension. Although the 3D sketchmaps were similar to the 1D sketchmaps with respect to the adoption of the first-person perspective, only the 3D sketchmaps depicted the spatial relations of route segments and placements of landmarks accurately, suggesting the existence of first-person (egocentric) survey-based type of representations. These results implicated that a simple distinction between the route and survey knowledge is insufficient to describe or explain a variety of different environmental representations used to represent spatial layouts.

Furthermore, the stepwise development of route to survey knowledge proposed by the LRS model by first forming associations between landmarks or locations and then integrating them into a cognitive map that preserves the geometry of the landmark configurations might not be the only way that could lead to the formation of a survey representation. Numerous studies over the past two decades have offered strong evidence for the existence of a special mode of navigation called *spatial updating* (e.g., Farrell & Thomson, 1998; Klatzky et al., 1990; Klatzky, Loomis, Beall, Chance, & Golledge, 1998; Loomis et al., 1993; Loomis, Klatzky, Philbeck, & Golledge, 1998; Wang & Spelke, 2000). Consistent with behavioral findings from the spatial cognition literature, we define spatial updating as an egocentric mode of navigation[1] during which a navigator continuously track and update transient self-to-object (egocentric) representations of surrounding objects/landmarks or locations while traversing a path, even under conditions where there are no constant availability of external visual and/or auditory cues (Loomis et al., 1998; Wang & Brockmole, 2003; Wang & Spelke, 2000). In its basic form, spatial updating is known as path integration (also called *dead reckoning,* see Loomis et al., 1999)—a process of navigation during which a traveler performs a moment-to-moment updating of the location of a starting point (origin) relative to his/her current position and orientation (Loomis et al., 1999). Animals that

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[1] It is also vital to note that an allocentric model of spatial updating has also been postulated (e.g., see O'Keefe & Nadel, 1978; Sholl, 1987)—such that object locations are encoded in an external reference frame and that one conducts position-updating relative to stable locations or landmarks in a fixed configuration. However, this research will refer exclusively to egocentric models of spatial updating, as postulated by the existing spatial cognition literature (e.g., see Wang & Spelke, 2000, 2002).

utilize path integration for finding their way back to their nests include gerbils (Mittelstaedt & Mittelstaedt, 1980), desert ants (Müller & Wehner, 1988; Wehner & Wehner, 1986), and golden hamsters (Etienne, 1980; Etienne, Maurer, Saucy, & Teroni, 1986). In its more advanced form, used by humans, spatial updating involves the tracking of multiple landmarks in the environment and estimating their new spatial relations to the navigator as he/she moves along a route (e.g., see Loomis et al., 1998; Philbeck, Klatzky, Behrmann, Loomis, & Goodridge, 2001; Rieser, 1999). In contrast to the common mode of navigation of route-based learning that involves learning about the spatial relations between objects/landmarks largely through visual information about their locations and distances from each other, during spatial updating, the navigator relies on internal (idiothetic) signals (i.e., proprioception and vestibular feedback) and external (allothetic) signals (i.e., acoustic and optic flow) to provide a “current estimate of position and orientation within a larger spatial framework" (Loomis et al., 1999, p. 129).

An important aspect of spatial updating is that it occurs within an *egocentric representation system* that updates transient self-to-object relations (Mou, McNamara, Valiquette, & Rump, 2004). An egocentric frame of reference (akin to a first-person perspective) specifies the spatial relations between objects/landmarks in the environment and intrinsic axes of the observer’s body in the form of self-to-object (egocentric) relations (Klatzky, 1998). On the other hand, during route-based learning, an allocentric reference frame specifies the relations between objects/landmarks independently of the self in an extrinsically defined coordinate system (Klatzky, 1998). Using this type of reference frame, the navigator registers information about the interobject (allocentric) relations amongst objects, landmarks, and places (Rieser, 1989; Easton & Sholl, 1995).

The first goal of this research was to provide experimental evidence for the existence of two qualitatively different types of survey-based representations, either assuming a first-person or third-person perspective. We suggest that first-person survey-based representations (termed hereafter as *egocentric-survey* representations) are formed as a result of egocentric spatial updating and encoded in an *orientation-specific* manner. We define this orientation-specific encoding of egocentric-survey representations as an encoding of spatial information from multiple, specific orientations (or viewpoints) which are physically experienced during navigation. Based on such orientation-specific representations, spatial information would be optimally retrieved from imagined orientations which are aligned with initially experienced orientations (Diwadkar & McNamara, 1997; Roskos-Ewoldsen, McNamara, Carr, & Shelton, 1998; Shelton & McNamara, 1997).

In contrast, we suggest that third-person survey-based representations (termed hereafter as *allocentric-survey* representations) are formed as a result of route-based learning occurring within an environmental or allocentric framework and encoded in an *orientation-free* manner. We define this orientation-free encoding of allocentric-survey representation as an encoding of spatial information from no specific or preferred orientation during navigation. Based on such orientation-free representations, spatial information would be retrieved from imagined orientations which are not specifically aligned with initially experienced orientations (Presson, DeLange, & Hazelrigg, 1989; Presson & Hazelrigg, 1984). We expect both types of survey-based representations to preserve spatial relations between environmental features accurately, which is characteristic of survey knowledge. However, the egocentric-survey representation would contain configurational knowledge of landmarks based on egocentric and orientation-specific views, whereas the allocentric-survey representation would contain configurational knowledge of landmarks based on allocentric and orientation-free views.

As for the second goal of this research, we aimed to examine individual differences in spatial updating and relate each type of navigational strategy—route/procedural, survey-based, and spatial updating—to the formation of a particular type of environmental representation—route/procedural, allocentric-survey, and egocentric-survey. Therefore, in Study 2 we designed a new self-report questionnaire the *Navigational Strategy Questionnaire (NSQ)*—for the assessment of three distinct types of navigational strategies. Specifically, the NSQ introduced a novel scale to assess the use of *spatial updating strategy*, along with two more traditional scales assessing *procedural* (*route-based*) and *survey-based* navigational strategies. Although spatial updating mechanisms have been known for the last few decades, no study so far has investigated individual differences in egocentric spatial updating. Most of the previous research on individual differences in spatial navigation has been limited to the investigations of how individuals differ in terms of route-based (procedural) navigation—which specifies a perception and encoding of landmark information in a direction-specific and non-spatial fashion (Werner, Krieg-Brückner, & Herrmann, 2000)—and survey-based (metric) navigation—which utilizes information about the metric elements of vectors, directions/bearings, and distances existing between landmarks for finding one’s way (Coluccia, Bosco, & Brandimonte, 2007; Cutmore, Hine, Maberly, Langford, & Hawgood, 2000; Garden, Cornoldi, & Logie, 2002).

Furthermore, existing self-report questionnaires developed to assess individual differences in spatial navigation have also focused on an assessment of route- and survey-based navigation (e.g., Hegarty, Richardson, Montello, Lovelace, & Sabbiah, 2002; Kato & Takeuchi, 2003; Lawton, 1994; Lawton & Kallai, 2002; Pazzaglia, Cornoldi, & De Beni, 2000; Pazzaglia & De Beni, 2001; Takeuchi, 1992). Although there are several questionnaires (see Hegarty et al., 2002; Lawton, 1994; Lawton, 1996; Lawton & Kallai, 2002; Pazzaglia et al., 2000; Pazzaglia & De Beni, 2001) which have items assessing spatial updating (e.g., items assessing a sense-of-direction and tracking of self-to-object relations), none of them regard such items as constituting an independent scale addressing a distinct navigational strategy of spatial updating.

Hypotheses and Predictions

This research includes two studies which examined individual differences in environmental representations and navigational strategies respectively. In study 1, participants were taken on a traversal of a previously unfamiliar route, at the end of which they were instructed to draw out sketchmaps and perform a series of navigational and visual-spatial assessments. We categorized their sketchmaps into three types: i) *procedural route*; ii) *allocentric-survey*; and iii) *egocentric-survey*. In order to show that the allocentric and egocentric survey maps represent two qualitatively different types of representations which are orientation specific and orientation-free respectively, we analyzed performance differences between the three groups of map sketchers on a number of navigational and spatial ability assessments. Specifically, we predicted that:

i) On a route pointing direction task (R-PDT), egocentric-survey map sketchers would outperform the allocentric-survey map sketchers. The R-PDT specifically assesses how well one performs an active tracking of self-to-object relations during route traversal. Successful performance on this task primarily depends on accurate retrieval of self-to-object relations rather than on knowledge of allocentric spatial layout. Similarly, on an imaginal pointing direction task (I-PDT) that assessed directional judgments from imagined orientations, we predict that egocentric-survey map sketchers would have faster response times than allocentric-survey map sketchers. Specifically, for egocentric-survey map sketchers, we suggest that spatial updating during route traversal would lead to the acquisition of multiple orientation-specific images specified on the basis of egocentric experience. In contrast, for allocentric-survey map sketchers, we suggest that route-based learning would lead to an orientation-free encoding of interobject relations from a third-person perspective. Based on our proposals that the egocentric-survey map sketchers would directly retrieve self-to-object (egocentric) relations from a first-person perspective and that the allocentric-survey map sketchers would infer object-to-object (allocentric) relations from a third-person perspective, we expect the former group to respond faster than the latter group on the I-PDT. On the other hand, in terms of accuracy, we do not predict the two groups of survey map sketchers to differ from each other, since we expect both groups to encode the spatial layout of the environment accurately.

ii) On a landmark recognition task (LRT) that assessed the visual memory of landmarks, egocentric-survey map sketchers would outperform allocentric-survey map sketchers. The multiple egocentric views of landmarks captured by the former group while updating their self-positions en route should facilitate their recognition of scenes of landmarks.

iii) Egocentric-survey map sketchers would outperform allocentric sketchers on an assessment of *egocentric spatial ability*. This ability enables one to imagine different orientations (perspectives) through movements of the egocentric frame of reference, which encodes object

> locations with respect to the front/back, left/right, and up/down axes of the observer's body (Kozhevnikov & Hegarty, 2001). On the other hand, allocentric-survey map sketchers would outperform egocentric-survey map sketchers on an assessment of *allocentric spatial ability*, which requires a person to imagine movements of an object or an array of objects relative to an object-based (allocentric) frame of reference that specifies the location of one object (or its parts) relative to other objects (Kozhevnikov & Hegarty, 2001). Specifically, we predicted that egocentric-survey map sketchers would be more successful than allocentric-survey map sketchers on a perspective-taking ability test (PTA) that assesses egocentric spatial ability, and that allocentric-survey map sketchers would perform more accurately than egocentric-survey map sketchers on a mental rotation test (MRT) that assesses allocentric spatial ability.

In study 2, in order explore the hypothesis that egocentric-survey representations were formed as a result of egocentric spatial updating, we designed a new self-report navigation questionnaire—the NSQ— composed of three separate scales assessing spatial updating, survey-based and procedural strategies. To show that individual differences in egocentric spatial updating exist, and to support our hypothesis that a spatial updating strategy is indeed largely utilized by egocentric-survey map sketchers, we predicted that on the spatial updating scale, the egocentric-survey map sketchers would report significantly higher scores than the two other groups of map sketchers. Furthermore, we aimed to demonstrate that each scale possessed satisfactory internal and test-retest reliabilities. In order to provide evidence for the predictive validity of our new spatial updating scale, we aimed to demonstrate that its scale scores would uniquely predict performance on navigational pointing tasks (i.e., R-PDT and I-PDT) that engage spatial updating processes in a large-scale urban environment. Besides that, we also aimed to demonstrate that the scale scores of survey-based strategy would significantly predict performance on an assessment of allocentric spatial ability (i.e., MRT). In addition, to relate study 1 predictions to considerations of individual differences in navigational strategy use, we hypothesized that each group of map sketchers would show a preference for one navigational strategy amongst themselves. Specifically, we predicted that: i) egocentric-survey map sketchers would report a higher use of the spatial updating strategy than the two other strategies in the formation of egocentric-survey representations; ii) allocentric-survey map sketchers would report a higher use of the survey-based strategy than the two other strategies in the formation of allocentric-survey representations; and iii) procedural route map sketchers would report a higher use of the procedural strategy than the two other strategies in the formation of procedural route representations.

STUDY 1

METHODS

Participants. Seventy-one participant (33 females) ranging from 19 to 45 years of age (*M* = 22.31, *SD* = 3.87) participated in the study. Forty-one participants were recruited from the psychology research participant pool at National University of Singapore (NUS) whereas 30 participants were recruited through online advertisement of the study. All the participants were recruited based on the prerequisite of being unfamiliar with the School of Design and Environment that specified having no former experience of frequent travel within its premises. They were given either course credits or monetary reimbursement for their participation.

Route traversal. The participants were led by the experimenter individually or in pairs on a route. The route is approximately 600m and spanned across three buildings: SDE1, SDE2, and SDE3, inclusive of levels three and four of both SDE1 and SDE3 (see Figure 1). Participants were instructed that they had to remember the route using whatever strategy or method they deemed appropriate, that landmarks would be pointed out to them to remember along the way, and that they would have to point to those landmarks and sketch a map of the whole route at its end.

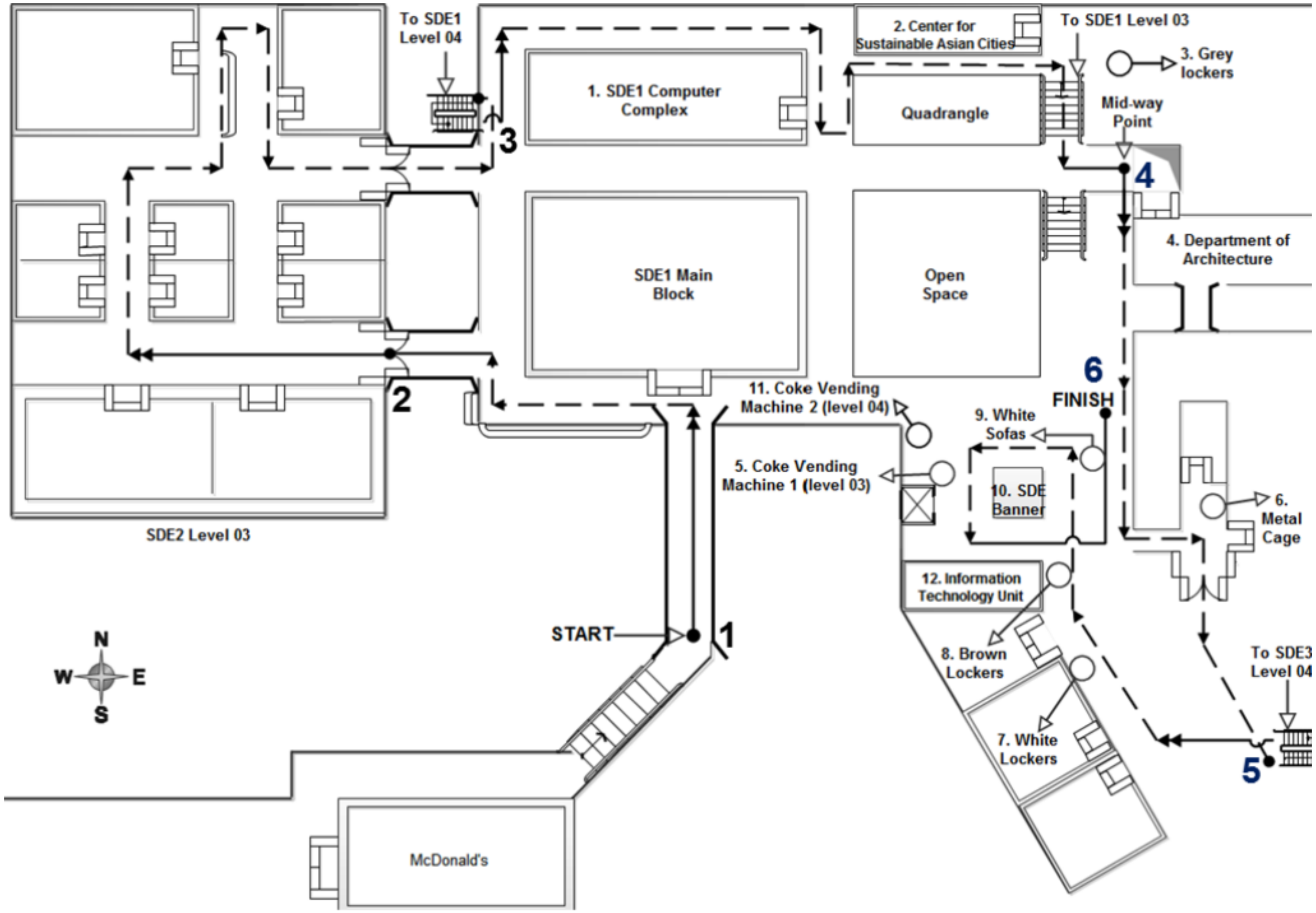


Figure 1. Floor plan of the route at School of Design and Environment (SDE) at National University of Singapore (NUS). Black dots represent the start of each of five route segments. The larger numbers (points 1 to 5) represent the starting positions of each of five route segments and point number 6 represents the finishing point. Double arrow heads represent the direction along the first leg of each segment. The smaller numbers from 1 to 12 indicate the 12 landmarks which were pointed out to each participant in sequence while walking the route. White circles indicate the approximate locations of those landmarks.

As shown in Figure 1, the route can be partitioned into five route segments, each represented by the path between a pair of consecutive points (e.g., the first segment is the path from point 1 to 2). We partitioned the route into these segments in order to facilitate our subsequent examination of sketchmaps. This was done to allow comparisons of the shapes of those segments in the formal plan with those of the segments depicted on participants' sketchmaps to ascertain the accuracy of the sketched segments and the entire spatial layout of the route. With reference to Figure 1, the first segment stretched from the starting point (point 1), across a bridge crossing (the first leg, pointing northwards), to the entrance to the third floor of SDE2 (point 2). The second segment stretched from that entrance along the indoor pathways of SDE2 (third floor) to the stairs leading to the fourth floor of SDE1. The third segment stretched from the stairway exit on the fourth floor of SDE1 (point 3) to the Department of Architecture on the third floor of SDE1 (point 4). The fourth segment stretched from the Department of Architecture to the stairs leading to the fourth floor of SDE3. While traveling along the third and fourth route segments, the starting point and the first two route segments were blocked from view by dense vegetation and the main block of SDE1. This ensured that the attainment of survey knowledge would not be eased by having a clear view of the previous paths of travel. The final segment stretched from the stairway exit on the fourth floor of SDE3 (point 5) to the finishing point (point 6) that was located in front of a set of sofas. A bench that faced a wall was located directly at the finishing point. It was located proximal to the starting point and the entire route could be conceived as a circuit. The starting point could not be seen from the ending point; this again ensured that an attainment of survey knowledge would not be eased by knowing the spatial relationship between the starting and ending points. Overall, the route was planned with a purpose of making participants travel on both the third and fourth floors of both SDE1 and SDE3. This was essential to test whether they were capable of representing these multilevel floor segments in their mental maps and sketch out maps which were similar to those discovered by Blajenkova et al. (2005).

In order to ensure that participants encoded salient landmarks along the way for the subsequent pointing tasks that required memory of them (i.e., R-

PDT & I-PDT), the experimenter pointed out 12 landmarks to participants and instructed them to remember both their names and location as to the best of their abilities. Figure 1 showed the locations of those landmarks and the sequence in which they were pointed out en route. The first three landmarks were located on SDE1 fourth story, the fourth landmark was located on SDE1 third story, the fifth and sixth landmarks were located on SDE3 third story, and the remaining six landmarks were located on SDE3 fourth story. The entrance to the Department of Architecture was selected as the mid-way point where participants were made to stop and inspect their surroundings for a few seconds. This was to enable participants to rehearse their memory of the first part of the route before further progress.

Tasks and materials. After traversing the route, participants drew sketchmaps of the route, and then performed navigational and spatial ability assessments. Measures of accuracy and response latency were recorded for all of the assessments. On each assessment, the participants were instructed to respond as fast as possible without sacrificing accuracy. The stimuli from the large-scale navigational tasks were designed and presented using E-Prime v. 1.1 (Psychology Software Tools, 2002).

Sketchmap task. The goal of the sketchmap task was to assess different types of mental environmental representations formed by the participants. They were given the following instructions: *Please sketch out a map of the route that you have just traversed from the start to the end. Please include as many route and topographical features as you possibly can. Make sure that your lines are clearly drawn and your landmarks are properly labeled. Please illustrate your map to the best of your abilities*, followed by blank sheets of A3 sized papers (27.9 cm x 43.2 cm), pencils, pens, and rulers to draw out their route. They were given 20 minutes for drawing and extra time when required. On average, each participant took between 15 to 20 minutes to draw out their map.

Large-scale navigational tasks.

Route Pointing Direction Task (R-PDT). The R-PDT required participants to point to landmarks and places situated on the route and at its periphery, relative to their heading direction. Specifically, this task aimed to assess participants' performance at retrieving self-to-object relations updated during route traversal. It was considered as one of the classical assessments of spatial updating that required participants to make directional estimates of non-visible landmarks situated in the surrounding environment (e.g., Easton & Sholl, 1995).

On each trial, the name of a non-visible landmark (i.e., a landmark that could not be seen from the ending point) was displayed in white on a black background. A white fixation cross against a black ground separated each trial with a one-second delay. The participants were instructed to focus their gaze on the screen while doing the task, and to make their responses by pressing one of the four buttons on the number pad (‘1’, ‘3’, ‘7’, and ‘9’), which had stickers of arrows glued over them. The participants were instructed that they need to press the key that represented the approximate direction to a specified landmark on every trial. The front-left (FL) and front-right (FR) pointing directions were indicated by the buttons ‘7’ and ‘9’ respectively, whereas the back-left (BL) and back-right (BR) pointing directions were indicated by the buttons ‘1’ and ‘3’ respectively. To ensure a relatively equal distribution of trials for each pointing direction, three landmarks corresponded to the FR direction, and four landmarks corresponded to FL, BL, and BR respectively.

Each participant performed three practice trials initially, followed by 15 experimental trials presented in a randomized sequence. In the experimental trials, eight of the landmarks were those which were pointed out to participants while they were traversing the route (e.g., grey lockers, see Figure 1), whereas the remaining seven trials presented names of landmarks and places not pointed out to them: three referred to landmarks where directional turns were made and four referred to landmarks and places located at the route’s periphery (e.g., McDonald’s outlet, see Figure 1).

Imaginal Pointing Direction Task (I-PDT). The I-PDT required the participants to imagine standing at particular landmark, facing another landmark, and point to a third target landmark based on the imagined orientation. It was adapted from a judgment of relative directions task that requires judgments of directions relative to specific imagined orientations or viewpoints in large-scale space (i.e., room-sized and environmental) (see McNamara, Rump, & Werner, 2003; Shelton & McNamara, 2001).

On each trial, the names of landmarks were presented on a computer screen. The names in the experimental trials corresponded to those of the 12 landmarks pointed out to the participants on the traversed route. The participants were instructed to imagine themselves standing at the location of a first landmark specified by the caption “STAND AT” at the top of the screen, mentally reorient themselves to face a second landmark specified by the caption “FACING” at the middle, and then point to a third landmark specified by the caption “POINT TO” at the bottom. This form of nominal text display was intended to avoid any likelihood of artificially inducing specific spatial representations of the environment. Such verbatim spatial language had been revealed by previous studies to be equivalent to pictorial images (e.g., maps) in conveying spatial information (e.g., Taylor & Tversky, 1992; Zaehle et al., 2007). Each trial was separated by a one-second black screen followed by a one-second white fixation cross situated at the top of the screen in the spot where the name of the first landmark appeared.

The names of 12 landmarks pointed out en route were applied in different combinations of threes. The different imagined orientations were represented by different orientation angles which specified the angular difference between the reference direction of north and the bearing of the second landmark (specified by “FACING”) from the first landmark (specified by “STAND AT”). A traveler’s compass with a radial display of angles was used in measuring out the various orientation angles. They ranged in absolute intervals of 30˚ from 0˚ to 150˚ (both clockwise and anticlockwise). The six angles (absolute values of 0˚, 30˚, 60˚, 90˚, 120˚, 150˚) were repeated five times each to make up 30 test trials. In terms of responding, similar to the R-PDT, the same four buttons (‘1’, ‘3’, ‘7’, and ‘9’) on the number pad were applied— with stickers of arrows glued over them— corresponding to the directions of FL, FR, BL, and BR. The numbers of landmarks specified by “POINT TO” were specified as follows: i) six in the FL direction; ii) nine in the FR direction; iii) eight in the BL direction; and iv) seven in the BR direction. Each stimulus display remained on the computer screen until a response was made.

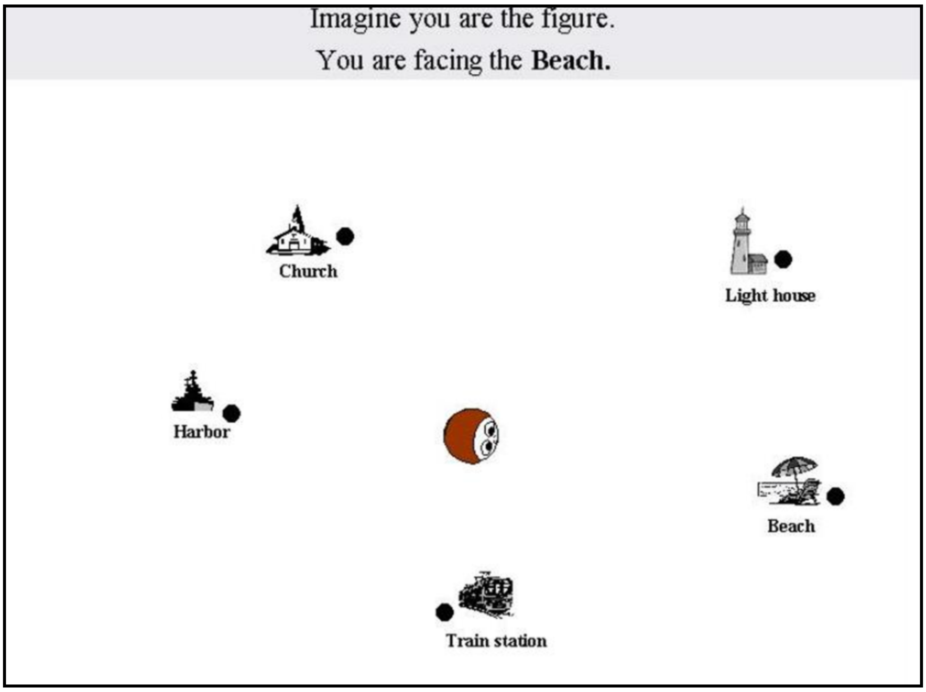
Each participant first performed three practice trials, followed by 30 experimental trials presented in a randomized sequence. The practice trials focused on arrays of objects located in the lab, and participants were monitored to complete all of them accurately prior to the start of test trials.

Landmark Recognition Task (LRT). The LRT measured the visual ability of participants to encode landmarks encountered along the route. Digital photographs of 30 landmarks were taken along the entire route, and photographs of 15 landmarks were taken from the Centre of English Language and Communication and the Faculty of Arts and Social Sciences at NUS that were beyond the route. Landmarks from photographs in the former group were regarded as route-based landmarks and those from latter group were regarded as “foils”. Each photograph centered on only one landmark/object with minimal capture of the background scene. Each photograph was also shot at an orientation angle that did not differ by more than 90˚ (clockwise and anticlockwise) from the actual heading directions on different paths of travel. On each trial, participants viewed a photograph and were instructed to press one of two buttons on the keyboard using either their left index finger or right index finger. Each button was associated with the identification of either a route-based landmark or a foil landmark. The order of the two button presses was counterbalanced across participants. Each trial was separated by a one-second white fixation cross on a black screen. Each landmark photograph remained on display until a response was made. The photographs of the 12 landmarks pointed out to participants were not included in the experimental trials; they were only included in the practice trials. Altogether, participants performed six practice trials followed by 45 experimental trials presented in a randomized sequence. The practice trials comprised of three landmarks which were pointed out to participants and three “foil” landmarks from SDE.

Spatial ability tests.

Mental Rotation Test (MRT). The MRT was employed to assess allocentric spatial ability. The test used was a computerized adaptation of Shepard and Metzler’s (1971) mental rotation test (MM Virtual Design, 2004). On each trial, participants viewed pairs of two-dimensional line drawings of three-dimensional geometric figures and judged whether they were the same or different. The figures were rotated in six degrees (40˚, 60˚, 80˚, 120˚, 160˚, 180˚) about three spatial axes: line of sight (X), vertical (Y), and horizontal (Z). The participants responded by clicking the left mouse button for pairs of figures which they perceive to be the same and by clicking the right mouse button those which they perceive to be different (mirror-reversed). The test included 36 trials (6 rotation angles x 3 axes x 2 types of responses) presented in a randomized sequence for each participant. Prior to the test, each participant performed six practice trials.

Perspective-Taking Ability Test (PTA). The PTA was employed to assess egocentric spatial ability. Two versions of the PTA were administered to each participant: a desktop-based two-dimensional version (2D-PTA) (Kozhevnikov, Motes, Rasch, & Blajenkova, 2006) and a three-dimensional version administered in an immersive virtual environment (3D-PTA) (Kozhevnikov, 2010). The 3D-PTA task was used to provide a more sensitive measure of egocentric spatial ability than that provided by the 2D-PTA. Its utilization was in accord with recent research that implicated 3D, immersive virtual environments to encourage individuals to use egocentric reference frames for spatial encoding and transformation (Kozhevnikov & Dhond, 2012). In the 2D-PTA, on each trial, participants viewed a map of a small town on the computer screen (see Figure 2). A small figure representing a person's head indicated the starting location where participants had to imagine themselves to be standing at. The eyes of the figure were looking toward one of the five locations that represented the to-be-imagined facing location (imagined heading). The participants were instructed to indicate the direction to a third (target) location from the imagined heading. Instruction appeared at the top of the screen, for example "Imagine you are the figure, you are facing the beach". Thus, participants had to imagine transforming their actual perspective (i.e., an aerial perspective of the character and the town) to that of the figure's perspective, and then then imagine pointing to the target from the figure's perspective.



Imagine you are the figure.
You are facing the **Beach.**

Figure 2. A sample trial in the two-dimensional Perspective-Taking Ability Test.

Altogether, participants performed six practice trials and 72 test trials (8 pointing directions x 9 imagined orientations) presented in a randomized sequence. The imagined orientation was computed as the angle between the imagined heading and the vertical axis of the computer screen; it varied from 100˚ to 180˚ in increments of 20˚. The correct response on each trial was one of eight pointing directions: i) front (F; 0˚); ii) front-right (FR; 45˚ to the right); iii) right (R; 90˚ to the right); iv) back-right (BR; 135 ˚ to the right); v) back (B; 180˚); vi) back-left (BL; 135 ˚ to the left); vii) left (L; 90˚ to the left); viii) and front-left (FL; 45 ˚ to the left). To indicate the pointing direction, participants had to click on one of the arrows on a computer screen which represented one of eight possible pointing directions. The arrows were positioned to preserve the spatial configuration (e.g., the arrow representing the FL direction was placed on the left and above the arrow representing L direction). Before the test trials, participants were monitored to perform the practice trials accurately to ensure they fully understood the instructions of the test. Accuracy and response latencies were recorded from all test trials.

The 3DI virtual environment was created using the Vizard Virtual Reality Toolkit v. 3.0 (WorldViz, 2007). In the virtual environment, the stimuli were presented through an nVisor SX 60 head-mounted display (HMD) (by Nvis

Inc.). The HMD has a 44˚ horizontal by 3˚ vertical FOV with a display resolution of 1280 x 1024 and under 15% geometric distortion. The HMD was used in conjunction with a position-tracking system which enables full 3D optical tracking of up to four wireless targets over large ranges (more than 10 x 10 meters) with sub-millimeter precision. During the experiments, each participant stood at the center of a room, wearing the HMD display (see Figure 3). A gyroscopic orientation sensor in the HMD supports a real-time picture-to-picture simulation in virtual reality and immediately updated the image rendered in the HMD with each movement of the participant's head. In addition, the participant's head position was tracked by four cameras located in each corner of the experimental room, which were sensitive to an infrared light mounted on the top of the HMD.

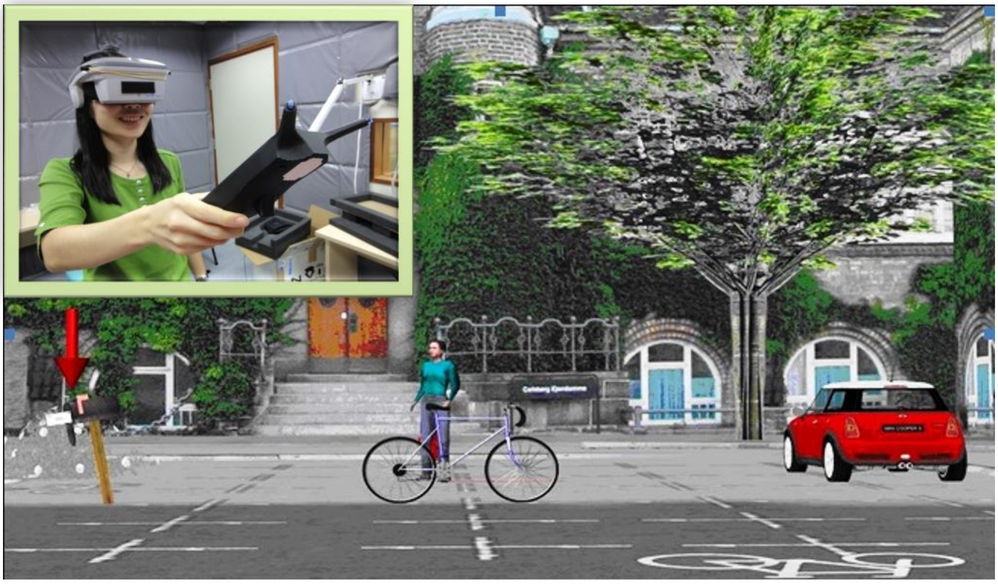


Figure 3. Three-dimensional Perspective-Taking Ability Test administered in an immersive, 3D environment.

Before administering 3D- PTA, to familiarize the participants with immersive virtual reality, there was an exploratory phase prior to the practice trials in which the participants were given general instructions about virtual reality and the use of the remote control device (7-10 min). During the practice and test phases the participants were required to stand still but were allowed to rotate their heads to view the scenes.

On each 3D-PTA trial, participants were placed in a location inside the scene in a 3DI virtual environment (Figure 3). They were explicitly instructed to imagine taking the perspective of the avatar located at the center of an array of objects (imagined heading) and then point to a specific target from the imagined perspective by using a pointing device. Altogether, participants performed six practice trials and 52 test trials (4 pointing directions x 13 imagined orientations) presented in a randomized sequence. The imagined orientation was computed as the angle between the imagined heading and the horizontal axis of the participant's forward view of the scene; it varied from -63˚ to -163˚ (anticlockwise) and from 63˚ to 163˚ (clockwise) in intervals of 20˚. The pointing direction on each trial was one of four responses: FR (45˚ to the right), BR (135˚ to the right), BL (135˚ to the left), and FL (45˚ to the left). Accurate responses pertained to chosen pointing directions which matched the correct pointing directions specified by the program within an error range between -30˚ (anticlockwise) and 30˚ (clockwise). Before the test trials, participants were monitored to perform six practice trials accurately to ensure they fully understood the instructions of the test. Accuracy and latency values were recorded from all test trials.

Procedure. All participants were tested over two sessions of experiments. In the first session, the experimenter brought the participants individually or in pairs on a traversal of a sheltered route. At the end of the route, all participants first performed the R-PDT on a laptop carried by the experimenter. They performed the R-PDT in a seated position facing a wall. After finishing the task, participants sat at the benches attached to tables available in the vicinity and were given 20 minutes to sketch the map of the traversed route.

After completing their sketchmaps, participants followed the experimenter on a walk (between 10 to 15 minutes) to the experimental lab. At the lab, they were tested on the remaining assessments. They first performed the I-PDT, followed by three more computerized assessments presented in a randomized sequence: the LRT, the MRT, and the 2D-PTA.

The above activities lasted two hours and upon their completion, all participants were asked to answer the following question ('yes' or 'no') in a post-test survey: *While doing the I-PDT, when you imagined yourself standing at the specified locations, did you imagine your orientation from the same perspective as that when you traveled on the route?* Besides that, written reports on the strategies applied to remember the route were randomly sought from thirty participants, who volunteered to narrate their navigational strategies. All participants were reminded to return for the second session, which was conducted within a week after the first session. Only forty-two participants (18 females) returned and were administered the 3D-PTA. They were tested individually (20 to 30 minutes in duration).

RESULTS

For the large-scale navigational tasks (R-PDT, I-PDT and LRT), analyses were performed on the data obtained from all 71 participants who completed them. As for the spatial ability tests (MRT, 2D-PTA, and 3D-PTA), one male participant did not complete the MRT and four participants (two females) did not complete the 2D-PTA. Thus, analyses were performed on the MRT data of 70 participants and on the 2D-PTA data of 67 participants. As for the 3D-PTA, analyses were performed on the data of all 42 returning participants who completed it. Altogether, there were 41 participants (17 females) who completed all six assessments.

Sketchmap categorization. Out of the pool of 71 participants who originally participated in the study, three participants failed to draw maps (i.e., they either reported being unable to or not knowing how to draw a map of the route). Another three participants drew maps which contained too few depictions of landmark and route features to warrant a proper examination, and an additional three participants drew maps which contained too many extraneous depictions which made them ineligible for categorization. Consequently, the sketchmaps of those six participants were removed due to their ineligibility for examination and categorization.

Two coders independently analyzed and categorized the remaining 62 sketchmaps (28 females) collected from the sample of 68 participants who drew maps into three categories: i) procedural route maps, ii) allocentric-survey maps, and iii) egocentric-survey maps. In the categorization of the sketchmaps, agreement between the two coders was 95% and any disagreement was discussed until a consensus was reached. Figure 4 shows representative samples from each sketchmap category

The sketchmaps categorized as *procedural route maps* (*N* = 24; 14 females) (see Figure 4a) represented linear, non-spatial representations of navigational procedure for getting from one place to another in a direction-specific sequence. The sketchmaps categorized as *allocentric-survey maps* (*N* = 22; 10 females) (see Figure 4b) represented the spatial layout of the route and its surrounding environment in a schematic and integrated manner that implicated the adoption of a top-down third-person perspective. The sketchmaps categorized as *egocentric-survey maps* (*N* = 16; 4 females) (see Figure 4c) represented the route and its surrounding environment either in a cross-sectional three-dimensional (3D) format or in a schematic format that clearly defined the separation of the two floors (levels) which had been traveled on. Notably, along the vertical dimension, the spatial layouts of separate floors were accurately aligned; the landmarks situated on the higher floor were depicted exactly above those situated beneath them on the lower floor. These depictions implicated an adoption of a first-person perspective.

Prior to any further analyses of the sketchmaps, to ensure that that the sexes were not unequally distributed during sketchmap categorization, a chi-square test was conducted; the results did not show an uneven distribution of the sexes across sketchmap categories, χ^2 (2) = 4.31, *p* = .116.

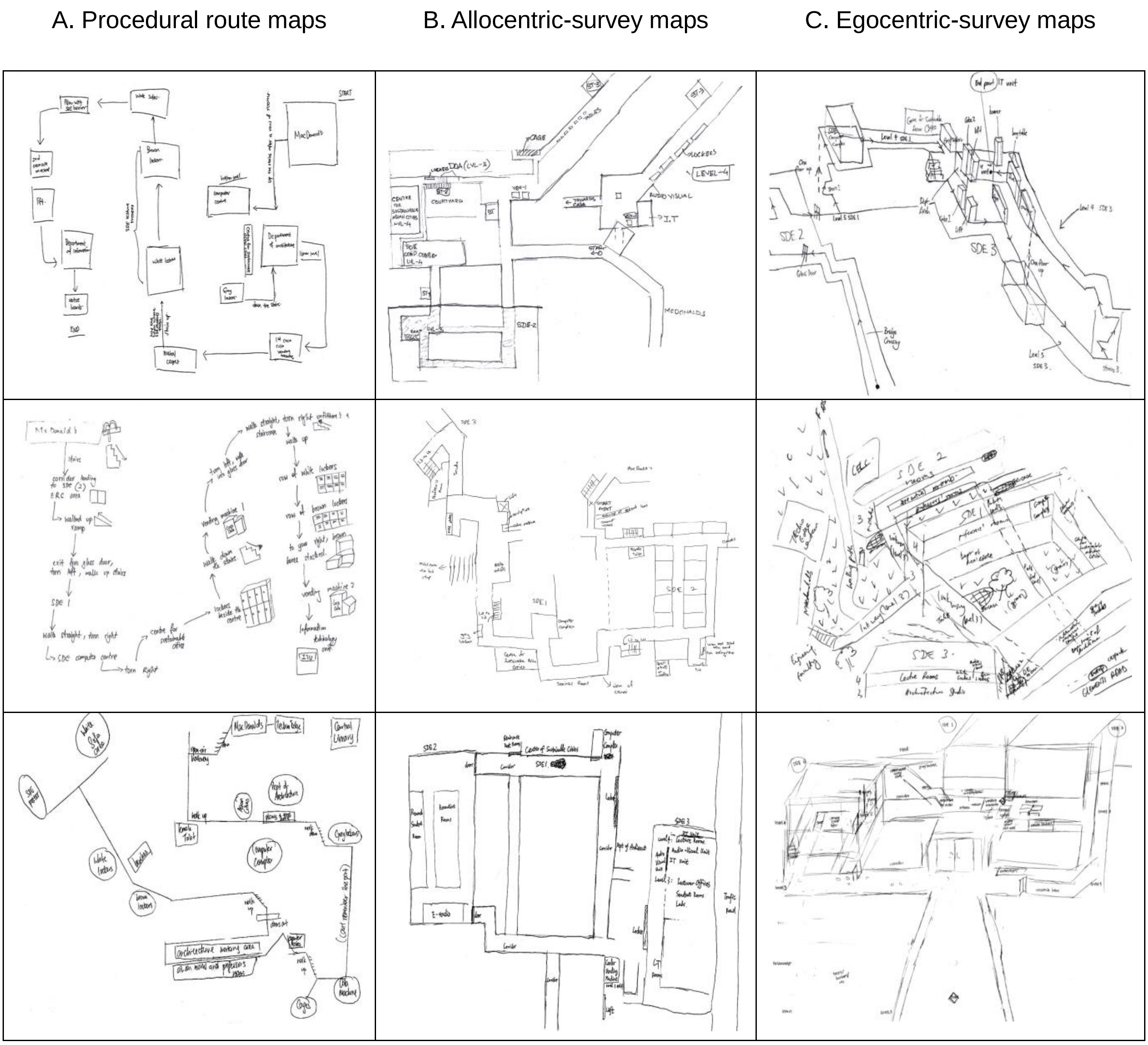


Figure 4. Representative sketchmaps from three categories.

After that, the sketchmaps from all the three categories were examined further by two independent coders who agreed that the three categories of sketchmaps differ according to the following five sketchmap variables/criteria:

i) *Frequency of landmarks*: This variable reflects the number of landmarks (range = 1-12 based the landmarks pointed out on the route) depicted on the sketchmap.

ii) *Frequency of accurate route segments*: This variable reflects the number of accurately depicted route segments (range: 1-5) which matched the geometric outlines of their counterparts displayed on the formal floor plan in Figure 1. As shown by the plan, the route was partitioned into five segments, each with a unique geometric outline. A depicted route segment was scored as accurate when it displayed: i) legs/paths of travel that connected perpendicular to each other at a *minimum* of two turning points or junctures which were in the same locations as those on the formal plan; and ii) legs/paths of travel which were approximately proportional in length with those of the corresponding route segment on the formal plan.

iii) *Route structure*: This nominal variable recorded the presence of parallel-running double lines which represented the paths of travel (see Figures 4b, c). Those lines showcased knowledge of the geometric layout of the various route segments (i.e., knowledge of the shape/geometry of the traversed route).

iv) *Floor separation*: This nominal variable recorded the presence of depictions of environmental features on separate floors. (e.g., see Figure 4c).

v) *Route orientation*: This nominal variable recorded the presence of a “heading up” orientation that showed the first leg of the route (the bridge crossing to SDE1) as pointing upwards. This orientation was regarded as being in congruence with the egocentric forward view observed during the first leg of travel. Maps with this type of orientation were in contrast to maps with orientation-free headings, which showed the first leg as pointing leftwards, rightwards, and downwards.

After rating each sketchmap based on the criteria above, the quantitative variables (‘frequencies of landmarks’ and ‘route segments’) representing different sketchmap features were separately analyzed using one-way

ANOVAs with Sketchmap Category as the between-subjects variable. The nominal variables (‘route structure’, ‘floor separation’, and ‘route orientation’) were analyzed using chi-square tests. The results are presented below.

Sketchmap differences in terms of frequency of landmarks. There was a significant difference in the frequencies of landmarks between the different sketchmap categories, *F* (2, 59) = 3.36, *p* = .042, η^2 = .102. Post-hoc comparisons using the Tukey *HSD* test showed that egocentric-survey maps depicted more landmarks (*M* = 9.81, *SD* = 1.47) than allocentric-survey maps (*M* = 8.41, *SD* = 1.94) (*p* = .033). As for procedural route maps, the amount of landmarks they depicted (*M* = 9.13, *SD* = 1.48) did not differ significantly from that of egocentric-survey maps (*p* = .410) and that of allocentric-survey maps (*p* = .316).

Sketchmap differences in terms of frequency of accurate route segments. There was a significant difference in the frequencies of accurate route segments between the different sketchmap categories, *F* (2, 59) = 82.22, *p* < .001, η^2 = .736. Post-hoc comparisons using the Tukey *HSD* test showed a higher presence of accurate route segments in both egocentric-survey (*M* = 4.13, *SD* = 0.81) and allocentric-survey maps (*M* = 3.91, *SD* = 0.81) than in procedural route maps (*M* = 1.25, *SD* = 0.85) (*p*s < .001). The egocentric-survey maps did not contain more accurate route segments than the allocentric-survey maps (*p* = .698).

Sketchmap differences in terms of route structure. A chi-square test showed an uneven distribution of sketchmaps with parallel-running double lines representing the paths of travel, χ^2 (2) = 30.39, *p* = .018. The proportions of egocentric-survey (100 %) and allocentric-survey maps (72.7 %) showing these double lines were significantly higher than that of the procedural route maps (16.7 %).

Sketchmap differences in terms of floor separation. Only allocentric- and egocentric survey maps were examined as no procedural route map showed any attempt at floor separation. A chi-square test showed a significant difference between the two categories in terms of floor separation, χ^2 (1) = 7.20, *p* = .007. The proportion of egocentric-survey maps which showed floor separation (100 %) were significantly higher than that of allocentric-survey maps (18.2 %),

Sketchmap differences in terms of route orientation. A chi-square test showed an uneven distribution of sketchmaps with the “heading up” orientation, χ^2 (2) = 11.35, p = .003. The proportion of egocentric-survey maps showing the “heading up” orientation (81.3%) was significantly higher than those of allocentric-survey maps (33.8 %) and procedural route maps (33.3 %).

In summary, starting with the procedural route maps, we regard them as portraying non-spatial route/procedural representations acquired from a first-person perspective. They showed equivalent frequencies of landmarks which were pointed out on the traversed route as the two other categories of survey maps. However, they showed much lower frequencies of accurate route segments than both categories of survey maps; this suggests that their sketchers retrieved non-spatial information from landmark- or route-based representations. Moreover, a relatively low proportion of these maps were structured by double lines; this suggests that most of their sketchers lacked knowledge about the geometric layout of the route segments.

As for the allocentric survey maps, we regard them as portraying survey-based representations acquired from a third-person perspective as a great majority showed the route segments as resting on a single level. In general, these maps showed relatively high frequencies of accurate route segments. The majority of these maps were also structured by double lines, which suggests that most of their sketchers had acquired knowledge of the geometric layout of the route segments. Moreover, two-thirds of the maps depicted the first leg of the route in the form of an orientation-free heading that pointed leftwards, rightwards, or downwards; this suggests that most allocentric-survey map sketchers had retrieved survey-based information from orientation-free viewpoints.

Lastly, for the egocentric-survey maps, we regard them as portraying survey-based representations acquired from a first-person perspective. All of them had relatively high frequencies of accurate route segments and every route segment was structured by double lines, which suggest that all of their sketchers had acquired knowledge of the geometric layout of the route segments. Moreover, these maps were unique for showcasing separate spatial layouts of the two floors that had been traveled on; this suggests that their sketchers had adopted a first-person perspective for organizing their survey knowledge along the vertical dimension. Interestingly, there were three maps with orientation-free headings (i.e., the first leg pointed either leftwards or rightwards) which showcased the route's spatial layout in a cross-sectional manner (i.e., an imagined side-view of the entire route) (for one sample, see the second map in Figure 4c). The presence of such maps gave more evidence to suggest that egocentric-survey map sketchers retrieved survey-based information from a first-person perspective.

Relationship between different types of sketchmaps and performance on large-scale navigational and spatial ability assessments.

Outlier removal. First, in the spatial ability tests (MRT, 2D-PTA, & 3D-PTA), the response latencies of all accurate trials falling below a lower limit of 500 milliseconds were removed; this lower limit was regarded as representing random responses. Then, in all assessments, for every participant, the response latencies of accurate trials surpassing ± 2.5 *SD* of his/her mean response latency of all accurate trials were removed. After that, for between-groups analyses, in each sketchmap category, the mean response latencies (of all accurate trials) of individual participants which surpassed ± 2.5 *SD* of the mean latency of all individuals within that category were removed. Similarly, in each sketchmap category, the accuracy scores of individual participants which fell below 2.5 *SD* of the mean accuracy score of all individuals within that category were removed. Following this procedure of outlier removal, the 2D-PTA accuracy score from one female procedural route map sketcher was excluded from ANOVA as it exceeded more than four standard deviations below the mean accuracy score of all procedural route map sketchers. Likewise, the mean I-PDT response latencies from one female procedural route map sketcher and one egocentric-survey map sketcher were excluded from ANOVA; each participant's latency was more than three standard deviations above the mean latency of the group of map sketchers she belonged to.

Sketchmap differences in terms of assessment measures of accuracy and response latency. The accuracy scores and their corresponding mean response latencies (in milliseconds) of individual participants obtained from each assessment were separately analyzed using one-way ANOVAs, with the between-subjects variable being Sketchmap Category for all analyses. Table 1 shows the descriptive statistics of accuracy scores and response latencies obtained from all assessments in each group of map sketchers, and the corresponding ANOVA results. The performance data from LRT were organized into two data sets for analyses: i) “LRT (total)” represented the accuracy scores (max. score = 45) and response latencies in the recognition of both ‘foil’ landmarks and landmarks encountered en route; and ii) “LRT (route-based)” represented the accuracy scores (max. score = 30) and response latencies in the recognition of landmarks encountered en route only.

Table 1

Descriptive Statistics of Accuracy Scores and Response Latencies and ANOVA Results of all Assessments

		Procedural route map sketchers *M* (*SD*)	Allocentric-survey map sketchers *M* (*SD*)	Egocentric-survey map sketchers *M* (*SD*)	F	df_{error}	η^2
R-PDT	ACC	5.96 (2.20)	8.50 (2.81)	10.50 (2.28)	16.83***	59	.36
	RT (s)	3.88 (1.43)	3.55 (1.05)	4.32 (3.04)	0.78	59	.03
I-PDT	ACC	11.67 (4.60)	16.91 (3.92)	18.56 (4.52)	18.23***	59	.38
	RT (s)	9.80 (3.59)	11.27 (2.96)	8.58 (2.10)	3.58*	57	.11
LRT (total)	ACC	27.29 (4.36)	28.68 (4.11)	29.88 (5.10)	1.65	59	.05
	RT (s)	2.81 (1.11)	2.94 (1.37)	2.27 (0.60)	1.81	59	.06
LRT (route –based)[a]	ACC	16.17 (4.88)	17.00 (3.87)	17.56 (4.75)	0.49	59	.02
	RT (s)	2.84 (1.30)	3.27 (1.63)	2.11 (0.70)	5.69**	38.39	.11
MRT	ACC	25.79 (4.22)	24.86 (4.87)	26.19 (5.55)	0.39	58	.01
	RT (s)	6.93 (1.33)	6.95 (1.64)	6.83 (1.64)	0.03	58	.001
2D-PTA[b]	ACC	63.50 (7.72)	67.63 (3.47)	68.19 (2.48)	3.49*	35.04	.14
	RT (s)	3.10 (1.51)	3.03 (1.30)	2.49 (1.01)	1.12	55	.04
3D-PTA	ACC	25.44 (8.26)	26.58 (7.08)	35.21 (6.00)	7.77**	39	.29
	RT (s)	5.16 (1.78)	5.53 (2.02)	5.39 (2.48)	0.12	39	.01

Note. ‘ACC’ and ‘RT (s)’ represent the dependent variables of accuracy scores and response times/latencies (in seconds).

[a] In the ANOVA of LRT (route-based landmarks) response latencies, the Welch test was applied due to violation of the homogeneity of variance (Levene’s F (2, 59) = 6.18, p = .004).

[b] In the ANOVA of 2D-PTA accuracy scores, the Welch test was used due to violation of the homogeneity of variance (Levene’s F = 7.72, p = .001).

* $p < .05$. ** $p < .01$ (two-tailed). *** $p < .001$. For all non-asterisked F statistics, $p > .05$.

To further examine the relationship between large-scale navigational performance and performance on allocentric and egocentric spatial ability tests, we computed the correlations between the accuracy scores obtained from the 41 participants who each completed all six assessments. Table 2 presents the intercorrelations among these scores. Notably, it shows that there are positive and moderately high intercorrelations (.27 ≤ *r*s ≤ .52) between the accuracy scores of the egocentric spatial ability tests (2D-PTA and 3D-PTA) and the large-scale navigational pointing tasks (R-PDT and I-PDT) (*p*s < .09). In contrast, the MRT accuracy scores did not show any significant correlation with any other set of accuracy scores (*p*s > .05). The correlations of the two sets of accuracy scores pertaining to total and route-based landmark recognition with those from the other assessments were all non-significant (*p*s > .05) aside from one between the scores of total landmark recognition and R-PDT (*p* < .001).

Table 2
Pearson Product-Moment Correlations between the Accuracy Scores of Navigational and Spatial Assessments (N = 41)

		1.	2.	3.	4.	5.	6.	7.
1.	R-PDT	_						
2.	I-PDT	.52**	_					
3.	LRT (total)	.41**	.26	_				
4.	LRT (route-based)	.28†	.21	.91**	_			
5.	MRT	-.14	.09	-.12	-.17	_		
6.	2D-PTA	.42**	.43**	.28†	.19	.20	_	
7.	3D-PTA	.44**	.27†	.09	-.02	.21	.37*	_

** *p* < .01 (two-tailed).
* *p* < .05 (two-tailed).
† *p* < .10 (two-tailed).

Large-scale navigational tasks. As shown in Table 1, with regards to accuracy scores, the ANOVA results showed significant differences between the three groups of map sketchers in the performance of R-PDT and I-PDT (*F*s > 16.82, *p*s < .001) but not in that of LRT (total) and LRT (route-based) (*F*s < 1.66, *p*s > .05). With regards to response latencies, the ANOVA results showed significant differences between the three groups of map sketchers in the performance of I-PDT and LRT (route-based) (*F*s > 3.57, *p*s < .05) but not in that of R-PDT and LRT (total) (*F*s < 1.82, *p*s > .05). The post-hoc comparisons of R-PDT and I-PDT accuracy scores, as well as I-PDT response latencies, were performed using the Tukey *HSD* test. The post-hoc comparisons of LRT (route-based) response latencies were performed using the Games-Howell test as a separate-variances version of the Tukey *HSD* test.

First, in the R-PDT, egocentric-survey map sketchers were found to have higher R-PDT accuracy scores than both groups of allocentric-survey map sketchers (*p* = .034) and procedural route map sketchers (*p* < .001). Moreover, allocentric-survey map sketchers were found to have higher accuracy scores than procedural route map sketchers (*p* = .003). In line with our prediction, these findings showed that egocentric-survey map sketchers were more accurate at judging self-to-object relations than both allocentric-survey and procedural route map sketchers.

Second, in the I-PDT, both groups of allocentric- and egocentric-survey map sketchers were found to have higher accuracy scores than procedural route map sketchers (*p*s < .001). Other than these significant differences, egocentric-survey map sketchers did not have significantly higher accuracy scores than allocentric-survey map sketchers (*p* = .380). In addition, with regards to I-PDT response latencies, egocentric-survey map sketchers were found to have significantly lower latencies than allocentric-survey map sketchers (*p* = .029). Other than that, the latencies of procedural route map sketchers did not differ significantly from those of the two other groups of map sketchers (*p*s > .240). In line with our prediction, these findings showed that egocentric-survey map sketchers responded faster than allocentric-survey map sketchers in the retrieval of spatial relations from multiple orientation-specific images/viewpoints.

Third, in the recognition of route-based landmarks, egocentric-survey map sketchers were found to have significantly lower latencies than both allocentric-survey map sketchers (*p* = .015) and procedural route map sketchers (*p* = .067) (marginally significant). Other than these significant differences, procedural route map sketchers did not have significantly lower response latencies than allocentric-survey map sketchers (*p* = .590). In line with our prediction, these findings showed that egocentric-survey map sketchers responded faster than allocentric-survey map sketchers in the recognition of egocentric views of landmarks which were encountered during route traversal.

Spatial ability tests. As shown in Table 1, with regards to accuracy scores, the ANOVA results showed significant differences between the three groups of map sketchers in the performance of 2D-PTA and 3D-PTA (Fs > 3.48, ps < .05) but not in that of MRT (p = .681). With regards to response latencies, significant differences between the three groups of map sketchers were not found for any spatial ability test (Fs < 1.13, ps > .05). The post-hoc comparisons of 2D-PTA and 3D-PTA accuracy scores were performed using the Games-Howell test and the Tukey *HSD* test respectively[2].

In the 2D-PTA, egocentric-survey map sketchers were found to have higher accuracy scores than procedural route map sketchers (p = .028). Similarly, allocentric-survey map sketchers were also found to have higher accuracy scores than procedural route map sketchers (p = .045). Other than these significant differences, egocentric-survey map sketchers did not have significantly higher accuracy scores than allocentric-survey map sketchers (p = .950).

In the 3D-PTA, egocentric-survey map sketchers were found to have higher accuracy scores than both groups of allocentric-survey (p = .008) and procedural route map sketchers (p = .002). Other than these significant differences, allocentric-survey map sketchers did not have significantly higher accuracy scores than procedural route map sketchers (p = .918).

Comparing the two versions of PTA, only the findings from the 3D-PTA supported our prediction that egocentric-survey map sketchers would outperform allocentric-survey map sketchers on an egocentric spatial ability test. The finding of egocentric-survey map sketchers performing significantly more accurately than allocentric-survey map sketchers in the 3D-PTA but not in the 2D-PTA supported previous research (Kozhevnikov et al., 2013) that viewed the 3D-PTA as offering a fine-grained or sensitive measure of individual differences in egocentric spatial ability.

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[2] Post-hoc comparisons in the 3D-PTA were done between 16 procedural route map sketchers, 12 allocentric-survey map sketchers, and 14 egocentric-survey map sketchers.

Gender differences. As gender differences in terms of visual-spatial and navigational abilities had been well documented in the extant literature (see Kimura, 1999; Montello, Lovelace, Golledge, & Self, 1999), the effects of gender on our participants' accuracy scores and response latencies were examined for all assessments. To ensure that gender effects did not affect our univariate analyses above, we first examined the interactive effects of gender by entering it as an independent variable alongside Sketchmap Category. Gender did not show any significant effect of interaction with Sketchmap Category across all assessments with regards to both measures of accuracy (*F*s < 2.98, *p*s > .065) and latency (*F*s < 1.38, *p*s > .260).

As for gender differences with respect to each assessment, we found that male participants obtained significantly higher accuracy scores than female participants in the performance of R-PDT (F (1, 69) = 9.74, p = .003, η^2 = .124 ; *M males* = 8.95, *SD* = 2.93, *M females* = 6.79, *SD* = 2.88) and 3D-PTA (F (1, 40) = 4.49, p = .040, η^2 = .101; *M males* = 31.29, *SD* = 7.79, *M females* = 26.00, *SD* = 8.30). Marginally significant gender differences, in which male participants obtained higher accuracy scores, were found in the performance of MRT (F (1, 68) = 4.02, p = .049, η^2 = .056; *M males* = 27.03, *SD* = 5.00, *M females* = 24.76, *SD* = 4.40), and in terms of total landmark recognition (F (1, 69) = 3.11, p = .082, η^2 = .043; *M males* = 28.74, *SD* = 4.71, *M females* = 26.85, *SD* = 4.25) and route-based landmark recognition (F (1, 69) = 3.54, p = .064, η^2 = .049; *M males* = 17.13, *SD* = 4.78, *M females* = 15.12, *SD* = 4.14). Non-significant gender differences were found in the performance of 2D-PTA, (F (1, 64) = 1.28, p = .261, η^2 = .020; *M* males = 66.72, *SD* = 5.72, *M* females = 64.57, *SD* = 9.55), and I-PDT (F (1, 69) = 2.56, p = .114, η^2 = .036; *M* males = 16.39, *SD* = 5.94, *M* females = 14.39, *SD* = 4.34).

Post-test survey responses. Chi-square tests for goodness of fit were performed on responses to the survey question: *While doing the I-PDT, when you imagined yourself standing at the specified locations, did you imagine your orientation from the same perspective as that when you traveled on the route?* The distribution of participants responding positively (*yes* responses) was found to be uneven across the sketchmap categories, χ^2 (2) = 9.24, p = .010. The proportions of positive respondents from the egocentric-survey map category (68.8 %) and procedural route map category (66.7 %) were significantly higher than that from the allocentric-survey map category (27.3 %). The relatively high positive responses from both the egocentric-survey and procedural map categories suggested that the majority of sketchers from both parties imagined themselves standing next to landmarks from a first-person route perspective.

Finally, written reports provided by thirty volunteers (10 females) on the strategies they applied for representing the route of travel were examined and classified by two coders. Based on the examination, all reports from the participating procedural route map sketchers (*n* = 7) explicitly mentioned attending to and remembering landmarks as being crucial for forming a mental representation of the route, especially those that were pointed out en route. On the other hand, the reports from the participating allocentric-survey map sketchers (*n* = 12) and egocentric-survey map sketchers (*n* = 11) reflected strong considerations for the mapping of spatial relations either between landmark locations or between the moving body and surrounding landmarks. Prominently, the majority of egocentric-survey map sketchers (*n* = 10) described the tracking of their position and orientation with references to salient sites like the traffic road and the starting point. In contrast, the great majority of allocentric-survey map sketchers described the mapping of spatial relations between landmark locations and/or the mental formation of the geometric layout of the route by piecing together route segments from an aerial or third-person viewpoint (*n* = 9). To showcase the differences in thinking styles associated with the formation of environmental representation, the following section presents one representative report from a participant from each sketchmap category:

i) Procedural route map sketcher: *As I am navigating the routes, I try to "video-record" down the routes I traversed, pausing at certain intervals to turn back and ensure that I "captured" the right images at the right places. When it comes to particular landmarks (e.g., center for sustainable Asian cities, dept of architecture), I focused hard on these images. To help me in capturing & "recording" the right images, I walked at a slow pace with my eyes constantly rotating to survey my surroundings*.

ii) Allocentric-survey map sketcher*: When I need help ascertaining the position of other landmarks or objects, my field of view takes on an aerial perspective, like when I am viewing a schematic map or blueprint. Then, I transpose myself to those particular landmarks so that in my mind, I have positioned or angled myself next to those landmarks.*

iii) Egocentric-survey map sketcher: *I tried to remember the turns that I had made. I tried to remember the landmarks and their location relative to me at each point in time. I tried to remember the relative positions of the landmarks, observing the landmarks relative to each other…going up the stairs made the task more difficult. I tried to remember based on a first-person's perspective*.

DISCUSSION

Study 1 proposed that there might be two distinct types of survey-based representations: an allocentric-survey representation and egocentric-survey representation. Two categories of sketchmaps—the allocentric-survey and the egocentric-survey maps—were regarded as giving a clear rendition of survey-based knowledge. In terms of similarities, both allocentric- and egocentric-survey maps presented accurate spatial representations of the route by having relatively high and approximately equal frequencies of accurate route segments. The spatial layout of these maps were also predominantly structured by parallel-running double lines These findings suggest that both groups of survey map sketchers were evenly matched in having survey knowledge of the spatial layout of environmental features and the geometric layout of route segments.

However, aside from these similarities, there were salient differences between the two types of survey maps. The allocentric-survey maps were regarded as representing the spatial layout of the environment from a top-down third-person perspective. The great majority of allocentric-survey maps showcased environmental features of landmarks and route segments as resting continuously on a single level. They also displayed the first leg of the route in an orientation-free manner. In contrast, the egocentric-survey maps were regarded as representing the spatial layout of the environment from a first-person or egocentric perspective. All of them showcased spatial layouts which preserved local egocentric representations embedded within larger survey-based representations. The majority of these maps also represented the first leg of the route in an orientation-specific “heading up” fashion, which could be seen as a characteristic way of conveying the egocentric view captured at the start of the route. Interestingly, several maps were unique for depicting separate spatial layouts in a cross-sectional, 3D format. They provided further evidence to suggest that the first-person perspective was involved in the formation of survey-based representations. Lastly, the egocentric-survey map sketchers depicted significantly more landmarks than the allocentric-survey map sketchers; this suggests that the former group had attended to and encoded the spatial locations of many landmarks while updating their self-positions during route traversal.

Overall, the findings from the examination of sketchmaps suggest that egocentric-survey maps were unique for preserving both spatial location information of landmarks and orientation information of how the self was oriented in the environment, particularly with reference to the starting viewpoint of the route. In contrast, the allocentric-survey maps were seen to have only preserved information about the spatial locations of landmarks. The presence of orientation-free headings in the great majority of these maps suggests that information about orientation-specific viewpoints were not preserved. As for the procedural route maps, we regard them as non-spatial representations that were encoded in a propositional format; this interpretation is consistent with the conclusions drawn from previous research that similarly investigated route-based representations using sketchmaps (see Tversky & Lee, 1998). The procedural route map sketchers are exceptional for having encoded information of landmarks along with their associated turns but not of spatial layout. This non-spatial, route-based style of navigation could therefore explain their relatively poor performance on the subsequent spatial tasks that require knowledge of spatial layout (i.e., I-PDT) and orientation information (i.e., R-PDT, 2D-PTA, and 3D-PTA).

Furthermore, the results from the large-scale navigational pointing tasks and perspective-taking tests gave greater evidence to suggest that egocentric-survey map sketchers relied more on egocentric spatial processing than allocentric-survey map sketchers. Starting with the R-PDT, the egocentric-survey map sketchers’ achievement of the highest accuracy scores among the three groups of sketchers suggests that they were the most successful at carrying out an active updating of self-to-object relations during route traversal. Importantly, the significantly more accurate performance of egocentric-survey map sketchers over allocentric-survey map sketchers suggests that the former group relied more on the navigational mechanism of updating their bodies’ position and orientation in relation to the landmarks that they passed by. Interestingly, this interpretation was supported by the written reports of egocentric-survey map sketchers, in which they claimed to have tracked their bodies’ positions and orientations with reference to salient route-based landmarks and/or the point of origin during route traversal.

On the other hand, with respect to the I-PDT, the two groups of survey map sketchers did not demonstrate a significant difference in accuracy scores; both parties were equally successful at retrieving information of spatial relations from their survey knowledge to solve the task. However, the egocentric-survey map sketchers responded significantly faster than the allocentric-survey map sketchers. To explain this finding, we suggest that the former group encoded multiple egocentric views of landmarks aligned alongside self-specified reference directions through a navigational process of spatial updating. Consequently, when they subsequently imagined an orientation or heading (on the I-PDT) that was aligned with a reference direction (i.e., an egocentric direction aligned with a line of objects/landmarks experienced during route traversal, see Kelly & McNamara, 2008), the stored egocentric spatial relations were directly retrieved, and that facilitated their overall speed of pointing responses. As for the allocentric-survey map sketchers, we suggest that they primarily encoded the spatial relations connecting different landmarks from a third-person perspective in an orientation-free manner, leading to a less accurate encoding of orientation information from the first-person perspective. Hence, their comparatively slower response times on the I-PDT could be attributed to the additional mental procedures or transformations that were engaged to infer interobject relations from the third-person perspective. Despite having significantly slower response times, the allocentric-survey map sketchers were not found to have scored significantly less accurately than the egocentric-survey map sketchers on the I-PDT. This absence of a significant difference in terms of accuracy supported our view that both allocentric- and egocentric-survey map sketchers encoded an equally accurate knowledge of spatial layout despite differences in the amount of accurately encoded orientation information. In addition, the finding of egocentric-survey map sketchers being comparatively faster during the recognition of route-based landmarks gave supporting evidence to suggest that they captured multiple egocentric views of landmarks while updating their self-positions during route traversal.

Altogether, these findings from the three large-scale navigational assessments strongly suggest that egocentric-survey map sketchers encoded multiple orientation-specific viewpoints—captured from a first person perspective based on updating self-to-object relations—whereas allocentric-survey map sketchers encoded orientation-free viewpoints—captured from a third-person perspective based on attending to object-to-object relations. This interpretation is also consistent with the finding of egocentric-survey map sketchers having better egocentric spatial ability—as measured by 3D-PTA—than allocentric-survey map sketchers, which suggests the former group have largely engaged egocentric spatial processing when performing the 3D-PTA and possesses larger egocentric processing capacity than the latter group. Notably, the common finding of egocentric-survey map sketchers outperforming the two other groups (either in accuracy or latency) on the egocentric spatial tasks of R-PDT, I-PDT, and 3D-PTA well supported our proposal that they rely on the navigational mechanisms of spatial updating as aforementioned, and that their environmental representations encoded not only accurate knowledge of spatial layout, but also of orientation information.

Overall, we demonstrated significant performance differences among the three groups of map sketchers on all behavioral assessments except the MRT. A review of the mean mental rotation latency of all our participants showed that it was almost two times higher than that of other college students from previous studies (e.g., Kozhevnikov et al., 2013). This suggests that we might have recruited a unique sample of participants who applied analytical strategies more than allocentric spatial strategies to solve the MRT, since the use of the latter type of strategy typically leads to faster response latencies than the former type of strategy (Kozhevnikov et al., 2006, 2013). Besides that, another finding to suggest that our participants might have favored the use of analytical strategies on the MRT came from the non-significant correlation between the accuracy scores of MRT and 2D-PTA that contrasted with the significant correlations which have been found between them in previous studies (Kozhevnikov et al., 2006, 2013). Other than this concern of analytical strategy use, it should be noted that the MRT was the only allocentric spatial ability test administered in this study. Thus, future studies should investigate performance differences among groups of map sketchers using other types of allocentric spatial ability tests; for examples, the Paper-Folding Test and Card Rotation Test (Ekstrom, French, & Harman, 1976).

STUDY 2

The goal of Study 2 was to examine individual differences in spatial updating and relate each type of navigational strategy—procedural, survey-based, and spatial updating—to the formation of a particular type of environmental representation—route procedural, allocentric-survey, and egocentric-survey. Thus, in Study 2 we designed a new self-report questionnaire the *Navigational Strategy Questionnaire (NSQ)*—for the assessment of three distinct types of navigational strategies. With the NSQ, we aimed to assess individual differences in three types of navigational strategies and assess each strategy's contribution to the formation of each of the three environmental representations that we found.

Review of Pre-existing Spatial Navigation Questionnaires

Currently existing self-report questionnaires on spatial navigation strategies focus on assessing two distinct types of navigational strategies: route/procedural and survey-based strategies (Kato & Takeuchi, 2003; Lawton, 1994, 1996; Lawton & Kallai, 2002; Pazzaglia, Cornoldi, & De Beni, 2000; Pazzaglia & De Beni, 2001, Takeuchi, 1992). Although some of these questionnaires have items that assess certain aspects of spatial updating such as a sense-of-direction and tracking of self-to-object relations (see Lawton, 1994; Lawton & Kallai, 2002; Pazzaglia, Cornoldi, & De Beni, 2000; Pazzaglia & De Beni, 2001), none of them has a single scale with items directed at assessing spatial updating strategy only. For instance, Lawton & Kallai (2002) developed a cross-cultural *Wayfinding Strategy Scale* that consists of 17 items assessing different spatial navigational strategies (see Lawton & Kallai, 2002, p. 392). After performing a principal component analysis ($n = 512$), the authors revealed two factors: a first factor (11 items) termed *orientation strategy* and a second factor (six items) termed *route strategy*. While the route strategy scale consists of items assessing a reliance on visible signs, landmarks, and verbal instructions to find directions (e.g., *Clearly visible signs pointing the way to different sections of the building or complex were important to me*), the orientation strategy scale consists of a majority of items related to survey-based navigation assessing a reliance on cardinal directions for wayfinding (e.g., *I keep track of the direction (north, south, east, or west) in which I was going*) and several items related to spatial updating assessing an updating of self-to-object relations (e.g., *I kept track of where I was in relation to a reference point, such as the center of town, lake, river, or mountain*).

Similarly, the *Spatial Representations Questionnaire* (Pazzaglia et al., 2000; Pazzaglia & De Beni, 2001) consists of 11 items assessing different spatial navigation strategies (see Pazzaglia & De Beni, 2001, pp. 506-507). However, unlike the Wayfinding Strategy Scale (Lawton, 1994, Lawton & Kallai, 2002) that had their items loaded on two factors representing two scales of navigational strategy, Pazzaglia et al. (2000) showed their items to load on five factors based on a factor analysis (*n* = 285). The first factor consisted of six items assessing a general *sense-of-direction* (SOD). In particular, one item relates to mental map formation (*Think about the way you orient yourself in different environments around you. Would you describe yourself as a person who tries to create a mental map of the environment?*), two items relate to SOD (e.g., *Do you think you have a good sense of direction?*), and three items relate to self-to-object updating (e.g., *In a complex building (store, museum) do you think spontaneously and easily about your direction in relation to the general structure of the building and the external environment?*). The second factor consisted of two items assessing the use of cardinal directions for orientation (e.g., *When you are in your city do you naturally individuate cardinal points, that is do you find easily where north, south, east, and west are?*). The third factor consisted of three items assessing the formation of a map-like representation of the surrounding environment (e.g., *Think of an unfamiliar city. Write the name__. Now try to classify your representation of the city: survey representation, that is, a map-like representation*). The fourth factor consisted of two items related to the acquisition of landmark knowledge (e.g., *Think of an unfamiliar city. Write the name__. Now try to classify your representation of the city: landmark-centered representation, based on memorizing single salient landmarks (such as monuments, buildings, crossroads, etc.).*And the fifth factor consisted of two items related to the acquisition of route/procedural knowledge (e.g., *Think about the way you orient yourself in different environments around you. Would you describe yourself as a person who orients him/herself by remembering routes connecting one place to another?*). In summary, the items which loaded on the second and third factors are related to survey-based strategy, and the items which loaded on the fourth and fifth factors are related to route/procedural strategy. Interestingly, the six items which loaded on the first factor are related to spatial updating. However, Pazzaglia & De Beni (2001) regarded them as assessing general SOD; apart from that, they neither regarded factor one as a scale of spatial updating strategy nor did they utilize the factor one items to differentiate their participants' navigational ability.

Besides the Spatial Representations Questionnaire, an assessment of SOD is also offered by the *Santa Barbara Sense-of-Direction (SBSOD) scale* (Hegarty et al., 2002) and the *Sense-of-Direction Questionnaire-Short Form (SDQ-S)* (Kato & Takeuchi, 2003; Takeuchi, 1992). The SBSOD was developed to serve as standardized self-report measure of environmental spatial ability. It consists of 15 items that constitute one scale which give a general assessment of spatial navigation ability (see Hegarty et al., 2002, pp. 445-446). Amongst the 15 items, several items were found to be related to spatial updating (e.g., *My "sense of direction" is very good*; *I am very good at judging directions*). However, these items were not grouped to constitute a separate scale assessing spatial updating strategy. The other items on the scale were found to be assessing route knowledge (e.g., *I can usually remember a new route after I have traveled it only once*), reliance on cardinal directions (e.g., *I tend to think of my environment in terms of cardinal directions (N, S, E, W)*), and visual memory of objects (e.g. *I have a poor memory for where I left things*). Like the spatial updating items, they were similarly not grouped to constitute separate scales of navigational strategies. This resulted in only one scale score on SOD being derived from the 15 SBSOD items.

As for the SDQ-S (Kato & Takeuchi, 2003; Takeuchi, 1992), it consists of items assessing route and survey-based strategies. In a study that examined individual differences in wayfinding strategies while navigating an unfamiliar environment (Kato & Takeuchi, 2003), a principal component analysis (*n* = 330) on 17 items from the SDQ-S (Takeuchi, 1992) (see Kato & Takeuchi, 2003, p.187) revealed two clear factors. On the first factor, eight items with discriminant loadings were regarded as constituting a first scale termed *awareness of orientation* (analogous to survey-based strategy) (e.g., *I can make correct choices as to cardinal directions in an unfamiliar place*. On the second factor, six items with discriminant loadings were regarded as constituting a second scale termed *memory for usual spatial behavior* (analogous to landmark/procedural strategy) (e.g., *I have poor memory for landmarks*). This scale is regarded as assessing route strategy. As compared to the other questionnaires mentioned above, this questionnaire is exceptional for not having any item that addressed spatial updating.

Overall, the review of the four existing self-report questionnaires above showed that they assessed various spatial navigation strategies, particularly route/procedural and survey-based strategies, while not conceptualizing spatial updating as a distinct navigational strategy. Although spatial updating items exist in the Wayfinding Strategy Scale (Lawton, 1994, 1996; Lawton & Kallai, 2002), the Spatial Representations Questionnaire (Pazzaglia et al., 2000; Pazzaglia & De Beni, 2001), and the SBSOD (Hegarty et al., 2002), they were not identified as composing a separate scale that assessed spatial updating strategy only. This absence of an existing self-report scale assessing spatial updating as a distinct navigational strategy might be explained by the fact that the studies which gave detailed insights of the cognitive and neural mechanisms of spatial updating have only been done primarily during the last fifteen years (e.g., see Burgess, 2006; Klatzky, Lippa, Loomis, & Golledge, 2003; Loomis, Lippa, Klatzky, & Golledge, 2002; Wang & Spelke, 2000; Wolbers & Hegarty, 2010; Wolbers, Hegarty, Büchel & Loomis, 2008).

Therefore, in the current research, we designed a novel scale of spatial updating strategy based on the experimental studies which implicated spatial updating as a special mode of navigation that enables navigators to maintain their position and orientation relative to their points of origin and environmental cues (Klatzky et al., 1990, 1998; Loomis et al., 1993, 1998, 2002; Philbeck et al., 2001; Wang & Simons, 1999; Wang & Brockmole, 2003; Wang & Spelke, 2000). We regard this scale as pertinent for addressing individual differences in spatial updating strategy, which cannot be addressed by any of the existing questionnaires.

Designing Three NSQ Scales

The NSQ was developed with the specific aim of identifying and differentiating a scale assessing spatial updating strategy from two other scales assessing procedural and survey-based strategies. A total of 60 items were designed to assess all three types of navigational strategies; 20 items were designed to assess each type of strategy (see Appendix). The NSQ scales and their exemplar items are presented below.

Route-based scale: 15 items were modified versions of items from the Wayfinding Strategy Scale (Lawton, 1994; Lawton, 1996; Lawton & Kallai, 2002): 10 items were designed to assess the mental connection of landmarks and route segments in a non-spatial, sequential fashion (e.g., *When I navigate, I pay attention to the landmarks at the turning points and try to remember their sequence*), and five items were designed to assess the dependence on a set of egocentric actions for navigation (e.g., *To reach my destination, I largely recruit a set of procedures telling me the actions to perform (i.e., go straight/back, turn left/right) at different locations on my route*). The remaining five items were modified versions of items from the Spatial Representations Questionnaire (Pazzaglia & De Beni, 2001) and the SDQ-S (Kato & Takeuchi, 2003); they assess the dependence on a visual memory or knowledge of landmarks for orientation and wayfinding (e.g., *To avoid getting lost, I usually try to memorize the landmarks around me, along with their associated turns*).

Survey-based scale: 15 items were modified versions of items from existing questionnaires that provide an assessment of survey-based strategy (Hegarty et al., 2002; Kato & Takeuchi, 2003; Lawton, 1994; 1996; Lawton & Kallai, 2002; Pazzaglia & De Beni, 2001): one item was designed to assess the ability to use cardinal directions for orientation (*I tend to judge my orientation in the environment in terms of cardinal directions (north, south, east, west),* and 14 items were designed to assess the ability to imagine environmental features in the form of a schematic representation from a survey-based (third-person) perspective (e.g., *My mental representation of the route that I traversed is analogous to a schematic map (e.g., floor-plan, blue-print, metro map) rather than a first-person perspective of routes and landmarks*.). As for the remaining five items, they were designed with references to previous experimental studies that documented the involvement of an object-to-object (allocentric) system in encoding and retrieving spatial relations between objects/landmarks (e.g., Easton & Sholl, 1995; Rieser, 1989; Sholl, 2001). In particular, one item was designed to assess the ability to imagine a survey-based map based on fixed allocentric coordinates (*When I reconstruct my mental map, its environmental orientation is fixed and does not change with my imagined heading directions*) and four items were designed to assess the ability to perceive spatial relations between landmarks from a third-person perspective (e.g., *My mental representation of space focuses on how landmarks/objects are spatially configured in the environment rather than on how they appear in a pictorial sequence*).

Spatial updating scale: Five items were modified versions of items from the SBSOD (Hegarty et al., 2002), the Indoor Wayfinding Strategy Scale (Lawton, 1996), and the Spatial Representations Questionnaire (Pazzaglia & De Beni, 2001): two items were designed to assess a sense-of-direction (e.g., *I have navigational intuition*), and three items were designed to assess an awareness of self-to-object relations under conditions where surrounding landmarks are not visible (e.g., *I can easily point to a specific place outside the building when I don't see it from the inside*). In addition, one item was designed with reference to the suggestion that expert navigators might possess a body-centered “internal compass” that keeps them oriented in unfamiliar environments (*I have an “internal compass”*) (see Jonsson, 2002). Besides these six items, 10 items were designed with references to previous experimental studies on path integration and spatial updating. In particular, three items were designed with references to studies (Loomis et al., 1998, 2002; Philbeck et al., 2001) that implicated the navigational mechanism of spatial updating as entailed by successful wayfinding (i.e., finding a specific target/destination in mind) under conditions where visibility is low or absent (e.g., *I can find my way under low visibility conditions (or even in darkness) in familiar places better than other people*). Three items were designed with reference to studies (Klatzky et al., 1990, 1998; Loomis, 1993) that implicated the navigational mechanism of spatial updating as entailed by the constant updating of one’s position relative to a point of origin (e.g., *I can easily keep track of my direction of travel on my route with respect to the starting point*). And four items were designed with references to studies (Wang & Simons, 1999; Wang & Brockmole, 2003; Wang & Spelke, 2000) that implicated the navigational mechanism of spatial updating as entailed by the tracking and updating of egocentric representations of surrounding objects/landmarks (e.g., *At any time during a route, I can point back to the landmarks I have passed by*). As for the remaining four items, they were designed with reference to an interview with a male American firefighter regarding the use of spatial updating strategy while conducting rescue in a building on fire with low visibility (Kozhevnikov & Zhong, 2011). He claimed to be able to form 3D egocentric mental representations of the rooms in the buildings he had done searches in; an exemplar item designed to reflect this 3D mode of spatial visualization is: *I visualize my environment in the form of a 3D spatial layout that maintains the spatial relations between my imagined self and surrounding landmarks/objects*.

Three spatial cognition experts reviewed the items on each scale in terms of their theoretical soundness and relevance to the three navigational strategies. One item designed to assess the survey-based strategy was found not to be addressing a direct use of it and was removed from the set of survey-based items during testing.

METHODS

Participants. The pilot NSQ, consisting of 20 items assessing the spatial updating and procedural strategies respectively and 19 items assessing the survey-based strategy, was administered to 500 (*N* = 248 females) participants to ensure a sample size large enough to satisfy sample size suggestions for principal component analyses (see MacCallum, Widaman, Zhang, & Hong, 1999). The sample included all 71 participants who participated in Study 1. The other 429 participants came from other departments and schools at NUS (humanities and social sciences, applied sciences, computing, engineering, business administration, and medicine). They were recruited through an online advertisement posted on the university’s intranet. The participants’ age ranged from 18 to 45 years old (*M* = 21.95). All of the participants completed an online version of the NSQ on a voluntary basis. Access to the NSQ was provided through a hyperlink on the online advertisement.

Amongst the 429 participants who completed the NSQ online and did not participate in Study 1, 39 new participants (15 females), ranging from 19 to 29 years of age (*M* = 22.31), were invited to perform the series of computerized assessments as featured in Study 1. The remaining 390 participants completed the NSQ only and were not invited for further testing. This resulted in a total of 110 participants (48 females) (*M* age = 22.30), inclusive of 71 participants from Study 1, who performed the computerized assessments and completed the NSQ. All of them completed the R-PDT, I-PDT, and LRT, 109 participants (48 females) completed the MRT, 105 participants (46 females) completed the 2D-PTA, and 81 participants (34 females) completed the 3D-PTA.

Materials and instruments. Each of the 39 new participants completed the same set of computerized assessments as featured in Study 1 in one session: i) R-PDT; ii) I-PDT; iii) LRT; iv) MRT; v) 2D-PTA; and vi) 3D-PTA.

Procedure. A short online advertisement about the study was posted on the NUS intranet. A hyperlink to the online NSQ was provided. The online NSQ was created using *SurveyTool.com* (2012). Each participant completed a short demographics questionnaire inclusive of their e-mail together with the NSQ. Participants' responses were registered based on rating each item on a 5-point scale with 1 = *totally disagree* and 5 = *totally agree*; ratings “2” to “4” indicated intermediate degrees of agreement/disagreement. They were instructed that some questions appear similar but differ in important ways, and that it was crucial to be as honest as possible in answering them. No time limit was imposed for the completion of the questionnaire. Fully completed questionnaires were recorded and stored by the online survey system.

Each of 39 participants who were invited for the computerized assessments first performed the large-scale navigational tasks of R-PDT, I-PDT, and LRT in sequence, followed by performing the spatial ability tests of MRT, 2D-PTA, and 3D-PTA, which were presented in a counter-balanced fashion. All of the participants completed these assessments successfully and their data entries were merged with those of the 71 participants from study 1 for analyses. The 390 participants who completed the NSQ only were thanked and debriefed through e-mail.

RESULTS

Internal reliability of NSQ scales.

Selection of best items with discriminant factor loadings. Principal component analysis (PCA) was performed on the responses to the 59 items collected from 500 participants. The initial analysis revealed 14 factors with eigenvalues above one. Three factors had noticeably higher eigenvalues (ranging from 2.65 to 12.08) than the others (ranging from 1.01 to 1.93). They explained 33.83% of the total variance; the other 11 factors explained an additional 24.44% of the variance. None of the 11 remaining factors reached component saturation, i.e., four or more loadings exceeding ± 0.60 (Guadagnoli & Velicer, 1988), their loadings ranged between -.379 and .437. Only one factor contained two loadings with values of .437 and -.379, and the remaining 10 factors did not have any loading that exceeded those values; hence, these 11 factors were excluded from further analysis.

Based on results from the initial PCA, a second PCA with Varimax rotation was performed, and for this analysis, the factor structure was limited to three factors. For the 20 items designed to assess spatial updating strategy, all of them had positive loadings on the first factor ranging from .212 to .696. For the 19 items designed to assess the survey-based strategy, all of them had positive loadings on the second factor ranging from .033 to .695. For the 20 items designed to assess procedural strategy, 19 of them had positive loadings on the third factor ranging from .182 to .677, and one had a negative loading of -.020 on the third factor. Based on the pattern of factor loadings, the first factor was regarded as assessing spatial updating strategy, the second factor was regarded as assessing survey-based strategy, and the third factor was regarded as assessing procedural strategy. The best items with discriminant loadings on each of the three factors are presented in Table 3.

With regard to selecting out the best items with discriminant loadings on the spatial updating factor, three items with equally high positive loadings on both the first and third factors were excluded, resulting in 17 items being retained to assess the spatial updating strategy with loadings ranging from .481 to .696. As for the second factor, two items with low loadings on the second factor (< .12), and five items with equally high positive loadings on both the first and second factors were excluded, resulting in 12 items being retained to assess survey-based strategy with loadings ranging from .274 to .695. Lastly, for the third factor, two items with low loadings on the third factor (< .19), and three items with equally high positive loadings on both the first and third factor were excluded, resulting in 15 items being retained to assess procedural landmark strategy with loadings ranging from 407 to .677. Altogether, items from the three scales constituted 44 items in the final questionnaire: 17 items constituted the spatial updating scale; 12 items constituted the survey-based scale; and 15 items constituted the procedural scale (see Table 3).

Table 3

Principal Component Loadings of 44 Discriminant Items based on a Three-Factor Solution using Varimax Rotation

	NSQ items [a]	Factor 1	Factor 2	Factor 3
1.	I have navigational intuition.	**.696**	.272	-.006
2.	I have an “internal compass”.	**.631**	.237	-.098
3.	I can easily point to a specific place outside the building when I don't see it from the inside.	**.618**	.272	-.021
4.	I can find my way under low visibility conditions (or even in darkness) in familiar places better than other people.	**.610**	.179	.009
5.	In an unfamiliar environment with no clear landmarks (e.g., forest, desert, new city) and/or in low visibility conditions (e.g., fog, heavy rain), I still have a good sense of where I am heading.	**.605**	.278	-.070
6.	At any time during a route, I can point back to the landmarks I have passed by.	**.581**	.123	.268
7.	Inside buildings with no salient landmarks/objects to serve as points of reference, I can still sense the direction I am facing.	**.578**	.228	-.077
8.	I can easily keep track of my direction of travel on my route with respect to the starting point.	**.575**	.232	.144
9.	If I travel in a novel multi-level building, I can easily imagine the 3D structure of the space.	**.566**	.321	-.007
10.	At any time during a route, I can point back to where I began.	**.563**	.139	.021
11.	I can point to the exit after several turns in a building without relying on salient landmarks/objects as points of reference.	**.563**	.271	-.085
12.	It is easy for me to estimate the distance and direction between my moving body and the landmarks I have passed by on the route.	**.540**	.190	.194
13.	I know the direction to familiar buildings even when it is blocked from sight by another one.	**.533**	.188	-.013
14.	I can sense where I am heading even with my eyes closed.	**.507**	.015	-.055
15.	If I were to return to my origin, I would attempt to find a shortcut based on judging the direction-of-return to the origin rather than retracing my footsteps.	**.496**	.183	-.299
16.	My mental representation of space reflects	**.483**	.303	.091

	realistic, large-scale structural layout of my surrounding environment with relatively accurate distances.			
17.	I visualize my environment in the form of a 3D spatial layout that maintains the spatial relations between my imagined self and surrounding landmarks/objects.	**.481**	.221	.090
18.	My mental representation of the route that I traversed is analogous to a schematic map (e.g., floor-plan, blue-print, metro map) rather than a first-person perspective of routes and landmarks.	.077	**.695**	-.142
19.	I usually attempt to mentally represent route segments, turns and their spatial relationships from a top-down aerial perspective.	.342	**.665**	-.008
20.	I rely primarily on a schematic mental representation of my environment to figure out my position in the environment.	.091	**.657**	.020
21.	I can plan out my route of travel by visualizing a schematic map from a top-down aerial perspective.	.268	**.626**	.019
22.	I usually attempt to visualize a map of the environment from a top-down aerial perspective as I travel.	.306	**.615**	.000
23.	I rely primarily on a schematic mental representation of my environment to help me in finding shortcuts.	.159	**.598**	-.084
24.	When I imagine reorienting myself on my mental map, I tend to visualize my environment from the top-down aerial perspective and turn my imagined position to face the new heading.	.114	**.574**	-.012
25.	My mental representation of my traveled route resembles a schematic plan of abstract spatial relationships rather than a pictorial, sequential plan of landmarks/objects.	.339	**.513**	-.107
26.	I tend to reconstruct my traveled route by imagining abstract spatial relationships amongst different places in a schematic plan rather than by imagining re-walking the route from a 3D first-person perspective.	.162	**.501**	-.130
27.	I usually rely on a schematic mental representation to orient and navigate to familiar places.	.262	**.499**	.067

28.	I tend to judge my orientation in the environment in terms of cardinal directions (north, south, east, west).	.223	**.398**	-.070
29.	When I reconstruct my mental map, its environmental orientation is fixed and does not change with my imagined heading directions.	.143	**.274**	.007
30.	When I navigate, I pay attention to the landmarks at the turning points and try to remember their sequence.	.019	-.073	**.677**
31.	To avoid getting lost, I usually try to memorize the landmarks around me, along with their associated turns.	-.101	-.021	**.653**
32.	I rely primarily on landmarks as signs of turning points along my route of travel.	.006	-.070	**.590**
33.	If I were to walk on my route again, I would depend heavily on a sequence of mental “snapshots” of landmarks or scenes to go to the places I had been to.	.013	-.092	**.548**
34.	I keep a mental record of the landmarks I see on my traveling route in a sequential fashion.	.193	.064	**.526**
35.	To reach my destination, I largely recruit a set of procedures telling me the actions to perform (i.e., go straight/back, turn left/right) at different locations on my route.	-.205	.054	**.510**
36.	I prefer following directions with descriptions of landmarks at turning points rather than using a map.	-.031	-.212	**.505**
37.	I find it much easier to recall my route as a set of procedures or actions than as a pattern of spatial relationships.	-.248	-.207	**.496**
38.	If I need to return to my origin, it is easier for me to retrace my route than to find a new shortcut.	-.351	-.032	**.490**
39.	I find it much easier to understand my route procedurally (i.e., where to head and where to turn) than based on forming a map-like mental representation.	-.118	-.200	**.481**
40.	It is very difficult for me to find a shortcut because I think of my route as a sequence of routes and turns.	-.392	-.068	**.464**
41.	My mental representation of space primarily involves sequences of route segments and turning points.	.082	.120	**.463**

42.	Whenever I get lost, I try to reorient myself in relation to the visible landmarks.	.142	.116	**.407**
43.	I remember my route traveled as a succession of different segment lengths and turns without clear spatial relationships.	-.065	-.035	**.332**
44.	I have stored mental “snapshots” of landmarks or scenes which do not inform me clearly of my position and orientation in the environment.	.011	.009	**.313**

Note. Loadings in each column were arranged in descending order. Loadings in bold within the Factor 1 column identify items which were designed to measure spatial updating strategy. Loadings in bold within the Factor 2 column identify items which were designed to measure survey-based strategy. Loadings in bold within the Factor 3 column identify items which were designed to measure procedural strategy.

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Internal and test-retest reliability of the NSQ scales. The internal reliability of the final set of items constituting each strategy scale is shown in Table 4. Cronbach’s α values of spatial updating and survey-based scales are above McKelvie’s (1994) recommended minimum coefficient of .85 whereas Cronbach’s α value of the procedural strategy scale is within the range of other recommended minimum coefficients (from .60 to .85) as reviewed by McKelvie.

In assessing the test-retest reliability of the NSQ, the original online version was re-administered after two weeks to a sample of 40 participants (18 females; *M* age = 22.9). First, their mean scale scores were computed by averaging their ratings on the selected discriminant items that constituted each scale in both test sessions. Then, the test-retest reliability of each NSQ scale was assessed by computing the correlation between two sets of scale scores, one from each test session. As shown in Table 4, the test-retest correlations for all three NSQ scales were high (rs $\geq .87$, ps $< .001$. The correlation coefficients for all three scales were all within McKelvie’s very good ($r \geq .85$) delayed test-retest reliability range.

Table 4

Internal and Test-Retest Reliability, and Descriptive Statistics of Three NSQ Scales

NSQ scale	Cronbach's α	Test-retest reliability (Pearson's *r*)	*M*	*SD*	Minimum	Maximum
Spatial updating	.90	.87**	3.08	0.63	1.00	4.82
Survey-based	.86	.88**	3.10	0.63	1.33	5.00
Procedural	.81	.87**	3.54	0.48	1.27	4.60

** $p < .01$ (two-tailed).

Descriptive statistics of the NSQ scales. For each participant, the ratings from the selected items on each factor were summed and averaged to create three scale scores corresponding to spatial updating (17 items), survey-based (12 items) and procedural strategies (15 items) respectively. Table 4 shows the descriptive statistics of the three strategy scales. The one-sample Kolmogorov-Smirnov test of goodness-of-fit showed no deviation from normality for the spatial updating, D (500) = 1.06, $p = .209$ (two-tailed), and survey-based strategy scales, D (500) = 1.09, $p = .182$ (two-tailed). However, deviation from normality was significant for the procedural strategy scale, D (500) = 1.77, $p = .004$ (two-tailed). The distribution of the procedural strategy scale scores was negatively skewed: *skewness* = -.756, *SE* = 0.109. Participants generally rated themselves higher on the items assessing procedural strategy than on those assessing spatial updating and survey-based strategies.

Predictive validity of NSQ scales.

Computation of efficiency scores. As previous studies have reported the confounding influence of speed-accuracy tradeoff (i.e., higher accuracy at the expense of slow response latency and vice versa) during visual-spatial task performance (e.g., Lohman, 1990; Lohman & Nichols, 1990), an integrated efficiency score combining both accuracy and response latency were computed for all computerized assessments. For each assessment, efficiency scores were computed by dividing the accuracy scores over the natural logarithmic function (Ln) of response latencies.[3] These scores have also been used by other spatial cognition researchers as indicators of the efficiency of visual-spatial processing and to avoid the speed-accuracy confound (e.g., Blazhenkova & Kozhevnikov, 2010, Kozhevnikov, Louchakova, Josipovic, & Motes, 2009, Kozhevnikov et al., 2013). Table 5 shows the intercorrelations between them and the three sets of NSQ scale scores.

Table 5

Pearson Product-Moment Correlations between NSQ Scale scores and Efficiency Scores of Navigational and Spatial Assessments (N = 80)

		1.	2.	3.	4.	5.	6.	7.	8.	9.
1.	NSQ spatial updating	_								
2.	NSQ survey-based	.67**	_							
3.	NSQ procedural	-.32**	-.34**	_						
4.	R-PDT	.49**	.33**	-.34**	_					
5.	I-PDT	.38**	.15	-.26*	.48**	_				
6.	LRT (route-based)	.20†	.12	.01	.27*	.09	_			
7.	MRT	.01	.02	-.10	-.02	.04	-.05	_		
8.	2D-PTA	.32**	.21†	-.22†	.33**	.29**	.05	.24*	_	
9.	3D-PTA	.19†	.19†	-.28*	.48**	.29**	.04	.23*	.50**	_

** *p* < .01 (two-tailed).
* *p* < .05 (two-tailed).
† *p* < .10 (two-tailed).

As shown in Table 5, with regards to the NSQ scale scores, the correlations between the spatial updating scale scores and the efficiency scores of R-PDT, I-PDT, and 2D-PTA were significantly positive and moderately high (.32 ≤ *r*s ≤ .49, *p*s < .01), the correlation between the survey-based scale scores and the efficiency scores of R-PDT was significantly positive (*p* < .01), and the correlations between the procedural scale scores and efficiency scores of R-PDT, I-PDT, and 3D-PTA were significantly negative (*p*s < .05). As for

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[3] A natural logarithmic transformation was used to normalize skewed response latency data. In this study, the one-sample Kolmogorov-Smirnov test indicated that the *Ln*-transformed latencies of each computerized assessment did not deviate significantly from a normal distribution (*p*s > .10). As for efficiency scores, there were no significant deviation from a normal distribution for R-PDT, I-PDT, LRT, MRT, and VR-PTA (*p*s > .23). However, the efficiency scores of the 2D PTA exhibited a negative skewness of -3.61 and significantly deviated from normality (*p* = .003).

the intercorrelations between the efficiency scores, the prominent finding was that the intercorrelations between the efficiency measures of large-scale navigational pointing tasks (R-PDT and I-PDT) and egocentric spatial ability tests (2D-PTA and 3D-PTA) were all significantly positive (ps $\leq .01$) and moderately high ($.29 \leq r$s $\leq .48$).

In the assessment of each NSQ scale's predictive validity, we converted all sets of efficiency scores into standardized z-scores corresponding to four dependent variables for regression on the three NSQ scale scores: i) large-scale navigational pointing; ii) egocentric spatial ability; iii) allocentric spatial ability; and iv) route-based landmark recognition. The first two variables were composite variables created to reduce the number of dependent variables used for regression on the NSQ scale scores. The composite measures of large-scale navigational performance were computed by converting the efficiency measures of R-PDT and I-PDT into two sets of z-scores respectively, followed by summing and averaging each pair of z-scores into a set of mean z-scores. Likewise, the composite measures of egocentric spatial ability were computed by converting the efficiency measures of 2D-PTA and 3D-PTA into two sets of z-scores respectively, followed by summing and averaging each pair of z-scores into a set of mean z-scores.[4] On the other hand, the third and fourth variables represented the standardized efficiency measures of MRT and route-based landmark recognition respectively.

In terms of predictions, we expect the spatial updating scale to be a significant predictor of large-scale navigational pointing performance, the survey-based scale to be a significant predictor of allocentric spatial ability, and the procedural scale to be a significant predictor of route-based landmark recognition.

Multiple regression of efficiency measures on NSQ scale scores. In examining the predictive validity of the three NSQ scales, we applied a two-step hierarchical multiple regression that first entered two sets of procedural

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[4] To support the legitimacy of creating the composite measures, we conducted a principal component analysis with Varimax rotation on all spatial assessments (R-PDT, I-PDT, MRT, 2D-PTA, and 3D-PTA), which revealed two clear factors with eigenvalues above one. R-PDT and I-PDT are related in having significant loadings on factor one only (R-PDT: .850; I-PDT: .760). 2D-PTA and 3D-PTA are related in having significant loadings on both factors (2D-PTA: .510 on factor one and .586 on factor two; 3D-PTA: .611 on factor one and .528 on factor two). MRT loaded significantly on factor two only (.873).

and survey-based scale scores as predictors for each dependent variable in a first model, followed by entering the set of spatial updating scale scores as an additional predictor in a second model. Similar to the dependent variables, all sets of NSQ scale scores were standardized as z-scores. We applied this regression method in order to have an initial assessment of the predictive validity of the procedural and survey-based scales, which assess two conventional and well-documented navigational strategies, prior to examining the additional predictive effect of the spatial updating scale. Table 6 shows the results from four sets of hierarchical multiple regressions; for each set of dependent efficiency scores, it presents the beta coefficient of each predictor and the total variance or predictive effect contributed by the predictors in each model (R^2).

Table 6

Results of Hierarchical Multiple Regression Analyses to predict Four Dependent Variables from Three NSQ Scales

	Large-scale navigational pointing performance			Egocentric spatial ability			Allocentric spatial ability			Route-based landmark recognition		
Predictors	*B*	*SE B*	β	*B*	*SE B*	β	*B*	*SE B*	β	*B*	*SE B*	β
Model 1												
NSQ procedural	-0.18	0.07	-0.24*	-0.21	0.10	-0.24*	-0.23	0.09	-0.25*	0.12	0.09	0.14
NSQ survey-based	0.15	0.07	0.20*	-0.14	0.10	0.15	-0.13	0.09	-0.14	0.16	0.09	0.18†
R^2		.13			.10			.06			.04	
Adjusted R^2		.11			.08			.04			.02	
F		7.89**			4.41*			3.47*			2.05	
Model 2												
NSQ procedural	-0.16	0.06	-0.21*	-0.19	0.10	-0.21†	-0.23	0.09	-0.25*	0.14	0.09	0.15
NSQ survey-based	-0.17	0.09	-0.23†	0.01	0.13	0.01	-0.13	0.12	-0.14	-0.04	0.12	-0.05
NSQ spatial updating	0.48	0.09	0.62***	0.19	0.13	0.22	-0.003	0.13	-0.003	0.30	0.12	0.33*
R^2		.31			.13			.06			.09	
Adjusted R^2		.29			.10			.04			.06	
F for ΔR^2		28.47***			2.28			0.001			5.95*	

*** $p < .001$.
** $p < .01$.
* $p < .05$.
† $p < .10$.

With reference to Table 6, we assessed the predictive validity of each NSQ scale in relation to each dependent variable. First, with regards to large-scale navigational pointing performance, in model 1, both the procedural and survey-based scales emerged as significant predictors (*p*s < .05). In model 2, the spatial updating scale emerged as a significant predictor ($p < .001$); its addition improved the prediction by 18% of the variance ($\Delta R^2 = .18$,). With the spatial updating scale's inclusion, the procedural scale remained as a significant predictor ($p = .016$) whereas the survey-based scale became a marginally significant predictor ($p = .052$). These findings generally showed that all three NSQ scales possess predictive validity in relation to large-scale navigational pointing performance.

Next, with regards to egocentric spatial ability, in model 1, the procedural scale emerged as a marginally significant predictor ($p = .044$) whereas the survey-based scale emerged as a non-significant predictor ($p = .188$). In model 2, the spatial updating scale did not emerge as a significant predictor ($p = .135$); its addition improved the prediction non-significantly by 3% of the variance ($\Delta R^2 = .03$). With the spatial updating scale's inclusion, the procedural scale remained as a marginally significant predictor ($p = .068$) and the survey-based scale remained as a non-significant predictor ($p = .938$). Similarly, with regards to allocentric spatial ability, in model 1, the procedural scale emerged as a significant predictor ($p = .012$) whereas the survey-based scale emerged as a non-significant predictor ($p = .153$). In model 2, the spatial updating scale did not emerge as a significant predictor ($p = .980$); its addition did not improve the prediction by any amount of variance. With the spatial updating scale's inclusion, the procedural scale remained as a significant predictor ($p = .013$) and the survey-based scale remained as a non-significant predictor ($p = .313$).

Lastly, with regards to route-based landmark recognition, in model 1, the procedural scale emerged as a non-significant predictor ($p = .171$) whereas the survey-based scale emerged as a marginally significant predictor ($p = .069$). In model 2, the spatial updating scale emerged as a significant predictor ($p = .016$); its addition improved the prediction by 5% of the variance ($\Delta R^2 = .05$). With the spatial updating scale's inclusion, the procedural scale remained as a non-significant predictor ($p = .119$) whereas the survey-based scale became a non-significant predictor (*p* = .735).

In summary, the results confirmed our prediction of the spatial updating scale as having predictive validity in relation to large-scale navigational pointing performance. Interestingly, they also showed the spatial updating scale to be a significant predictor of route-based landmark recognition. This suggests that an effective use of spatial updating strategy also relies on landmark knowledge of a traversed route. As for the two other NSQ scales, although the results did not confirm our specific predictions about their predictive validity, they showed the procedural scale to have predictive validity in relation to large-scale navigational pointing performance, egocentric and allocentric spatial abilities, and the survey-based scale to have predictive validity in relation to large-scale navigational pointing performance.

Relationship between sketchmap categories and navigational strategies. To reveal the relationship between different types of sketchmaps and navigational strategies, a 3 (Sketchmap Category) x 3 (Navigational Strategy) mixed-model ANOVA was performed on the 62 map sketchers from Study 1 who completed the NSQ in Study 2. Sketchmap Category was the between-subjects factor and Navigational Strategy was the within-subjects factor. The NSQ scale scores were transformed into z-scores as dependent measures.[5]

With regards to three sets of NSQ scale z-scores, the ANOVA showed a significant main effect of Sketchmap Category, F (2, 59) = 5.13, $p = .009$, $\eta^2 = .148$, but a non-significant main effect of Navigational Strategy, F (1.29, 75.99) = 1.88, $p = .172$, $\eta^2 = .031$ (Greenhouse-Geisser corrected). Moreover, there was a significant interaction between Navigational Strategy and Sketchmap Category, F (2.58, 75.99) = 9.56, $p < .001$, $\eta^2 = .245$ (Greenhouse-Geisser corrected). As shown in Figure 5, this interaction resulted in a different distribution of NSQ z-scores across the three sketchmap categories for each navigational strategy.

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[5] Z-scores were used in view of the negative skewness present in the distribution of procedural scale scores that culminated in them generating a higher mean than those of the two other scales (see Table 4). Consequently, the use of raw NSQ scale scores would not give an accurate assessment of between-group differences in terms of self-reported navigational strategies, so z-scores had to be applied to give standardized comparisons of NSQ scale scores between the sketchmap categories.

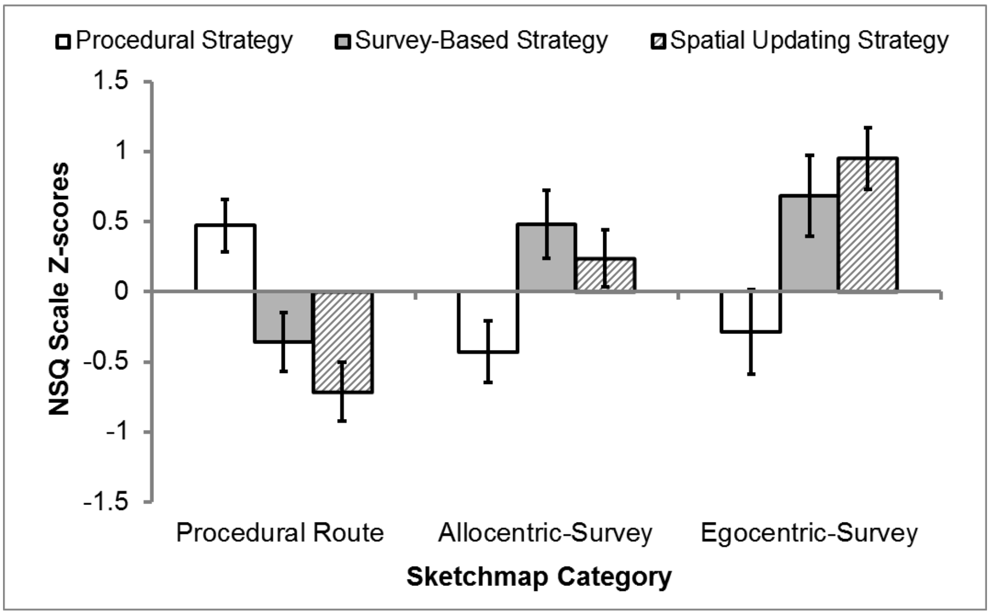

Figure 5. Sketchmap differences in terms of self-reported navigational strategies. Error bars show ± 1 *SEM*.

The differences between the three groups of map sketchers in terms of the z-scores of each NSQ scale were analyzed with alpha adjusted to 0.017 using Bonferroni correction. Significant main effects of Sketchmap Category were found in terms of the z-scores of: i) the spatial updating scale, F (2, 59) = 14.76, $p < .001$, $\eta^2 = .333$; ii) the survey-based scale, F (2, 59) = 5.33, $p = .007$, $\eta^2 = .153$; and iii) the procedural scale, F (2, 59) = 4.90, $p = .011$, $\eta^2 = .142$. All follow-up between-groups comparisons were performed using the Tukey *HSD* test.

On the spatial updating scale, egocentric-survey map sketchers reported higher scores than both allocentric-survey map sketchers ($p = .073$) (marginally significant) and procedural route map sketchers ($p < .001$). Similarly, allocentric-survey map sketchers reported higher spatial updating scale scores than procedural route map sketchers ($p = .004$).

On the survey-based scale, allocentric-survey map sketchers reported higher scores than procedural route map sketchers ($p = .033$). Similarly, egocentric-survey map sketchers reported higher scores than procedural route map sketchers ($p = .013$). Other than that, the difference in scores between the allocentric- and egocentric-survey map sketchers was non-significant ($p = .842$).

On the procedural scale, procedural route map sketchers reported higher scores than both egocentric-survey (p = .069) (marginally significant) and allocentric-survey map sketchers (p = .013). Other than that, the difference in scores between the allocentric- and egocentric-survey map sketchers was non-significant (p = .912).

In summary, the between-groups comparisons showed that among the three groups of map sketchers, egocentric-survey map sketchers reported the highest scores on the spatial updating scale whereas procedural route map sketchers reported the highest scores on the procedural scale.

As for analyzing the differences between the z-scores of the three NSQ scales within each sketchmap category, planned comparisons (in accordance with our predictions) were applied with alpha set at 0.05 (one-tailed).

First, amongst the egocentric-survey map sketchers, planned comparisons showed that they reported higher scores on the spatial updating scale than on both the survey-based scale, t (15) = 1.56, *SEM* = 0.17, p = .070 (one-tailed) (marginally significant), and the procedural scale, t (15) = 2.54, *SEM* = 0.49, p = .012 (one-tailed). A post-hoc comparison further showed that they reported higher scores on the survey-based scale than on the procedural scale, t (15) = 2.11, *SEM* = 0.54, p = .045 (one-tailed).

Second, amongst the allocentric-survey map sketchers, planned comparisons showed that they reported higher scores on the survey-based scale than on the spatial updating scale, t (21) = 1.56, *SEM* = 0.16, p = .067 (one-tailed) (marginally significant), and procedural scale, t (21) = 2.34, *SEM* = 0.39, p = .015 (one-tailed). A post-hoc comparison further showed that they reported higher scores on the spatial updating scale than on the procedural scale, t (21) = 2.00, *SEM* = 0.33, p = .030 (one-tailed).

Third, amongst the procedural map sketchers, planned comparisons showed that they reported higher scores on the procedural scale than on the spatial updating scale, t (23) = 4.72, *SEM* = 0.25, $p < .001$ (one-tailed), and survey-based scale, t (23) = 2.88, *SEM* = 0.29, p = .004 (one-tailed). A post-hoc comparison further showed that they reported higher scores on the survey-based scale than on the spatial updating scale, t (23) = 2.09, *SEM* = 0.17, p = .025 (one-tailed).

In summary, the within-group analyses were consistent with our predictions and showed that each group of map sketchers preferred a particular navigational strategy amongst themselves: the egocentric-survey map sketchers preferred the spatial updating strategy, the allocentric-survey map sketchers preferred the survey-based strategy, and the procedural map sketchers preferred the procedural strategy.

Gender differences. To investigate gender difference for each navigational strategy, we performed three univariate contrasts between the sexes on all 500 participants. An effect of gender was found for all three navigational strategies: i) spatial updating: F (1, 498) = 43.14, $p < .001$, η^2 = .080; in favor of males; ii) survey-based: F (1, 498) = 49.56, $p < .001$, η^2 = .091; in favor of males, and iii) procedural: F (1, 498) = 18.56, $p < .001$, η^2 = .036; in favor of females. On the spatial updating scale, male participants (M = 3.63, SD = 0.40) reported higher scores than female participants (M = 3.45, SD = 0.54). Similarly, on the survey-based scale, male participants (M = 3.29, SD = 0.61) reported higher scores than female participants (M = 2.91, SD = 0.60). In contrast, on the procedural strategy scale, female participants (M = 3.63, SD = 0.40) reported higher scores than male participants (M = 3.45, SD = 0.54).

Interestingly, these gender differences derived from our total sample were consistent with those derived from the Wayfinding Strategy Scale (Lawton, 1994; Lawton, 1996; Lawton and Kallai, 2002), which showed men to report a higher use of orientation strategy but a lower use of route strategy than women. They were also consistent with many other previous studies implicating males to prefer a visual-spatial strategy that involves consideration for spatial relations and environmental cues and females to prefer a landmark/route-based strategy that involves recognizing salient landmarks and associating egocentric responses with them (e.g., Dabbs, Chang, Strong, & Milun, 1998; Lawton, Charleston, & Zieles, 1996; Saucier et al., 2002).

DISCUSSION

In this study, we designed and validated the new NSQ to provide a first-time self-assessment of spatial updating strategy, differentiating it against two other navigational strategies related to survey-based and procedural navigation. Based on the factor analyses performed on the NSQ data collected from a large pool of participants from various academic disciplines, three distinct factors, each with a sizeable number of items with discriminant loadings, were identified to represent three navigational strategy scales: spatial updating, survey-based, and procedural. Each scale was shown to have high internal and test-retest reliabilities, as well as predictive validity in relation to large-scale navigational pointing performance.

Prominently, the main finding of this study showed the novel spatial updating scale to have predictive validity in relation to navigational performance, characterized by large-scale navigational pointing and route-based landmark recognition, in a large-scale urban environment. In addition to the procedural and survey-based scales that accounted for 13% of the variance towards the prediction of large-scale navigational pointing performance, the spatial updating scale was found to have contributed an additional 18% to the total variance. This unique variance contributed by the spatial updating scale exceeded the total variance contributed by the two other scales and this importantly implicates that the spatial updating strategy—which was not conceptualized by any existing spatial navigation questionnaire as a distinct navigational strategy—to be a principal navigational strategy that is directly relevant for navigation in a large-scale urban environment.

Furthermore, with respect to the relationship between the NSQ scales and the sketchmaps, we found that the egocentric-survey map sketchers exhibited the highest scores on the spatial updating scale in both between-groups and within-group comparisons. Their prominent preference for the spatial updating strategy supported our hypothesis of spatial updating as engendering the formation of egocentric-survey representations. Following the same pattern of results, we found that the procedural route map sketchers exhibited the highest scores on the procedural scale in both between-groups and within-group comparisons. Their prominent preference for the procedural strategy corresponded well with their depiction of environmental features in a non-spatial/procedural fashion and suggests that a major reliance on the procedural strategy leads to the acquisition of route knowledge, but not of survey knowledge.

On the other hand, for the survey-based navigational strategy, we found that the survey-based scores of allocentric-survey and egocentric-survey map sketchers did not differ significantly. This finding showed that the survey-based scale was unable to identify a specific group of map sketchers with a prominent preference for the survey-based strategy. This inability of the survey-based scale to do so could be explained by its composition of the lowest number of discriminant items among the three scales (i.e., 12 items), which might be insufficient to offer a scale score that renders a truly discriminant measure of survey-based strategy. Thus, to improve our survey-based scale as a better scale for capturing individual differences in survey-based strategy, we recommend future studies that use it to expand its current number of items with more discriminant ones that address wider aspects of survey-based navigation.

Overall, this study was crucial for demonstrating the significant relationships of spatial updating strategy use with large-scale navigational performance and the formation of egocentric-survey representations. Notably, our finding of the spatial updating scale as having predictive validity supports its use in future studies as a valid self-report measure in predicting large-scale navigational performance. As for the procedural and survey-based scales, although we revealed their predictive validity in relation to large-scale navigational pointing performance, we neither revealed the procedural scale as a significant predictor of route-based landmark recognition nor the survey-based scale as a significant predictor of allocentric spatial ability that was measured by the MRT. Therefore, to give more support for the predictive validity of these two scales, future studies can employ other tasks involving navigation in large-scale space that may offer a more focused assessment of procedural and survey-based strategies. For examples, the predictive validity of the procedural scale could be further assessed with a *scene recognition task* that requires participants to arrange the scenes they recognize into a sequence that fits the one they encoded from route traversal (e.g., see Cornell, Sorenson, & Mio, 2003); and the predictive validity of the survey-based scale could be further assessed using a *map reading (wayfinding) task* that requires participants to utilize a schematic map to find their way through an unfamiliar route from the start to the end (e.g., see Pazzaglia & De Beni, 2001).

GENERAL DISCUSSION

The main goal of this research was to investigate whether a unique type of egocentric-survey representation exists and whether a navigational strategy of spatial updating could lead to its acquisition.

The results of Study 1 indicated that there are indeed two distinct types of survey representations as represented by the allocentric- and egocentric-survey maps. Both types of survey maps encoded information about the spatial layout of environmental features but the egocentric-survey maps stood apart from the allocentric-survey maps for having encoded orientation information pertaining to multiple egocentric and orientation-specific viewpoints. Furthermore, the findings of the egocentric-survey map sketchers having significantly better performance than the allocentric-survey map sketchers on the spatial updating tasks (i.e., R-PDT and I-PDT) that required the updating and retrieval of self-to-object relations suggest that the former group relies highly on spatial updating mechanisms when navigating in environmental space.

The results of Study 2 showed that individual differences in spatial updating exist and that they could be captured by a self-report scale addressing spatial updating strategy, which was found to be the best predictor of large-scale navigational performance.

In conjunction, these two studies demonstrated significant relationships between different types of navigational strategies and environmental representations. They showed that the three navigational strategies were distinct with regards to different navigational mechanisms. For the procedural strategy, it is typified by the mechanisms of attending to landmarks at turning points, mentally associating observed landmarks in a sequential/non-spatial fashion, and relying on a set of specific procedures (i.e., go straight/back, turn left/right) for finding one’s destination. For the survey-based strategy, it is typified by the mechanisms of integrating interobject relations between landmarks, turning points, and route segments into an allocentric spatial layout, and positioning and orienting oneself based on a top-down third-person perspective. And for the spatial updating strategy, it is typified by the mechanisms of constantly updating one’s self-to-object or self-to-origin relations during navigation, maintaining an egocentric orientation with respect to surrounding landmarks, and forming transient egocentric representations of observed landmarks and scenes.

Altogether, our findings imply that these different navigational mechanisms contributed to the formation of three distinct types of environmental representations. The different ways in which the three environmental representations were encoded further suggest that each type of environmental representation might confer certain advantages and disadvantages for navigation. For instance, in having a procedural route representation that encoded mostly information about landmarks encountered on the route and their associated turns in a visual or verbal format, one would not be successful on spatial tasks that require accurate encoding of spatial layout, but might be successful in finding his/her destination based on visual memory of salient landmarks (see Denis, Pazzaglia, Cornoldi, & Bertolo, 1999). On the other hand, having an allocentric-survey representation would enable one to be successful at deriving accurate estimates of Euclidean (straight-line) distances and/or cardinal directions between different places for efficient navigation in a familiar environment (see Rothkegel, Wender, & Schumacher, 1998). However, due to the encoding of spatial layout primarily in an orientation-free manner, allocentric-survey map sketchers would not perform as well as egocentric-survey sketchers (either in accuracy or latency) on spatial tasks that require knowledge of orientation-specific representations (e.g., I-PDT, R-PDT, and 3D-PTA). Lastly, having an egocentric-survey representation, as this research suggests, would enable one to maintain one’s egocentric orientation with respect to recognizable landmark cues after fresh exposures to new surroundings. However, spatial updating might not be a beneficial strategy once a navigator becomes disoriented. Should an egocentric-survey map sketcher become disoriented in relation to landmarks encountered en route, it would be very difficult for him/her to orient correctly in the right direction and navigate towards his/her destination (cf. Wang & Spelke, 2000). In contrast, allocentric-survey map sketchers, after disorientation, should still be able to navigate successfully to their destinations since their mental maps are based on an allocentric format that is non-dependent on their egocentric orientation towards surrounding landmarks.

Aside from addressing navigational mechanisms and environmental representations, this research importantly highlights that navigational performance is affected by the presence of individual differences in spatial updating. We regard an understanding of individual differences in spatial updating as beneficial for the development of more spatial cognition models for addressing the mechanisms of human spatial updating in greater detail.

In the extant literature, spatial updating in humans has been traditionally investigated using the triangle completion or path completion task that usually requires participants to return to a point of origin after walking on two legs of a triangular path (see Loomis et al., 1999). In general, most participants have been found to commit *systematic errors* of path integration while walking back to the origin (i.e., over-turning or under-turning while heading back to the origin and over-shooting or under-shooting the length of a return leg) (Loomis et al., 1993). Existing models such as the “encoding error” model (Fujita, Klatzky, Loomis, and Golledge, 1993) attributes such errors wholly to an inaccurate encoding of path features (i.e., leg lengths and turning angles) while forming an internal representation of a traveled path. A previous study that examined this model further suggested that the encoding of path features was affected by participants’ experience with navigating different types of paths which varied in complexity (Klatzky, Beall, Loomis, Golledge, & Philbeck, 1999). Interestingly, these previous research eschewed the possibility that the systematic errors of path integration might be reflective of errors committed by a heterogeneous pool of participants with varying levels of spatial updating ability. As the current research showcased spatial updating strategy use to be pertinent for large-scale navigational performance, it is likely that participants who reported relatively high scores on the spatial updating scale might commit fewer systematic errors than those who reported lower scores on the same scale in a triangle completion task. Based on this possibility, the encoding error model, as well as any future spatial cognition model, should ascertain whether the encoding of path features is affected by individual differences in spatial updating strategy use, rather than by the experience of navigating various paths alone.

Furthermore, aside from behavioral investigations of spatial updating/path integration, the three NSQ scales could be helpful for research on neural correlates of individual differences in spatial navigation. A stronger support of individual differences in the use of each type of navigational strategy will be attained if each set of scale scores were to correlate with the levels of brain activity of specific regions of interest during the performance of a computerized navigational task. This type of correlation has been previously found in the form of a positive relationship between SBSOD scale scores and differential levels of activity in the right hippocampus (see Wegman & Janzen, 2011). However, as the SBSOD only offers one set of scale scores, it cannot be used to pinpoint the neural correlates of different navigational strategies. The three sets of scale scores offered by the NSQ can thus serve as better candidates for this purpose.

Starting with the procedural strategy, future studies can investigate whether its scale scores correlate with activation in the parahippocampal gyrus that has been shown to associate egocentric turning behaviors with relevant landmarks or locations (Janzen & van Turennout, 2004; Janzen, Wagensveld, & van Turennout, 2007; Wegman & Janzen, 2011), and the caudate nucleus that has been identified with the use of a non-spatial response/analytical strategy akin to the procedural strategy (Bohbot, Lerch, Thorndycraft, Iaria, & Zijdenbos, 2007; Iaria, Petrides, Dagher, Pike, & Bohbot, 2003). For the survey-based strategy, future studies can investigate whether its scale scores correlate with activation in the right hippocampus that has been shown to be present during the encoding of distal boundary cues and spatial landmarks during orientation (Doeller & Burgess, 2007; Iaria et al., 2003), and in the active use of a cognitive map for wayfinding (Iaria, Chen, Guariglia, Ptito, & Petrides, 2007; Maguire et al., 1998). Lastly, for the spatial updating strategy, future studies can investigate whether its scale scores correlate with activation in the precuneus that has been shown to increase linearly with the number of objects encoded for making egocentric pointing responses (i.e., pointing back to a particular object after a forward translation) (Wolbers et al., 2008). In general, finding all of these potential relationships will help to pinpoint the specific neural region(s) associated with the use of each type of navigational strategy.

Aside from the theoretical implications highlighted above, in the practical sense, an understanding of individual differences in navigational strategies is beneficial to the design and application of in-vehicle navigation systems so as to cater to the needs of different drivers who rely on different navigational strategies. Previous research showed that participants who self-reported a relatively good sense-of-direction (Baldwin, 2009; Furukawa, Baldwin, & Carpenter, 2004) and a high reliance on the survey/orientation strategy (Baldwin, 2009) demonstrated significantly better route recall after simulated driving using an allocentric visual map display rather than verbal route instructions (e.g., “turn left”, “continue forward”). In contrast, participants who self-reported a poor sense-of-direction demonstrated significantly better route recall after simulated driving using verbal route instructions (Furukawa et al., 2004). These previous studies were notable for highlighting that a driver’s preferred navigational strategy should complement a suitable form of in-vehicle navigation system to ensure optimal navigation and environmental spatial learning.

In this respect, the NSQ can serve as a new instrument that helps to identify drivers with distinct strategic preferences in the effort to accommodate their navigational styles with suitable forms of in-vehicle navigation systems. For instance, we suggest that individuals with relatively high scores on the spatial updating scale may exhibit the best driving performance and spatial knowledge acquisition based on an in-vehicle navigation system with an electronic “track-up” map display. The “track up” map typically shows a fixed traveler’s icon (e.g., a triangular arrowhead) that remained pointing upwards as the map elements rotated and translated with movement (Rodes & Gugerty, 2012). This type of display may be the most suitable for high users of spatial updating strategy as it gives the driver an egocentric sense of orientation within the environment and enables him/her to perform a direct alignment of allocentric headings on the map with egocentric forward views (Aretz, 1991; Rodes & Gugerty, 2012).

Aside from accommodating the navigational strategies of drivers with suitable in-vehicle navigation systems, future research can help to inform the design of better virtual environment (VE) navigation systems for assessment and training purposes. In this research, we applied an immersive VE offered by the 3D-PTA and demonstrated that the egocentric-survey map sketchers outperformed the two other groups of map sketchers in the 3D-PTA; this suggests that 3D-PTA's immersive VE facilitates egocentric spatial processing. In addition, the findings of egocentric-survey map sketchers having the highest scores on the spatial updating scale among the three groups of map sketchers, and that those scale scores were positively related to performance on the 3D-PTA and spatial updating tasks (i.e., R-PDT and I-PDT), suggest that a 3D, immersive VE may be well suited for doing future assessment or training of navigators who rely highly on the spatial updating strategy. Besides that, in view of individual differences in navigational strategies, future VE navigation systems should also strive to accommodate the preferred navigational strategy of each user with suitable interfaces and visual displays which facilitate the use of that strategy. Doing so is likely to ensure effective performance and learning in a VE, as well as an optimal transfer of spatial information for navigation/wayfinding from the VE to the real world.

Finally, with regard to personnel selection, our findings indicate that the NSQ spatial updating scale may be applied for the selection of professionals whose daily work demands them to rely extensively on spatial updating for positional and directional awareness. To name a representative few, such professionals include firefighters, naval divers, and aviation pilots (see Loomis et al., 1999). The selection of such individuals with relatively high spatial updating strategy use may help to promote their on-job competency and reduce work-related dissatisfaction.

In conclusion, this research is the first to show the existence of individual differences in spatial updating, the possible ways of assessing such individual differences, and that a major preference for spatial updating strategy underpinned the formation of a unique type of environmental representation—the egocentric survey-based representation. Critically, it highlights spatial updating strategy as a distinct navigational strategy that is directly related to spatial navigation in a large-scale urban environment and that the NSQ, particularly the spatial updating scale, has theoretical implications for future research, as well as practical implications with regards to improving navigational performance, training and personnel selection.

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Appendix: 60 NSQ Items

Procedural Strategy (20 items)

Non-spatial/sequential route representation (10 items)

1. If I were to traverse a complex route, my poor judgments of spatial relationships would made me lose my way easily.
2. I find it difficult to preserve the spatial relationships among the sequence of landmarks I have encountered on my route.
3. My mental map looks like a sequence of landmarks seen from the first-person perspective.
4. When I navigate, I pay attention to the landmarks at the turning points and try to remember their sequence.
5. If I were to walk on my route again, I would depend heavily on a sequence of mental “snapshots” of landmarks or scenes to go to the places I had been to.
6. I keep a mental record of the landmarks I see on my traveling route in a sequential fashion.
7. It is very difficult for me to find a shortcut because I think of my route as a sequence of routes and turns.
8. My mental representation of space primarily involves sequences of route segments and turning points.
9. I form successive associations of different scenes seen from the first-person perspective along the route I traveled.
10. I remember my route traveled as a succession of different segment lengths and turns without clear spatial relationships.

Visual memory for landmarks (5 items)

1. To avoid getting lost, I usually try to memorize the landmarks around me, along with their associated turns.
2. I rely primarily on landmarks as signs of turning points along my route of travel.
3. I prefer following directions with descriptions of landmarks at turning points rather than using a map.
4. Whenever I get lost, I try to reorient myself in relation to the visible landmarks.
5. I have stored mental “snapshots” of landmarks or scenes which do not inform me clearly of my position and orientation in the environment.

Egocentric procedures (5 items)

1. To reach my destination, I largely recruit a set of procedures telling me the actions to perform (i.e., go straight/back, turn left/right) at different locations on my route.
2. I find it much easier to recall my route as a set of procedures or actions than as a pattern of spatial relationships.
3. If I need to return to my origin, it is easier for me to retrace my route

than to find a new shortcut.

4. I find it much easier to understand my route procedurally (i.e., where to head and where to turn) than based on forming a map-like mental representation.
5. Whenever I get directions from someone, I strongly prefer a clear description of the procedures to take (i.e. where to head and where to turn) in order to avoid getting lost.

Survey-Based Strategy (20 items)

Cardinal directions (1 item)

1. I tend to judge my orientation in the environment in terms of cardinal directions (north, south, east, west).

Schematic/2D mental map (14 Items)

1. I am able to integrate different parts of my route and their associated features into a schematic mental representation.
2. I have a schematic mental map like a floor plan that contains abstract spatial relationships among known landmarks/objects.
3. My mental representation of the route that I traversed is analogous to a schematic map (e.g., floor-plan, blue-print, metro map) rather than a first-person perspective of routes and landmarks.
4. I usually attempt to mentally represent route segments, turns and their spatial relationships from a top-down aerial perspective.
5. I rely primarily on a schematic mental representation of my environment to figure out my position in the environment.
6. I can plan out my route of travel by visualizing a schematic map from a top-down aerial perspective.
7. I usually attempt to visualize a map of the environment from a top-down aerial perspective as I travel.
8. I rely primarily on a schematic mental representation of my environment to help me in finding shortcuts.
9. When I imagine reorienting myself on my mental map, I tend to visualize my environment from the top-down aerial perspective and turn my imagined position to face the new heading.
10. My mental representation of my traveled route resembles a schematic plan of abstract spatial relationships rather than a pictorial, sequential plan of landmarks/objects.
11. I tend to reconstruct my traveled route by imagining abstract spatial relationships amongst different places in a schematic plan rather than by imagining re-walking the route from a 3D first-person perspective.
12. I usually rely on a schematic mental representation to orient and navigate to familiar places.
13. I can mentally integrate multi-level routes to form a schematic representation from a top-down aerial perspective.
14. I can easily plan my route on a map of a new place. [a]

Fixed map orientation (1 item)

1. When I reconstruct my mental map, its environmental orientation is fixed and does not change with my imagined heading directions.

Interobject relations (4 items)

1. Even if I were to disorient myself by spinning around on the spot, I would have no problem in mentally representing the positions of surrounding objects relative to one another.
2. I mentally represent the landmarks I encountered in the form of spatially organized clusters.
3. My mental representation of space focuses on how landmarks/objects are spatially configured in the environment rather than on how they appear in a pictorial sequence.
4. I tend to visualize the positions of surrounding landmarks/objects relative to one another rather than relative to my body when I travel.

Spatial Updating Strategy (20 items)

Sense-of-Direction (2 items)

1. I have navigational intuition.
2. Inside buildings with no salient landmarks/objects to serve as points of reference, I can still sense the direction I am facing.

Egocentric orientation toward non-visible landmarks (3 Items)

1. I can easily point to a specific place outside the building when I don't see it from the inside.
2. I can point to the exit after several turns in a building without relying on salient landmarks/objects as points of reference.
3. I know the direction to familiar buildings even when it is blocked from sight by another one.

Internal compass (1 item)

1. I have an “internal compass”.

Wayfinding under low visibility (3 items)

1. I can find my way under low visibility conditions (or even in darkness) in familiar places better than other people.
2. In an unfamiliar environment with no clear landmarks (e.g., forest, desert, new city) and/or in low visibility conditions (e.g., fog, heavy rain), I still have a good sense of where I am heading.
3. I can sense where I am heading even with my eyes closed.

Updating of self-to-origin relations (3 items)

1. I can easily keep track of my direction of travel on my route with respect to the starting point.
2. At any time during a route, I can point back to where I began.
3. If I were to return to my origin, I would attempt to find a shortcut based on judging the direction-of-return to the origin rather than retracing my footsteps.

Egocentric tracking of landmarks (4 items)

1. At any time during a route, I can point back to the landmarks I have passed by.
2. It is easy for me to estimate the distance and direction between my moving body and the landmarks I have passed by on the route.
3. While navigating, I attempt to remember the locations of landmarks on the route since they help me to track my position in space and not to lose my way.
4. While navigating, I actively recruit landmarks/objects as anchor points to track my position in the environment rather than only remembering them in a sequence.

3D mental map (4 items)

1. If I travel in a novel multi-level building, I can easily imagine the 3D structure of the space.
2. My mental representation of space reflects realistic, large-scale structural layout of my surrounding environment with relatively accurate distances.
3. I visualize my environment in the form of a 3D spatial layout that maintains the spatial relations between my imagined self and surrounding landmarks/objects.
4. If I were to recall my route, it would appear like a rolling film from the first-person perspective with good preservation of the spatial relationships between my body and registered landmarks/objects.

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[a] This survey-based item was excluded from testing.