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Relating allocentric and egocentric survey-based representations to the self-reported use of a navigation strategy of egocentric spatial updating☆

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This study aimed to relate two different forms of survey-based representations encoded after real-world route learning to the differential use of allocentric and egocentric frames of reference, and a navigation strategy of egocentric spatial updating that focuses on the computations of self-to-object relations. Using sketchmaps and assessments of spatial and landmark knowledge, Study 1 implicated the existence of allocentric and egocentric survey-based representations that preserved survey knowledge of the environment based on the primary engagement of allocentric and egocentric frames of reference respectively. In Study 2, an egocentric spatial updating strategy scale was designed as part of a new self-report *Navigation Strategy Questionnaire (NSQ)*, and validated with regards to relevant behavioral measures of spatial and landmark knowledge. Notably, egocentric-survey map sketchers reported the highest scores on this new scale among three groups of map sketchers, supporting the proposal that they were highly involved in egocentric spatial processing during route learning.

1. 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;

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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, Freksa, & 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 retrieval of landmark locations (Thorndyke & Goldin, 1983; see also; Rothkegel, Wender, & Schumacher, 1998).

Despite being 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). For instance, Ishikawa and Montello (2006) showed that there were participants who consistently demonstrated poor estimations of directions and distances despite repeated route exposure, as well as others who demonstrated highly accurate performance on the same spatial measures from the very first session. In addition, another problem with the Siegal and White's (1975) LRS model is that it cannot account for an accumulating amount of evidence suggesting that the spatial memory of physical environments could be acquired and represented through two types of perspectives: the *first-person (field)* and *third-person (observer)* perspectives (see, e.g., Blajenkova, Motes, & Kozhevnikov, 2005; Hirtle & Hudson, 1991; Nigro & Neisser, 1983; Sutton, 2010; Taylor & Tversky, 1996; Werner et al., 1997). The first-person perspective is closely linked to one's visuo-perceptual experience (Herrmann, 1996) and assuming this perspective requires one to visualize or recall scenes from a body-centered field of view (Nigro & Neisser, 1983). In contrast, the third-person perspective is closely linked to a bird's eye or aerial view of a spatial layout (Cohen, 1989) and assuming this perspective requires one to imagine scenes from an external or disembodied vantage point (Nigro & Neisser, 1983).

In a previous study which implicated the involvement of these two perspectives in the formation of survey-based representations, Blajenkova et al. (2005) asked each of their participants to draw a sketchmap after traversing a route comprising of two levels in a previously unfamiliar building, and classified those sketchmaps into three categories: i) one-dimensional (1D) sketchmaps that showed landmarks connected in a sequential and non-spatial fashion; ii) two-dimensional (2D) sketchmaps that showed the route's spatial configuration on one plane which implicated the adoption of an aerial view; and iii) two-level three-dimensional (3D) sketchmaps that was exceptional for showing the spatial layout of each floor separately but in alignment along the vertical dimension. The finding of 3D sketchmaps was novel and interestingly suggested that their sketchers might have primarily engaged the first-person perspective while generating survey-based representations. Overall, these results showed that individual differences in the formation of environmental representations exist and highlighted that certain individuals could acquire survey-based representations after just one exposure to a novel environment. In view of this research, the traditional stage-like procedure of route learning—characterized by first attending to landmark and route information, followed by abstract mapping of inter-relationships between landmarks or places (Thorndyke & Goldin, 1983; Thorndyke & Hayes-Roth, 1982)—should then not be considered as the only way that could lead to the formation of survey-based representations.

1.1. Spatial navigation through egocentric spatial updating

Over the past three decades, numerous studies have offered strong evidence for the existence of a special mode of navigation called *spatial updating* (e.g., Farrell & Thomson, 1998; Klatzky, Lippa, Loomis, & Golledge, 2003; Klatzky, Loomis, Beall, Chance, & Golledge, 1998; Klatzky et al., 1990; Loomis, Klatzky, Philbeck, & Golledge, 1998; Loomis, Lippa, Klatzky, & Golledge, 2002; Loomis et al., 1993; Wang & Brockmole, 2003; Wang & Spelke, 2000; Wang et al., 2006). Importantly, several researchers have proposed that spatial updating can exist through two formats or reference systems in which egocentric (self-to-object) and allocentric (object-to-object) spatial relations are processed respectively (see, e.g., Burgess, 2006; Hodgson & Waller, 2006; Mou, McNamara, Valiquette, & Rump, 2004; Rump & McNamara, 2013; Sholl, 2001; Wang et al., 2006). For the purpose of this current research, this paper focuses on the greater relevance of egocentric spatial updating for navigation as it has been suggested to be more involved in forming an online representation of the location of surrounding landmarks as one moves (see, e.g., Rieser, 1999; Wang & Brockmole, 2003) and that the egocentric experience that is inherent in its use has been proposed to contribute to the selection and encoding of reference directions in long-term spatial memory (see McNamara, Rump, & Werner, 2003; Rump & McNamara, 2013). Hence, in this paper, spatial updating is defined in egocentric terms as a dynamic process whereby a navigator continuously computes and updates transient self-to-object relations towards surrounding objects/landmarks or locations while traversing a path (see Amorim, Glasauer, Corpinot, & Berthoz, 1997; Loomis et al., 1998; Philbeck, Klatzky, Behrmann, Loomis, & Goodridge, 2001). During egocentric spatial updating, a navigator relies on internal (idiothetic) signals (i.e., proprioception and vestibular feedback) and external (allothetic) signals (i.e., acoustic and optic flow) to continuously compute estimates of self-position and orientation within external space (Loomis, Klatzky, Golledge, & Philbeck, 1999). In its basic form, egocentric spatial updating is known as *path integration* (also called *dead reckoning*, Loomis et al., 1999). It has been found to be practiced by animals like gerbils (Mittelstaedt & Mittelstaedt, 1980), desert ants (Müller & Wehner, 1988; Wehner & Wehner, 1986), and golden hamsters (Etienne, 1980; Etienne, Maurer, Saucy, & Teroni, 1986), and is normally characterized by a navigator's continuous updating of the location of a starting point relative to his/her current position and orientation during locomotion (Loomis et al., 1999; see also; Wiener, Berthoz, & Wolbers, 2011). In terms of similarity, both path integration and egocentric spatial updating rely largely on an egocentric frame of frame (akin to the first-person perspective) (Klatzky, 1998) or an egocentric representation system (Mou et al., 2004)—also known as a body-centered spatial framework (Bryant, Tversky, & Franklin, 1992; Franklin & Tversky, 1990; Tversky, Morrison, Franklin, & Bryant, 1999)— to compute and represent the location and orientation of surrounding objects with respect to the navigator's body. Principally, it is this dependence on the egocentric (body-centered) representation system or framework that distinguishes egocentric spatial updating from the higher level of route-based learning that is characterized by survey knowledge acquisition through survey-based (metric) navigation (see Trullier, Wiener, Berthoz, & Meyer, 1997).

In contrast to egocentric spatial updating, survey-based navigation centrally relies on an allocentric reference frame (akin to the third-person perspective) (Klatzky, 1998) or an environmental representation system (Mou et al., 2004; see also; Sholl, 2008) to visualize the coordinates of objects, landmarks and places and their interrelationships. This allocentric or environmental reference system has been widely implicated to be recruited in the storage of offline or long term/comprehensive spatial memories of configurations of objects or landmarks (see, e.g., Shelton & McNamara, 2001; McNamara et al., 2003; Mou et al., 2004; Mou & McNamara, 2002; Mou, Liu, & McNamara, 2009; Mou, Zhao, & McNamara, 2007). Based on spatial knowledge assessment of the relative locations of objects, spatial memories of object arrays have been suggested to be organized allocentrically according to the intrinsic reference axes of object arrays, which are perceptually salient or symmetrical lines of arrangements of objects commonly aligned with orientations of 0°–180° (i.e., a north-south axis) and/or 90°–270° (i.e., an east-west axis) (see, e.g., Shelton & McNamara, 2001; Mou & McNamara, 2002; Greenauer & Waller, 2010). Crucially, Mou et al.'s (2004) model of spatial memory and updating proposes that the initial egocentric experience with the object configuration (i.e., a ground-level view of the objects from a designated viewpoint) contributes to the selection of intrinsic reference axes/directions along which objects are optimally organized for storage in spatial memory (see also Mou et al., 2007; for further elaboration of this model). Yet despite highlighting the importance of egocentric experience, the linkage of egocentric spatial updating or path integration to an eventual acquisition of spatial memory in the form of a survey-based representation remains unknown. Therefore, this paper aims to clarify the extent to which egocentric spatial updating can contribute to the formation of survey-based representations. Specifically, it asks whether two subtypes of survey-based representations can emerge from the differential implementation of egocentric spatial updating as a strategic construct.

1.2. Study aims and purpose of the Navigation Strategy Questionnaire

To provide evidence for two potential subtypes of survey-based representations, the first study was conducted based on real-world navigation of a previously unfamiliar route, sketchmap drawing, and behavioral testing of and landmark and spatial knowledge. It focuses on examining the fidelity of the stored spatial memories associated with these two kinds of mental/cognitive maps formed after route learning, in line with the paradigm of past research (e.g., Hirtle & Hudson, 1991; Ishikawa & Montello, 2006; Thorndyke & Hayes-Roth, 1982). Specifically, it is proposed that a higher engagement of egocentric spatial updating during route learning, together with the involvement of the allocentric reference system for long-term storage of interobject relations, would engender egocentric survey-based representations—termed hereafter as *egocentric-survey representations*. On the other hand, it is proposed that a lower engagement of egocentric spatial updating, but comparatively greater allocentric reference frame use through survey-based navigation, would engender allocentric survey-based representations—termed hereafter as *allocentric-survey representations*. In conjunction, these proposals centrally suggest that bearers of egocentric-survey representations would engage the egocentric reference frame or the first person perspective to a larger extent than bearers of allocentric-survey representations in the processing of spatial information during route learning. It is vital to note that the first study set out to relate the preferential use of different reference frames or perspectives to the formation of survey-based representations, and that it was not designed to address the specific question of whether a particular subtype of survey-based representation is orientation-specific (i.e., optimal organization and retrieval of spatial relations from specific orientations or viewpoints, see, e.g., Easton & Sholl, 1995; Sholl & Nolin, 1997) or orientation-free (i.e., no specific preference for any orientation in the encoding and retrieval of spatial relations, see, e.g., Presson & Hazelrigg, 1984; Presson, DeLange, & Hazelrigg, 1989). This was due to environmental constraints (e.g., route segments and arrays of landmarks with no regular geometric shapes) that complicated the design of a suitable spatial task for analyzing orientation-specificity.

To provide greater evidence for the proposal of egocentric spatial updating being highly involved in the formation of the egocentric-survey representation, a new *Navigation Strategy Questionnaire (NSQ)* was designed in Study 2 to explore the relationships between different types of environmental representations and the strategies that characterize different navigational modes or styles. The NSQ introduced a novel self-report scale of egocentric spatial updating strategy together with two traditional self-report scales of procedural/route and survey-based strategies that are conceptually similar to those designed by previous studies (e.g., Kato & Takeuchi, 2003; Lawton, 1994; Takeuchi, 1992). Critically, with the introduction of the new spatial updating scale, this study aimed to investigate the influence of individual differences in egocentric spatial updating on mental map formation and processing of spatial relationships in a large-scale environment. The design of this spatial updating scale is a novel attempt as previous studies had only shown individuals to differ in the use of route and survey-based navigation strategies (e.g., Baldwin & Reagan, 2009; Baldwin, 2009; Kato & Takeuchi, 2003; Lawton, 1994, 1996).

To date, pre-existing self-report spatial navigation questionnaires have only focused on assessing route and survey-based strategies (see, e.g., Kato & Takeuchi, 2003; Lawton, 1994, 1996; Lawton & Kallai, 2002; Pazzaglia, Cornoldi, & De Beni, 2000; Pazzaglia & De Beni, 2001; Takeuchi, 1992). Although some questionnaires have items that assess certain mechanisms of spatial updating (Hegarty, Richardson, Montello, Lovelace, & Sabbiah, 2002; Lawton & Kallai, 2002; Lawton, 1994; Pazzaglia & De Beni, 2001; Pazzaglia et al., 2000), none of those items constituted a scale aimed at assessing egocentric spatial updating strategy only. For instance, in the design of the *Wayfinding Strategy Scale* (Lawton & Kallai, 2002), the researchers performed principal component analysis ($n = 512$) and found two factors seen as representing *route* and *orientation* strategies respectively. The route strategy factor included items assessing a reliance on visible signs, landmarks, and verbal instructions to find directions, while the orientation strategy factor was a mix of items assessing a reliance on cardinal/compass directions and interobject relations while navigating (related to survey-based strategy) and items assessing the spatial updating mechanism of tracking 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*, see Lawton & Kallai, 2002, p. 392). Similarly, in an examination of the *Questionnaire on Spatial Representation* designed by Pazzaglia et al. (2000), Pazzaglia and De Beni (2001) performed factor analysis ($n = 285$) and revealed five factors. Notably, the first factor grouped six items termed as representing a general "sense of direction"; amongst them, three could be seen as assessing the spatial updating mechanisms of visualizing non-visible landmarks and maintaining one's egocentric orientation in relation to environmental cues (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?*, see Pazzaglia & De Beni, 2001, p. 507). As for the four other factors, they grouped items pertaining to survey-based navigation (i.e., items assessing an awareness of compass directions for orientation purpose) and route navigation (i.e., items assessing the use of landmarks for orientation and memory of routes and landmarks). The third spatial navigation questionnaire that includes items assessing spatial updating is the *Santa Barbara Sense-of-Direction (SBSOD) scale* (Hegarty et al., 2002) that renders one scale score representing environmental spatial ability. The SBSOD has several items assessing one's directional awareness (e.g., *My "sense of direction" is very good,* see Hegarty et al., 2002, p.445) that could be seen as akin to assessing the spatial updating mechanism of tracking self-to-object relations. Its other items assess route knowledge, survey-based knowledge, and visual memory of objects.

The review of the three questionnaires above showed that although each one of them has several items related to egocentric spatial updating, those items were incorporated into a scale that was conceptualized as assessing either orientation strategy (Lawton & Kallai, 2002) or "sense of direction" (Hegarty et al., 2002; Pazzaglia & De Beni, 2001). Those items were neither conceptualized as assessing egocentric spatial updating nor grouped together as a scale for the purpose of investigating individual differences in egocentric spatial updating. This absence of any existing self-report scale assessing egocentric spatial updating strategy may also stem from the fact that a better understanding of the cognitive and neural mechanisms of spatial updating has only been attained during recent times (for reviews, see Burgess, 2006; Wolbers & Hegarty, 2010). Therefore, by designing a new scale of egocentric spatial updating strategy that is differentiated from two other scales addressing conventional route/procedural and survey-based strategies, this study aimed to examine individual differences in egocentric spatial updating and find out whether egocentric spatial updating within environmental space is related to the formation of a unique egocentric-survey representation.

1.3. Study overview and predictions

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 behavioral assessments. The employment of the sketchmap drawing task took into account numerous previous studies which applied it to infer how people visualize and mentally organize environmental space and features (see, e.g., Appleyard, 1970; Lynch, 1960; Metz, 1990; Wise & Kon, 1990; Taylor & Tversky, 1992; Tversky & Lee, 1998). Importantly, previous studies have demonstrated sketchmaps to be reliable conveyors of environmental knowledge (Blades, 1990), and valid predictors of navigational performance (Rovine & Weisman, 1989) and spatial/survey-based knowledge (Billinghurst & Weghorst, 1995; Lohmann, 2011).

Based on different salient characteristics, the sketchmaps were grouped into three categories— i) *procedural route*; ii) *allocentric-survey*; and iii) *egocentric-survey*—that were analogous in the style of portrayal to Blajenkova et al.'s (2005) 1D, 2D, and 3D sketchmaps, and then analyzed for between-groups differences in behavioral measures. In order to show that the allocentric- and egocentric-survey representations could be distinguished in terms of spatial knowledge assessments, egocentric-survey map sketchers were expected to outperform allocentric-survey map sketchers on two pointing-to-landmarks tasks that assessed the processing of spatial relationships. Specifically, in an *Imaginal Pointing Direction Task* (I-PDT) that assessed pointing responses based on imagined headings, it was predicted that egocentric-survey map sketchers would respond faster than allocentric-survey map sketchers due to the former group's faster retrieval of interobject relations with referral to encoded egocentric viewpoints. On the other hand, in terms of accuracy, the two groups of survey map sketchers were not expected to differ as the attainment of survey knowledge by both groups should lead to the encoding of relatively accurate spatial information about landmark locations. In addition to the pointing tasks, egocentric-survey map sketchers were further expected to outperform allocentric-survey map sketchers on a landmark recognition task (LRT) that assessed the visual memory of landmarks. This is because egocentric-survey map sketchers' encoding of landmarks from multiple egocentric viewpoints during route learning should subsequently lead to faster retrieval of landmark knowledge.

In Study 2, the NSQ was designed and tested for validity based on the above navigation tasks. To give evidence for the existence of individual differences in egocentric spatial updating, it was predicted that the spatial updating scale would demonstrate significant predictive validity with respect to the PDTs, and that the egocentric-survey map sketchers would report significantly higher scores than either of the two other groups of map sketchers. In addition, the relationships between the navigation strategies and environmental representations were examined in order to discover the preferred strategies of each group of map sketchers.

2. Study 1

2.1. Method

2.1.1. Participants

Seventy-one participants (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. The advertisement required participants to be unfamiliar with the School of Design and Environment (SDE) at NUS. Upon contacting the experimenter, potential participants were queried about whether they have been to a list of places at SDE (e.g., Department of Architecture, Art Studio), and only individuals who declared to have not been to any of those places were allowed to participate. They were given either course credits or monetary reimbursement for their participation.

2.1.2. Route traversal

The participants were led by the experimenter individually or in pairs on a route. The route was approximately 600 m and spanned across three buildings: SDE1, SDE2, and SDE3, inclusive of levels three and four of both SDE1 and SDE3 (see Fig. 1). The 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.

As shown in Fig. 1, the route can be partitioned into five 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). This partitioning was done based on major entrances or exits (glass doors or stairways, see black dots 1 to 5 in Fig. 1), and signal temporary hiatus in the journey where the experimenter would update the participant about his/her whereabouts in order to ensure that he/she was paying attention to learning the route. The partitioning was also done to facilitate the subsequent examination of sketchmaps and allow comparisons of the shapes of those segments in the formal plan with those of the segments depicted in the participants' sketchmaps. The first segment stretched from the starting 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 commenced on the fourth floor of SDE1 and stretched from the exit of the SDE1 stairway (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. The final segment stretched from the stairway exit on the fourth floor of SDE3 (point 5) to the finishing 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 (point 6). 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. Overall, the route was planned with a purpose of making participants travel on a circuitous path spanning the third and fourth floors of SDE1 and SDE3 with large exposures to proximal landmark cues that could be used as anchor points during

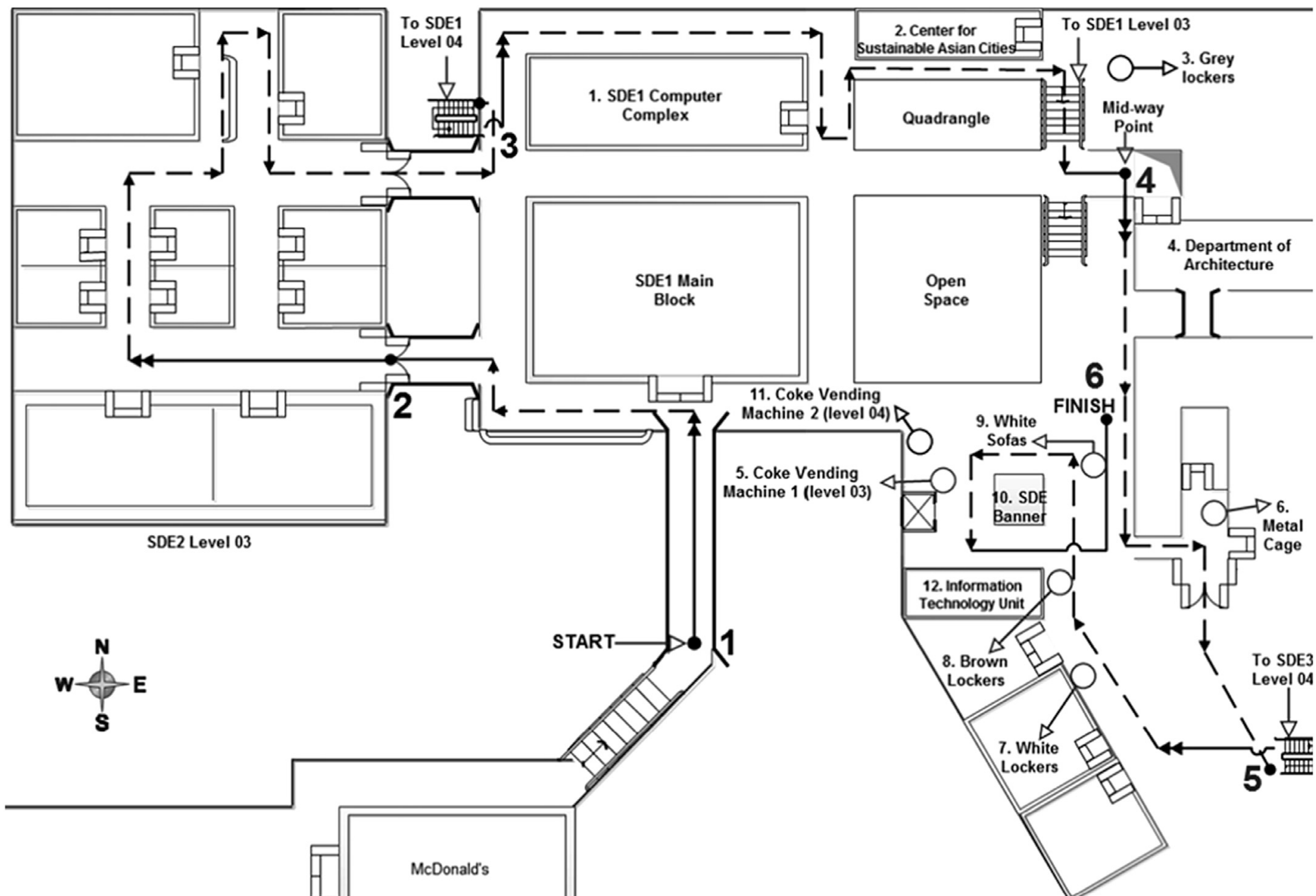

Fig. 1. Floor plan of the route at School of Design and Environment (SDE) at National University of Singapore (NUS) (not drawn to scale). Black dots numbered from 1 to 5 represent the start of each of five route segments. Dot numbers 1 and 6 represent the starting and finishing positions respectively. Double arrow heads represent the direction along the first leg of each segment. Numbers indicate the 12 landmarks which were pointed out to participants in sequence. White circles indicate the approximate locations of those landmarks and the arrows extending from them link them to the names of the 12 landmarks which were mentioned to the participants in the numerical order depicted. The participants were tested on their spatial knowledge of the relative locations of these 12 landmarks in an imaginal pointing direction task.

egocentric spatial updating. This course of action was similar to the route learning paradigm of Blajenkova et al. (2005), who guided their participants on a traversal of two floors.

In order to ensure that participants encoded salient landmarks along the way for the subsequent pointing tasks that required memory of them, the experimenter pointed out 12 landmarks to participants and instructed them to remember both their names and location to the best of their abilities in preparation for the subsequent assessments. Fig. 1 shows the locations of those landmarks on the respective floors of the three buildings and the sequence in which they were pointed out en route. The entrance to the Department of Architecture was selected as the mid-way point (point 4) where participants were told to stop and inspect their surroundings for a short while (approximately 10s) before further progress. It is worth noting that the first landmark (i.e., the computer complex/studio found on SDE 1 level 4) was designated on the third segment because pilot-testing had shown that many participants needed some time to orientate themselves (i.e., deliberate about their positions and orientations) in the unfamiliar premise. Therefore no landmarks were pointed out to the participants on the first two segments in order to ease their cognitive load. All of the landmarks were regarded as proximal cues because they were directly encountered during route traversal. They also share a common feature with respect to a 3-D rectangular shape. Half of them were found on the final segment on level 4 of SDE 3 due to the availability of a relatively greater number of objects on that level compared to other levels.

2.1.3. Tasks and materials

After traversing the route, participants were first asked to perform a route pointing direction task, followed by drawing out sketchmaps of the route, performing an imaginal pointing direction task, and a landmark recognition task. The latter two tasks were performed in the experimental lab to examine the processing of spatial relationships and landmark knowledge based on the stored mental maps of the route and its supplementary environmental features. Measures of accuracy and response times were recorded for all of the assessments. The stimuli for the behavioral tasks were designed and presented using E-Prime v. 1.1 (Psychology Software Tools, 2002).

2.1.3.1. Route pointing direction task (R-PDT). The R-PDT was administered to the participants when they reached the end of the route. It required them to face northwards in a testing area adjacent to the finishing and point to landmarks situated on the route and at its periphery (see Procedure, for details). This task primarily aimed to assess participants' performance at retrieving the self-to-object relations which they constantly tracked and updated during route traversal. It was adapted from a "point-to-unseen targets" task that required participants to make directional estimates of non-visible landmarks situated in the surrounding environment (Sholl, 1987).

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 needed 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. On each trial, the name of the target landmark remained on display until a button press was made.

Each participant performed three practice trials initially, followed by 15 experimental trials presented in a randomized sequence. In the experimental trials, eight trials referred to the landmarks that were explicitly pointed out to participants during route traversal while the remaining seven trials referred to landmarks and places which were encountered but unmentioned by the experimenter during route traversal. The former eight landmarks were included in the subsequent imaginal pointing direction task and were mentioned in order to ensure that the participants were aware of them when performing this second pointing task.

2.1.3.2. Sketchmap task. The goal of the sketchmap task was to assess the different types of environmental representations or mental maps formed by the participants. The participants were given the following instructions on paper: *Please sketch out a map of the route that you have just traversed from the start to the end. Together with your depicted route, please include as many route and environmental/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 × 43.2 cm), pencils, pens, and rulers to draw out their route. The participants were explicitly told that the starting point was not at McDonald's but at the start of the bridge crossing to the SDE complex. These instructions required our participants to sketch out their mental maps with an emphasis on the route. Depictions of route segments configured in a spatial manner were seen as important evidence for inferring the attainment of survey knowledge.

2.1.3.3. Imaginal pointing direction task (I-PDT). This task was conducted in the lab after the completion of the R-PDT and required the participants to imagine standing at a particular landmark, facing another landmark, and pointing to a third target landmark based on the imagined orientation. It was adapted from the *Judgments of Relative Direction (JRD)* task that requires judgments of directions relative to specific imagined orientations or viewpoints in large-scale space (see, e.g., Easton & Sholl, 1995; Shelton & McNamara, 2001; Mou & McNamara, 2002). The JRD was originally conceptualized as primarily assessing the representation of allocentric spatial relations between three objects in spatial memory (Mou et al., 2004), and has been used widely to exhibit viewpoint- or orientation-dependent performance (i.e., lower angular errors and/or reaction times based on pointing to a third landmark from an imagined viewpoint/orientation that aligns with an allocentric or intrinsic reference direction) (e.g., Mou et al., 2007, 2009, 2004; Greenauer & Waller, 2008, 2010; Mou & McNamara, 2002; Shelton & McNamara, 2001). Recent studies using the JRD showed that egocentric learning views can contribute as well as allocentric learning orientations to the establishment of reference directions in the organization of spatial memory (e.g., Greenauer & Waller, 2008; Mou et al., 2009), and that a dominant reference direction spanning across spatially distinct object arrays can be specified on the basis of an egocentric learning view (Greenauer & Waller, 2010; Greenauer, Mello, Kelly, & Avraamides, 2013). Moreover, Mou et al. (2009) suggest that such egocentric reference directions may be established in the absence of a clear intrinsic structure (i.e., no regularity in a configuration of objects that can facilitate the inference of allocentric reference axes/directions). Since the landmarks presented in the I-PDT did not constitute a configuration with a regular geometric shape, the I-PDT was proposed to assess the extent to which interobject spatial relations were represented on the basis of egocentric reference directions. In this study, such reference directions were conceptualized as learning views that were self-specified and encoded by the participants during route traversal (e.g., views of straight paths with landmarks on the sidelines).

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 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 the likelihood of inducing specific spatial representations of the environment that could originate from the use of image displays. Notably, such spatial language has been revealed by previous studies to be analogous to pictorial images (e.g., maps) in conveying spatial information (e.g., Taylor & Tversky, 1996; 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 headings were represented by different orientation angles which specified the angular difference between the reference direction of north (aligned with the first leg of the route, see Fig. 1) 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 imagined headings. They ranged in absolute intervals of 30° from 0° to 150° (both clockwise and anticlockwise). The six angles (absolute/unsigned 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 evenly distributed 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.

2.1.3.4. Landmark recognition task (LRT). The LRT measured the ability to encode landmarks encountered along the route. Digital photographs of 30 landmarks/objects 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 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. This was due to pilot testing data that showed a ceiling effect in the recognition performance of these 12 landmarks. Therefore, this task relates to an incidental learning of landmarks. This incidental learning process was intended to provide an examination of how different types of self-preferred navigation strategies could contribute to the self-initiated process of landmark knowledge acquisition (see Study 2). 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.

2.1.4. Procedure

The experimenter arranged appointments with the participants at the McDonald's restaurant adjacent to the starting point of the route (see Fig. 1) and upon their arrival, briefed them about the tasks to be completed before leading them individually or in pairs on a traversal of the sheltered campus route. To avoid crowds of pedestrians whose presence might distract the participants, experimental sessions were routinely conducted during early morning hours when few pedestrians were present. Not more than two participants were tested in each experimental session. The experimenter carried laptops for the purpose of data-collection from the R-PDT, walked at a steady walking speed together with the participant(s), and timed the progression to the end-point to ensure that each route traversal was completed after approximately 10 min. At the end of the route, the finishing point was designated by a bench located in front of a set of sofas on the fourth level of SDE3. Once there, each participant performed the R-PDT using the experimenter's laptop. The R-PDT was performed immediately after reaching the finishing point as it was intended to assess participants' transient representations of egocentric spatial relations that will decay with increasing delays before testing. Participants performed the R-PDT in a seated position facing a wall that obstructed the view of the path in front of them and the views of the landmarks to be pointed to in the task. This testing area was chosen due to the minimum provision of cues or distraction that may affect pointing performance. The final heading orientation of the participants was northwards, parallel to the orientation of the first leg of travel (see Fig. 1).

After finishing the task, participants remained at the testing area and were given 20 min to sketch the map of the traversed route together with the surrounding environmental features. They first read the sketchmap task instructions and were then told to commence drawing with the A3 paper being positioned in a landscape orientation. They were instructed to take as much time as possible, to draw on both sides of the paper whenever necessary, and to label their depicted landmarks and relevant environmental features. On average, each participant took 20 min to draw out their map. Participants who could not complete drawing on time were given an additional five minutes. No participant spent more than 25 min to complete sketchmap drawing.

After completing their sketchmaps, participants followed the experimenter on a walk (between 10 and 15 min) to the experimental lab. While walking back to the lab, the participants were informed that they would perform a second pointing task and were instructed to rehearse their memory of the route and the locations of the 12 landmarks pointed out to them using whatever mental technique or strategy they deem appropriate. At the lab, they first performed the I-PDT, followed by the LRT. The I-PDT was performed first so as to ensure that the amount of time taken for memory rehearsal was kept relatively constant across all participants. At the end of the experiment, 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 (i.e., a first-person perspective)?* Besides that, written reports on the strategies applied to learning or remembering the route were randomly sought from thirty participants, who volunteered to narrate their travel experience. Each experimental session lasted approximately two hours.

2.2. Results

2.2.1. 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 irrelevant depictions which made them ineligible for categorization. Consequently, their sketchmaps were removed from examination and categorization.

Two coders independently analyzed and categorized the remaining 62 sketchmaps (28 females) into three categories: i) procedural route maps, ii) allocentric-survey maps, and iii) egocentric-survey maps. Fig. 2 shows two exemplars from each category. The categorization procedure followed that of Blajenkova et al. (2005) and differentiated the sketchmaps according to the level of detail of the spatial layout that was conveyed. Sketchmaps that displayed a sequential linkage of landmarks with little or no details of the spatial layout of the environment were regarded as procedural route maps. In contrast, sketchmaps that displayed a coherent spatial structure of the route—with spatial relationships between its constituent segments approximating those rendered in the official floor plan—were regarded as survey maps. Importantly, egocentric-survey maps were distinguished from allocentric-survey maps primarily based on the schematic partitioning of environmental features belonging to separate floors; the majority of maps that organized features according to separate floors were categorized as egocentric-survey maps. This categorization method was previously done by Blajenkova et al. (2005) in their categorization of 2-D and 3-D sketchmaps, the latter of which exhibited floor separation and implicated the involvement of first-person

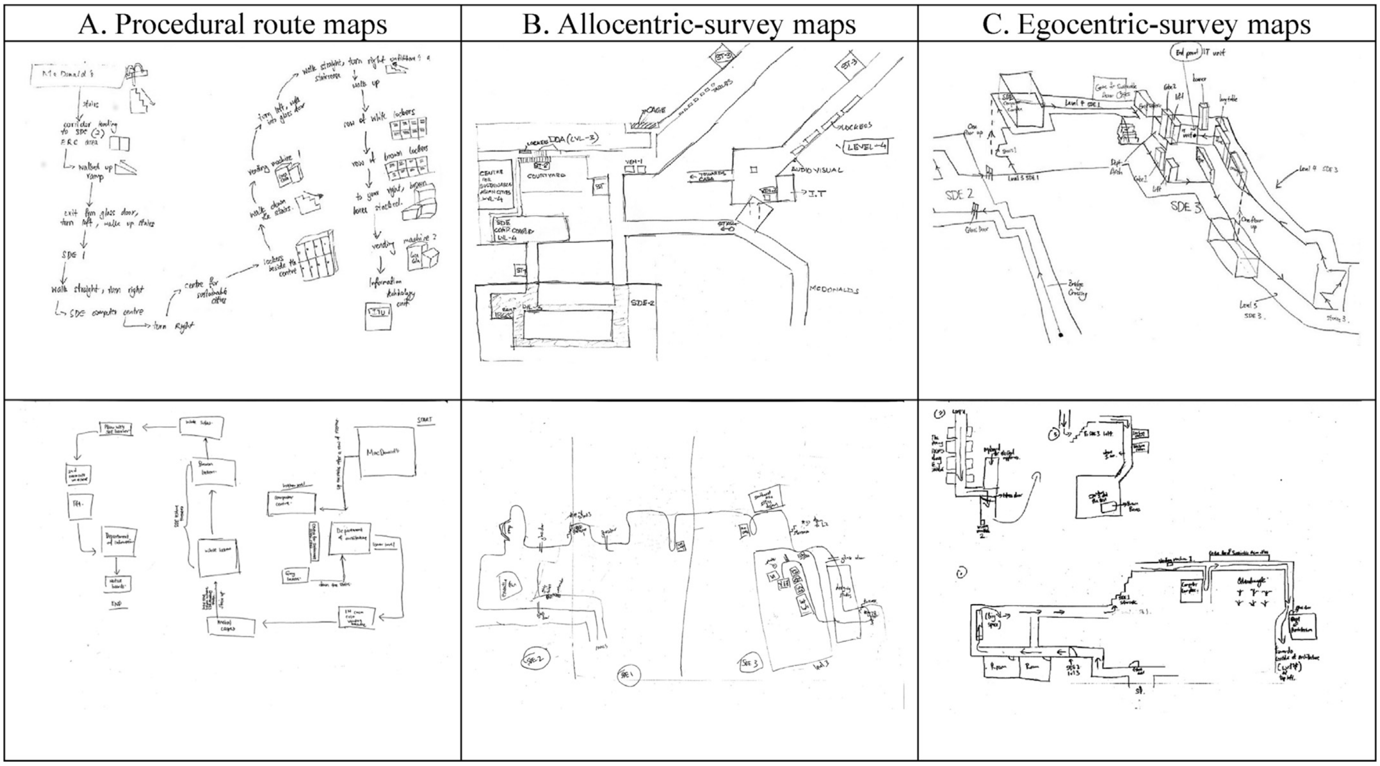

Fig. 2. Exemplars from the three sketchmap categories. Procedural route maps exhibit linkages of the landmarks in sequence without accurate information of their spatial configuration. Allocentric-survey maps exhibited the overall spatial layout of the route without clear partitioning of the features according to the two floors. Egocentric-survey maps distinguished themselves from allocentric-survey maps for exhibiting clear renditions of environmental features on separate floors together with parallel-running double lines that delineated the paths on each floor.

perspective in differentiating environmental features along the vertical.

In the categorization of the sketchmaps, the agreement between the two coders was 95% and any disagreement was discussed until a consensus was reached. Disagreements concerned the categorization of a four maps into the two survey map categories. These maps exhibited some attempts at floor separation using lines of demarcation and relatively accurate renditions of the overall spatial layout but did not clearly convey the width of paths through the use of parallel-running double lines (see bottom map in Fig 2b). The use of 1D lines in depicting the paths suggests that the sketchers of these maps might have minimized the use of the egocentric reference frame in judging the widths of the paths, resorting instead to representing them allocentrically in a simplified or abstract format. Written reports about route learning strategies collected from these four sketchers showed that they strongly favored an aerial overview in mapping out the interrelationships between landmarks. Consequently, these four sketchmaps were categorized as allocentric-survey maps.

The sketchmaps that represented linear, non-spatial representations of the procedure or sequence of getting from one place to another in a direction-specific sequence were categorized as *procedural route maps* ($N = 24$; 14 females) (see Fig.2a). The sketchmaps that 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 were categorized as *allocentric-survey maps* ($N = 22$; 10 females) (see Fig. 2b). The sketchmaps that represented the route and its surrounding environment either in a cross-sectional three-dimensional (3D) format (see top map in Fig. 2c) or in a schematic format that clearly defined the separation of the two floors (see bottom map in Fig. 2c) which had been traveled on were categorized as *egocentric-survey maps* ($N = 16$; 4 females). The depiction of stairways was commonly adopted to show clear demarcation between the floors and the spatial layouts of separate floors aligned with each other along the vertical dimension.

Prior to any further analysis 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, $\chi^2\,(2) = 4.31$, $p = 0.116$.

After being categorized into three categories, the sketchmaps were examined further according to five sketchmap criteria or variables described below. This examination of the sketchmap was intended to render a closer picture of the amount of environmental knowledge acquired by the participants from route learning. They were chosen based on references to previous studies that analyzed their sketchmaps based on similar types of criteria (e.g., Appleyard, 1970; Blajenkova et al., 2005; Rovine & Weisman, 1989). It is vital to note that no standard or fixed set of criteria for sketchmap analysis currently exist and the introduction of the five criteria in this study should be viewed as a novel endeavor at examining the fidelity of environmental knowledge. After rating each sketchmap based on these criteria, the two quantitative variables (*frequency of landmarks*; *frequency of route segments*) representing different sketchmap features were analyzed using one-way ANOVAs with Sketchmap Category as the between-subjects variable. The remaining three nominal variables (*route structure*; *floor separation*; *route orientation*) were analyzed using chi-square tests.

2.2.1.1. Frequency of landmarks. This variable reflects the number of landmarks (range = 1–12 based on the landmarks pointed out on the route) depicted on each of the participants' sketchmaps. There was a significant difference in the frequencies of landmarks between the different sketchmap categories, $F(2, 59) = 3.36$, $p = 0.04$, $\eta^2 = 0.10$. Post-hoc comparisons using Tukey *HSD* revealed that egocentric-survey maps depicted more landmarks ($M = 9.81$, $SD = 1.47$) than allocentric-survey maps ($M = 8.41$, $SD = 1.94$) ($p = 0.03$). 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 ($p = 0.41$) and that of allocentric-survey maps ($p = 0.32$).

2.2.1.2. 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 Fig. 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 perpendicularly to each other at a minimum of two turning points which were situated in the same locations as those found in 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. The first prerequisite of two turning points was essential because all the segments involved two major turns and their shape could not be properly assessed without the depiction of such turns. As for the second prerequisite of proportionality, the lengths of the constituent paths before and after each turn were compared for each segment; ratios were estimated and compared to the ratios of the lengths of their counterparts in the official floor plan. A segment was scored as accurately drawn as long as the two sets of ratios were in equal proportions.

There was a significant difference in the frequencies of accurate route segments between the different sketchmap categories, $F(2, 59) = 82.22$, $p < 0.001$, $\eta^2 = 0.74$. Post-hoc comparisons using Tukey *HSD* revealed 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 ($M = 1.25$, $SD = 0.85$) ($ps < 0.001$). The egocentric-survey maps did not contain significantly more accurate route segments than the allocentric-survey maps ($p = 0.69$).

2.2.1.3. Route structure. This nominal variable recorded the presence of parallel-running double lines which represented the paths of travel (see Fig. 2b, c). Those lines showcased considerations of the width of the paths that constitute each route segment and attempts at conveying the layout geometry of the overall route in greater detail. 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, $p = 0.02$. 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%).

2.2.1.4. Floor separation. This nominal variable recorded the presence of depictions of environmental features on separate floors. (see Fig. 2c). 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, $\chi^2(1) = 7.20$, $p = 0.007$. The proportion of egocentric-survey maps which showed floor separation (100%) were significantly higher than that of allocentric-survey maps (18.2%).

2.2.1.5. 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 alignment with the forward progression along first leg of the route (i.e., the bridge leading to the SDE complex). Maps with this feature of aligned orientation were different from maps with headings showing the first leg as pointing leftwards, rightwards, and downwards, which did not seem to suggest the retrieval of an egocentric view of the heading at the start of the route. A chi-square test showed an uneven distribution of sketchmaps with the "heading up" orientation, χ^2 (2) = 11.35, $p = 0.003$. 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%).

2.2.1.6. Summary from sketchmap analyses. In summary, the procedural route maps, showed equivalent frequencies of landmarks 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-based representations. As for the allocentric survey maps, they showed relatively high frequencies of accurate route segments. The majority of these maps showed the route segments as resting on a single level and structured by double lines; this suggests that their sketchers preserved knowledge of the geometric layout of the route segments. In addition, two-thirds of the allocentric-survey maps depicted the first leg of the route—and the overall orientation of the depicted environment—in the form of headings that pointed leftwards, rightwards, or downwards (see top map in Fig. 2b, for a westward map orientation). This shows that many allocentric-survey map sketchers might have retrieved survey-based or spatial information from third-person viewpoints that are not aligned with the northbound orientation of the first leg of the route. Lastly, for the egocentric-survey maps, they had relatively high frequencies of accurate route segments and every route segment was structured by double lines. However, unlike the allocentric-survey maps, the great majority of egocentric survey-based maps depicted a "heading up" orientation with the first leg of the route positioned in an upright manner. It is possible that these egocentric-survey map sketchers began their recollection of their route by reactivating their egocentric experience of forward progression along the first leg.

2.2.2. Relating the sketchmap categories to behavioral task performance

The accuracy scores and their corresponding response times (RTs) for correct responses obtained from each behavioral task were separately analyzed using one-way ANOVAs, with the between-subjects variable being Sketchmap Category for all the analyses. Prior to analyses, all sets of variables were examined for potential outliers. Two female participants—one from the procedural route map category and the other from the egocentric-survey map category—were found to be outliers (±2.5 *SD*) in the analysis of I-PDT RTs and had their RTs excluded from ANOVA. Each participant's RT was more than three standard deviations above the mean RT of the group of map sketchers she belonged to. Table 1 shows the descriptive statistics of accuracy scores (ACC) and their corresponding RTs for all the tasks in each group of map sketchers, and the ANOVA results. The performance data from LRT were analyzed based on two sets of variables: i) "LRT (total)", which represents the accuracy scores and RTs in the correct recognition of all campus landmarks (both 'foil' landmarks and landmarks encountered en route; max. score = 45); and ii) "LRT (route-based)", which represents the accuracy scores and RTs in the correct recognition of landmarks encountered en route only (max. score = 30). The

Table 1
Descriptive statistics of accuracy scores and response times of behavioral tasks along with ANOVA results.

Tasks	Variables	Procedural route map sketchers *M* (*SD*)	Allocentric-survey map sketchers *M* (*SD*)	Egocentric-survey map sketchers *M* (*SD*)	*F* (2, 59)	η^2
R-PDT	ACC	5.96 (2.20)	8.50 (2.81)	10.50 (2.28)	16.83**	0.36
	RT (sec)	3.88 (1.43)	3.55 (1.05)	4.32 (3.04)	0.78	0.03
I-PDT	ACC	11.67 (4.60)	16.91 (3.92)	18.56 (4.52)	18.23**	0.38
	RT (sec)[a]	9.80 (3.59)	11.27 (2.96)	8.58 (2.10)	3.58*	0.11
LRT (total)	ACC	27.29 (4.36)	28.68 (4.11)	29.88 (5.10)	1.65	0.05
	RT (sec)	2.81 (1.11)	2.94 (1.37)	2.27 (0.60)	1.81	0.06
LRT (route-based)	ACC	16.17 (4.88)	17.00 (3.87)	17.56 (4.75)	0.49	0.02
	RT (sec)	2.84 (1.30)	3.27 (1.63)	2.11 (0.70)	5.69**	0.11

**$p < 0.01$ (two-tailed).
*$p < 0.05$ (two-tailed).
[a] The value of df_{within} in the analysis of I-PDT RT was 57 due to the removal of two outliers.

analysis of the recognition performance of all landmarks in addition to that of the recognition of route-based landmarks was to examine whether group differences could stem from the additional knowledge of landmarks from other parts of the campus. The RT of the total landmark variable reflected the average time it took for a participant from each sketchmap group to correctly recognize a campus landmark regardless of whether or not it belonged to the traversed route.

With regards to accuracy scores, the ANOVAs (see Table 1) revealed significant differences between the three groups of map sketchers in the performance of R-PDT and I-PDT (*Fs* > 16.82, *ps* < 0.001) but not in that of LRT (total) and LRT (route-based) (*Fs* < 1.66, *ps* > 0.05). With regards to RTs, the ANOVA results showed significant differences between the three groups of map sketchers in the performance of I-PDT and LRT (route-based) (*Fs* > 3.57, *ps* < 0.05) but not in that of R-PDT and LRT (total) (*Fs* < 1.82, *ps* > 0.05). All further post-hoc comparisons of R-PDT and I-PDT accuracy scores, as well as I-PDT RTs, were performed using the Tukey *HSD* test. The post-hoc comparisons of LRT (route-based) response latencies were performed using the Games-Howell test (a separate-variances version of 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 ($p = 0.03$) and procedural route map sketchers ($p < 0.001$). Moreover, allocentric-survey map sketchers were found to have higher accuracy scores than procedural route map sketchers ($p = 0.003$).

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 (*ps* < 0.001). There were no significant differences between egocentric-survey map and allocentric-survey map sketchers ($p = 0.38$). However, with regards to I-PDT RTs, egocentric-survey map sketchers were found to be significantly faster than allocentric-survey map sketchers ($p = 0.03$). Other than that, the RTs of the route map sketchers did not differ significantly from those of the two other groups of map sketchers (*ps* > 0.24). Consistent with the predictions, these findings suggest that egocentric-survey map sketchers took a more direct or efficient approach than allocentric-survey map sketchers in the retrieval of survey knowledge.

Third, in the recognition of route-based landmarks, egocentric-survey map sketchers were found to have significantly faster RTs than both allocentric-survey map sketchers ($p = 0.02$). The RTs of procedural did not differ significantly from egocentric-survey map sketchers ($p = 0.06$) and allocentric-survey map sketchers ($p = 0.590$). Once more, as predicted, these findings suggest that egocentric-survey map sketchers were faster than allocentric-survey map sketchers at accessing multiple egocentric views of landmarks which were encountered during route traversal.

2.2.3. Gender differences

As gender differences in terms of visual-spatial and navigational abilities had been well documented in the literature (see, e.g., Kimura, 1999; Lawton, 1994; Montello, Lovelace, Golledge, & Self, 1999), the effects of gender on the non-outlying accuracy scores and RTs were examined in all the behavioral assessments.

To ensure that gender effects did not affect the univariate analyses above, the potential interactive effect of gender was examined by entering it as an independent variable alongside Sketchmap Category. Gender did not show any significant effect of interaction with Sketchmap Category across all the assessments with regards to both measures of accuracy (*Fs* < 2.98, *ps* > 0.065) and RTs (*Fs* < 1.38, *ps* > 0.260). As for gender differences with respect to the behavioral assessments, male participants obtained significantly higher accuracy scores in the performance of R-PDT (F (1, 69) = 9.74, $p = 0.003$, $\eta^2 = 0.124$; *M males* = 8.95, *SD* = 2.93, *M females* = 6.79, *SD* = 2.88). However, in the LRT, male participants did not attain significantly higher accuracy scores in total landmark recognition (F (1, 69) = 3.11, $p = 0.08$, $\eta^2 = 0.04$; *M males* = 28.74, *SD* = 4.71, *M females* = 26.85, *SD* = 4.25), and route-based landmark recognition (F (1, 69) = 3.54, $p = 0.064$, $\eta^2 = 0.05$; *M males* = 17.13, *SD* = 4.78, *M females* = 15.12, *SD* = 4.14). Likewise, non-significant gender differences were found in the performance of I-PDT (F (1, 69) = 2.56, $p = 0.114$, $\eta^2 = 0.04$; *M* males = 16.39, *SD* = 5.94, *M* females = 14.39, *SD* = 4.34).

2.2.4. 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 (i.e., from a first-person perspective)?* The distribution of participants responding positively (*yes* responses) was found to be uneven across the sketchmap categories, χ^2 (2) = 9.24, $p = 0.01$. 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 suggest 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 ($n = 11$) conveyed 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 bodies' positions and orientations with references to salient sites such as the starting point and an outlying traffic road (behind the Department of Architecture). 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 visualizing and merging route segments from an aerial or third-person viewpoint ($n = 9$). To showcase the differences in navigational styles associated with the formation of environmental representation, the following section presents one exemplary report of a sketcher 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, Department of Architecture), I focused hard on these images. In order to capture and "record" 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 like I was on the route.*

2.3. Discussion

The results of Study 1 suggest the presence of two subtypes of survey-based representations illustrated in the forms of two categories of sketchmaps—the allocentric-survey and the egocentric-survey maps. Both forms of sketchmaps were seen as conveying survey-based knowledge inasmuch as presenting a coherent spatial layout of the whole route that approximated the official floor plan. Both allocentric- and egocentric-survey maps presented relatively accurate spatial representations of the route by having equally high frequencies of accurate route segments. The spatial layouts of these maps were also predominantly structured by parallel-running double lines that exhibit considerations for the widths of the constituent paths of the route. These findings suggest that both groups of survey map sketchers were evenly matched in their survey knowledge of the route with regards to its overall configuration and the relationships between its composing segments.

Aside from these similarities, there were salient differences between the two categories of survey maps. The allocentric-survey maps conveyed graphical elements which reflected attempts by their sketchers to depict the spatial layout of the environment primarily 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 (i.e., the environmental features from separate floors overlapped with one another and were not depicted separately according to each floor). Many allocentric-survey map sketchers also depicted the first leg of the route in a manner that suggests a poor consideration of the egocentric viewpoint that ran parallel to the northbound orientation of the bridge crossing at the start of the route. In contrast, the egocentric-survey maps exhibited elements which reflected attempts by their sketchers to depict the spatial layout of the environment from a first-person perspective. All of them showcased floor separation or some schematic partitioning of the environmental features according to route segments. This unique form of schematic rendering seems to suggest that egocentric-survey map sketchers organized their survey-based knowledge on the basis of local or discrete egocentric representations of the various route segments (see Chown, 1999; Meilinger, Riecke, & Bülthoff, 2007; Meilinger & Vosgerau, 2010). Such local mental maps also highlight the possibility that egocentric-survey map sketchers might have used micro-reference frames for organizing the spatial relationships intrinsic to spatially distinct sets of objects (see Greenauer & Waller, 2010). In addition to this potential form of organizing and integrating spatial information, it is also vital to note that the great majority of egocentric-survey maps exhibited the first leg of the route in a "heading up" orientation. Most probably, this suggests that many egocentric-survey map sketchers imagined the start of the route from an egocentric viewpoint that had the bridge to the SDE complex laid out in front of them. Furthermore, egocentric-survey map sketchers depicted significantly more landmarks than the allocentric-survey map sketchers, and this suggests that egocentric-survey map sketchers might have relied on landmark locations to a larger extent to update their self-positions and form their survey-based representations.

To show that egocentric-survey map sketchers relied more on egocentric spatial processing than allocentric-survey map sketchers, the results from the pointing direction tasks provided important findings. 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 online computation of egocentric spatial relations immediately after route traversal. The written reports of egocentric-survey map sketchers showed that they tracked their bodies' positions and orientations with reference to salient route-based landmarks and/or the point of origin during route traversal. This navigational mechanism of updating self-position and orientation in relation to proximal landmarks might be pivotal in leading to their significantly more accurate route pointing performance than the two other groups of map sketchers.

With regards to the I-PDT, egocentric-survey map sketchers were found to have responded significantly faster than allocentric-survey map sketchers, as well as being more likely than allocentric-survey map sketchers to self-report the imagination of their headings ("*stand at__, facing__*") from the first-person perspective. Moreover, the finding of egocentric-survey map sketchers being significantly faster than allocentric-survey map sketchers in route-based landmark recognition gave evidence to suggest that the former group was better at encoding landmarks from multiple egocentric viewpoints during route traversal. Combining these findings with the former implication that egocentric-survey map sketchers might have local mental maps, it is possible that egocentric-survey map sketchers organized their spatial memory with regards to egocentric learning views (i.e., views of walkways and/or salient landmarks) that engendered the representations of their local mental maps. This possibility bears correspondence to the findings by Meilinger, Riecke, et al. (2007) that implicated the establishment of multiple local reference directions based on the heading directions experienced while traversing each straight segment of a route. Importantly, the exposure to object arrays from different egocentric learning views has been shown to specify new reference directions along which relatively fast judgments of relative directions can be made (Greenauer et al., 2013). Therefore, whenever egocentric-survey map sketchers imagined a heading that was aligned with a particular egocentric reference direction, the stored egocentric spatial relations would be directly retrieved. In contrast, allocentric-map sketchers might have specified the spatial relations connecting different landmarks from an aerial or third-person perspective in a manner that did not select for or give preference to any specific egocentric orientation or viewpoint while retrieving spatial information. Most probably, they inferred interobject relations during imaginal pointing by performing additional mental computations or transformations, leading to comparatively slower response times. Yet despite having slower response times, the allocentric-survey map sketches were found to have comparable levels of accuracy in imaginal pointing as the egocentric-survey map sketchers; this supports the view that both groups of survey map sketchers possessed comparable survey knowledge of the relative locations of the landmarks regardless of differences in the ease of access to spatial orientation information.

In conjunction, the findings from the three behavioral assessments and the post-test surveys suggest that egocentric-survey map sketchers relied primarily on the egocentric reference frame or first-person perspective to directly acquire their survey knowledge of a previously unfamiliar environment while allocentric-survey map sketchers relied primarily on the allocentric reference frame or third-person perspective to attain the same level of survey knowledge. To avoid the simplistic notion that the two forms of survey-based representations are qualitatively different inasmuch as the exclusive use of either egocentric and allocentric reference frame would lead to the acquisition of survey knowledge, it is vital to know that this study did not eschew the relevance of allocentric reference frame use for preserving a comprehensive spatial memory of the overall environment among the egocentric-survey map sketchers, and the relevance of egocentric frame use for attending to landmark and route features among the allocentric-survey map sketchers. In a statistical sense, the primary engagement of either reference frame can be conceived as the relatively greater weight attached to that particular reference frame in the processing of spatial information during route learning.

Another reason to avoid strong claims about either survey-based representation being wholly allocentric or egocentric in nature stemmed from real-world environmental constraints that deterred the identification of the exact orientations of the egocentric and allocentric reference directions. The irregular configuration of the 12 selected landmarks limited the number of pointing directions available for each imagined heading in the I-PDT and led to small and uneven numbers of trials across the set of imagined headings. The small number of trials per imagined headings deterred an unequivocal analysis of within-subjects differences in pointing performance by imagined headings, which is needed if one aims to pinpoint the exact orientation(s) or viewpoint(s) along which spatial information is optimally stored and accessed (see, e.g., Mou & McNamara, 2002; Shelton & McNamara, 2001). Nevertheless, owing to fact that this study was not aimed at investigating the degree of orientation-specificity of the survey maps, future studies can initiate this endeavor by harnessing virtual reality technology which enables the full control of environmental variables in virtual space, particularly with regards to the dimensions of the navigable space, the perceptual characteristics of objects/landmarks and their relative locations, and the shape of the route between the objects/landmarks (see, e.g., Mou, McNamara, & Zhang, 2013, for a virtual environment that involved navigating between objects in a well-configured array).

In addition, there are some caveats to note with regards to the use of the sketchmap task in future studies. There has been recent research showing that drawing ability, assessed using psychometric tests of figure copying and figure drawing from memory, affects the expression of geographical knowledge through free-hand sketches of a map of the world (Bell & Long, 2009). This suggests that drawing ability may confound one's expression of geographical or environmental knowledge through sketchmaps and that individual differences drawing ability, which was not assessed in this study, as well as in numerous previous studies (e.g., Appleyard, 1970; Blades, 1990; Blajenkova et al., 2005; Lohmann, 2011; Lynch, 1960; Rovine & Weisman, 1989; Taylor & Tversky, 1992; Tversky & Lee, 1998), may need to be assessed and controlled for in future studies using sketchmaps. Furthermore, it is crucial to note that there are currently no universal criteria for sketchmap analysis and that the this study should not be viewed as advocating a standard set of criteria for all future analyses of sketchmaps. The search for the best method to analyse sketchmaps should be viewed as an ongoing process (see, e.g., Lohmann, 2011). To date, there have been algorithms which are specifically created for examining the degree of alignment between the spatial elements (e.g., orientation of landmarks relative to street segments, typology of landmarks, connectivity of street segments) of sketch and metric maps (e.g., formal city or district plans) (see Jan & Schwering, 2015; Schwering et al., 2014). By examining the degree of similarity between a sketchmap and its corresponding metric map, a careful evaluation of the sketcher's fidelity of environmental or geographical knowledge can be reached. Consequently, this computational approach may be of great benefit to future studies that aim to devise an optimal mode of sketchmap analysis.

3. Study 2

This study aimed to identify individual differences in egocentric spatial updating with regards to spatial knowledge acquisition as conveyed by pointing-to-landmarks performance, and to clarify the relationships between three types of self-reported navigation strategies (egocentric spatial updating, survey-based, procedural) and the three sketchmap categories discovered in Study 1. Specifically, it aims to examine whether egocentric-survey map sketchers would self-report the use of the egocentric spatial updating strategy to a higher level than the two other groups of sketchers.

3.1. Designing the Navigation Strategy Questionnaire (NSQ)

The NSQ was designed with the specific aim of differentiating a scale assessing preference for spatial updating strategy from two other more traditional scales assessing preferences for procedural and survey-based strategies. 20 items were designed to assess each type of navigation strategy, constituting a total of 60 items.

3.1.1. Egocentric spatial updating strategy items

Five items were modified versions of items from the SBSOD (Hegarty et al., 2002), the *Indoor Wayfinding Strategy Scale* (Lawton, 1996), and the *Questionnaire on Spatial Representation* (Pazzaglia & De Beni, 2001): two of them assess sense-of-direction (e.g., *I have navigational intuition*), and three other items assess 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*). Furthermore, 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"*, Jonsson, 2002). Besides the above 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 experimental research (Loomis et al., 2002, 1998; Philbeck et al., 2001) that implicated successful wayfinding performance using spatial updating under conditions of low visibility (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., 1998, 1990; Loomis et al., 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 the experimental studies (Wang & Brockmole, 2003; Wang & Spelke, 2000) that implicated the navigational mechanism of spatial updating as entailed by the tracking and updating 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 application of egocentric spatial updating to fire rescue (Zhong, 2011). He claimed to be able to form 3D egocentric mental representations of the rooms in the buildings he had done searches in: “When I go into a low visibility environment, I know I start at this door and then I start to build like a 3D map of the building in my head, it is not like a blueprint, it is like an actual 3D building with me inside it.” An exemplar item designed to reflect this 3D mode of spatial visualization is: *If I travel in a novel multi-level building, I can easily imagine the 3D structure of the space.*

3.1.2. Survey-based strategy items

Fifteen 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 & Kallai, 2002; Lawton, 1994, 1996; Pazzaglia & De Beni, 2001): one item was designed to assess the ability to use cardinal directions for orientation (e.g., *I tend to judge my orientation in the environment in terms of cardinal directions (north, south, east, west))*, and fourteen items were designed to assess the ability to imagine environmental features in the form of a schematic representation from a 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; Wang et al., 2006). In particular, one item was designed to assess the ability to visualize a cognitive map based on fixed allocentric coordinates (e.g., *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*).

3.1.3. Procedural/route strategy items

Fifteen items were modified versions of items from the Wayfinding Strategy Scale (Lawton & Kallai, 2002; Lawton, 1994, 1996): ten of these 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 the other five items were designed to assess the dependence on a set of procedures 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 *Questionnaire on Spatial Representation* (Pazzaglia & De Beni, 2001) and the *Sense of Direction Questionnaire-Short Form (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*).

3.1.4. Checking the NSQ for face validity

Two researchers in spatial cognition reviewed the items on each scale in terms of their theoretical soundness and relevance to the three navigation strategies. One item designed to assess the survey-based strategy (*I can easily plan my route on a map of a new place*) was found not to be addressing a direct use of it and was removed from the set of survey-based strategy items during testing. The 59 items were intermixed and presented to participants in a random sequence computed by a random number generator.

3.2. Methods

3.2.1. Participants

The pilot NSQ, consisting of 20 items assessing the spatial updating, 20 items assessing procedural strategies, 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 new 429 participants, 39 participants (15 females), ranging from 19 to 29 years of age ($M = 22.31$), were invited for an experimental session in which they were taken on the same route as the participants in Study 1, and administered the R-PDT, I-PDT, and LRT after route traversal. This resulted in a total of 110 participants (48 females) (M age $= 22.30$), inclusive of 71 participants from Study 1, who performed all the behavioral assessments and completed the NSQ.

3.2.2. Procedure

A short online advertisement about the study was posted on the NUS intranet. 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 experimental session was first taken on the route and then asked to perform the behavioral tasks of R-PDT, I-PDT, and LRT in sequence. All of the participants completed these assessments successfully and their data entries were merged with those of the 71 participants from Study 1 for further statistical analyses.

3.3. Results

3.3.1. Selection of best items with discriminant factor loadings

Principal component analysis (PCA) with Varimax rotation was performed on the responses to the 59 items collected from 500 participants. The initial solution revealed 14 factors with eigenvalues above one. The first three extracted 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 while the remaining 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 (see Guadagnoli & Velicer, 1988), their loadings ranged between −0.379 and 0.437. Hence they were not retained in the 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 0.212 to 0.696. For the 19 items designed to assess the survey-based strategy, all of them had positive loadings on the second factor ranging from 0.033 to 0.695. For the 20 items designed to assess procedural strategy, 19 of them had positive loadings on the third factor ranging from 0.182 to 0.677, and one had a negative loading of −0.020 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.

In accordance with statistical recommendations (Stevens, 2009), items from each factor with loadings that exceeded 0.30 were considered as significant in view of the large sample size ($N = 500$). In 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 0.481 to 0.696 ($M = 0.566$). As for the second factor, two items with low loadings on the second factor (<0.12) 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 0.274 to 0.695 ($M = 0.551$). The item with the factor loading of 0.274 was retained as it approximated the significance level of 0.30 and that it has lower and non-significant loadings on the two other factors (<0.15). Lastly, for the third factor, two items with low loadings on the third factor (<0.19), 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 0.407 to 0.677 ($M = 0.497$). Altogether, the final 44 items, with their discriminant loadings on each of the three factors, are presented in Table 2: 17 items constituted the spatial updating scale; 12 items constituted the survey-based scale; and 15 items constituted the procedural scale.

3.3.2. 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 3. Cronbach's α values of spatial updating and survey-based scales are above McKelvie's (1994) recommended minimum coefficient of 0.85, whereas Cronbach's α value of the procedural strategy scale is within the range of other recommended minimum coefficients (from 0.60 to 0.85) as reviewed by McKelvie (1994).

In assessing the test-retest reliability of the NSQ, the original online version was re-administered after two weeks to a sample of 40 students (18 females; M age = 22.9). Their mean scale scores were computed by averaging across the selected discriminant items for each scale, followed by computing correlations between the two testing sessions. As shown in Table 3, the test-retest correlations were high ($rs \geq 0.87$, $ps < 0.001$. The correlation coefficients for all three scales were all within McKelvie's (1994) very good ($r \geq 0.85$) delayed test-retest reliability range.

3.3.3. Descriptive statistics of the NSQ scales

For each participant, the ratings from the selected items on each factor were averaged to create three scale scores corresponding to spatial updating (17 items), survey-based (12 items) and procedural (15 items) strategies respectively. Table 3 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, $D\,(500) = 1.06$, $p = 0.209$ (two-tailed), and survey-based strategy scales, $D\,(500) = 1.09$, $p = 0.18$ (two-tailed). However, deviation from normality was significant for the procedural strategy scale, $D\,(500) = 1.77$, $p = 0.004$ (two-tailed). The distribution of the procedural strategy scale scores was negatively skewed: $skewness = -0.756$, $SE = 0.11$. Participants generally rated themselves higher on the items assessing procedural strategy than on those assessing spatial updating and survey-based strategies.

3.3.4. Assessing the validity of NSQ scales

As previous studies have reported the confounding influence of speed-accuracy tradeoff (i.e., higher accuracy at the expense of longer response times and vice versa) during visuospatial task performance (e.g.,Lohman, 1988; Lohman & Nichols, 1990), an integrated efficiency score combining both accuracy and response latency were computed for all the behavioral assessments. For each assessment, efficiency scores were computed by dividing the accuracy scores over the natural logarithmic function (*Ln*) of response latencies.[1] These scores have been used by other spatial cognition researchers to minimize the confounding effect of speed-accuracy tradeoff and to represent the efficiency of visual-spatial processing (see, e.g., Blazhenkova & Kozhevnikov, 2010; Kozhevnikov, Louchakova, Josipovic, & Motes, 2009; Kozhevnikov et al., 2013). Support for the use of this efficiency measure stemmed from a significant positive correlation between the accuracy scores and the logarithmic transformed response latencies of the R-PDT, $r\,(110) = 0.19$, $p = 0.044$, implicating the presence of speed-accuracy tradeoff in this task. Table 4 shows the intercorrelations between the efficiency scores of the behavioral tasks and the NSQ scale scores.[2] In the assessment of each NSQ scale's predictive validity, the efficiency scores obtained from R-PDT, I-PDT, and route-based LRT were standardized as z-scores and used as three sets of dependent variables.

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

[1] A natural logarithmic transformation was used to normalize the positively 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 ($ps > 0.10$).

[2] Correlational and multiple regression analyses were also conducted using the accuracy scores of the behavioral tasks and the NSQ scale scores. They yielded patterns of significant results that were highly analogous to the current results based on the efficiency measure.

Table 2
Principal Component Loadings of 44 Discriminant Items based on a Three-Factor Solution using Varimax Rotation.

	NSQ items	Factor 1	Factor 2	Factor 3
1	I have navigational intuition.	**0.696**	0.272	−0.006
2	I have an "internal compass".	**0.631**	0.237	−0.098
3	I can easily point to a specific place outside the building when I don't see it from the inside.	**0.618**	0.272	−0.021
4	I can find my way under low visibility conditions (or even in darkness) in familiar places better than other people.	**0.610**	0.179	0.009
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.	**0.605**	0.278	−0.070
6	At any time during a route, I can point back to the landmarks I have passed by.	**0.581**	0.123	0.268
7	Inside buildings with no salient landmarks/objects to serve as points of reference, I can still sense the direction I am facing.	**0.578**	0.228	−0.077
8	I can easily keep track of my direction of travel on my route with respect to the starting point.	**0.575**	0.232	0.144
9	If I travel in a novel multi-level building, I can easily imagine the 3D structure of the space.	**0.566**	0.321	−0.007
10	At any time during a route, I can point back to where I began.	**0.563**	0.139	0.021
11	I can point to the exit after several turns in a building without relying on salient landmarks/objects as points of reference.	**0.563**	0.271	−0.085
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.	**0.540**	0.190	0.194
13	I know the direction to familiar buildings even when one is blocked from sight by another one.	**0.533**	0.188	−0.013
14	I can sense where I am heading even with my eyes closed.	**0.507**	0.015	−0.055
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.	**0.496**	0.183	−0.299
16	My mental representation of space reflects realistic, large-scale structural layout of my surrounding environment with relatively accurate distances.	**0.483**	0.303	0.091
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.	**0.481**	0.221	0.090
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.	0.077	**0.695**	−0.142
19	I usually attempt to mentally represent route segments, turns and their spatial relationships from a top-down aerial perspective.	0.342	**0.665**	−0.008
20	I rely primarily on a schematic mental representation of my environment to figure out my position in the environment.	0.091	**0.657**	0.020
21	I can plan out my route of travel by visualizing a schematic map from a top-down aerial perspective.	0.268	**0.626**	0.019
22	I usually attempt to visualize a map of the environment from a top-down aerial perspective as I travel.	0.306	**0.615**	0.000
23	I rely primarily on a schematic mental representation of my environment to help me in finding shortcuts.	0.159	**0.598**	−0.084
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.	0.114	**0.574**	−0.012
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.	0.339	**0.513**	−0.107
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.	0.162	**0.501**	−0.130
27	I usually rely on a schematic mental representation to orient and navigate to familiar places.	0.262	**0.499**	0.067
28	I tend to judge my orientation in the environment in terms of cardinal directions (north, south, east, west).	0.223	**0.398**	−0.070
29	When I reconstruct my mental map, its environmental orientation is fixed and does not change with my imagined heading directions.	0.143	**0.274**	0.007
30	When I navigate, I pay attention to the landmarks at the turning points and try to remember their sequence.	0.019	−0.073	**0.677**
31	To avoid getting lost, I usually try to memorize the landmarks around me, along with their associated turns.	−0.101	−0.021	**0.653**
32	I rely primarily on landmarks as signs of turning points along my route of travel.	0.006	−0.070	**0.590**
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.	0.013	−0.092	**0.548**
34	I keep a mental record of the landmarks I see on my traveling route in a sequential fashion.	0.193	0.064	**0.526**
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.	−0.205	0.054	**0.510**
36	I prefer following directions with descriptions of landmarks at turning points rather than using a map.	−0.031	−0.212	**0.505**
37	I find it much easier to recall my route as a set of procedures or actions than as a pattern of spatial relationships.	−0.248	−0.207	**0.496**
38	If I need to return to my origin, it is easier for me to retrace my route than to find a new shortcut.	−0.351	−0.032	**0.490**
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.	−0.118	−0.200	**0.481**
40	It is very difficult for me to find a shortcut because I think of my route as a sequence of routes and turns.	−0.392	−0.068	**0.464**
41	My mental representation of space primarily involves sequences of route segments and turning points.	0.082	0.120	**0.463**
42	Whenever I get lost, I try to reorient myself in relation to the visible landmarks.	0.142	0.116	**0.407**
43	I remember my route traveled as a succession of different segment lengths and turns without clear spatial relationships.	−0.065	−0.035	**0.332**
44	I have stored mental "snapshots" of landmarks or scenes which do not inform me clearly of my position and orientation in the environment.	0.011	0.009	**0.313**

Bold numbers in Table 2 refer to the discriminant loadings (or pattern coefficients) of the items that were designed to assess egocentric spatial updating strategy (Factor 1), survey[HYPHEN]based strategy (Factor 2), and route/procedural strategy (Factor 3)

Table 3
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	0.90	0.87**	3.08	0.63	1.00	4.82
Survey-based	0.86	0.88**	3.10	0.63	1.33	5.00
Procedural	0.81	0.87**	3.54	0.48	1.27	4.60

**$p < 0.01$ (two-tailed).

second model. Similar to the dependent variables, all sets of NSQ scale scores were standardized as z-scores. The NSQ z-scores of the 110 participants involved in regression analyses were derived from the z-scores computed based on the total sample of 500 participants. The two-step regression method allowed an initial assessment of the predictive validity of the procedural and survey-based scales, which are regarded as conventional scales assessing two well-documented navigation strategies, before examining the additional predictive effect of the spatial updating scale, which is a brand-new construct. Importantly, this method enabled the examination of the proportion of unique variance in efficiency scores that the new spatial updating scale could account for. Table 5 shows the results from three sets of hierarchical multiple regressions, each of which regressed one set of efficiency z-scores on three sets of NSQ z-scores.

First, with regards to route pointing efficiency, in model 1, the procedural scale emerged as a marginally significant predictor, $t\,(107) = -1.84$, $p = 0.07$, while the survey-based scale emerged as a significant predictor, $t\,(107) = 3.17$, $p = 0.002$. In model 2, the spatial updating scale emerged as a significant predictor, $t\,(106) = 3.90$, $p < 0.001$; its inclusion explained an additional 11% of the variance ($\Delta R^2 = 0.11$). With the spatial updating scale as the third predictor, the procedural scale remained as a non-significant predictor, $t\,(106) = -1.70$, $p = 0.09$, while the survey-based scale became a non-significant predictor, $t\,(106) = -0.28$, $p = 0.78$.

Second, with regards to imaginal pointing efficiency, in model 1, the procedural scale emerged as a significant predictor, $t\,(107) = -2.26$, $p = 0.03$, while the survey-based scale emerged as a non-significant predictor, $t\,(107) = 0.44$, $p = 0.66$. In model 2, the spatial updating scale emerged as a significant predictor, $t\,(106) = 0.4.51$, $p < 0.001$; its inclusion explained an additional 15% of the variance ($\Delta R^2 = 0.15$). With the spatial updating scale as the third predictor, the procedural scale remained as a significant predictor, $t\,(106) = -2.15$, $p = 0.03$, while the survey-based scale became a significant predictor, $t\,(106) = -2.79$, $p = 0.01$.

Third, with regards to route-based landmark recognition, in model 1, the procedural scale emerged as a non-significant predictor, $t\,(107) = 1.38$, $p = 0.17$, while the survey-based scale emerged as a marginally significant predictor, $t\,(107) = 1.84$, $p = 0.07$. In model 2, the spatial updating scale emerged as a significant predictor, $t\,(106) = 2.44$, $p = 0.02$; its inclusion explained an additional 5% of the variance ($\Delta R^2 = 0.05$). With the spatial updating scale's inclusion, the procedural scale remained as a non-significant predictor, $t\,(106) = 1.57$, $p = 0.12$, while the survey-based scale became a non-significant predictor, $t\,(106) = -0.34$, $p = 0.74$.

In summary, the results showed all three scales as significant predictors of imaginal pointing efficiency and the spatial updating scale as the best predictor of behavioral performance typified by route and imaginal pointing efficiency. Interestingly, the spatial updating scale significantly predicted route-based landmark recognition efficiency, suggesting that landmark knowledge acquisition complements an effective use of egocentric spatial updating strategy. Moreover, it is worth noting that an analogous

Table 4
Pearson product-moment correlations between NSQ scale scores and efficiency scores of behavioral tasks.

Assessments	1	2	3	4	5
1. NSQ spatial updating	_				
2. NSQ survey-based	0.72**	_			
3. NSQ procedural	−0.27**	−0.31**	_		
4. R-PDT	0.49**	0.35**	−0.27**	_	
5. I-PDT	0.36**	0.11	−0.24*	0.39**	_
6. LRT (route- based)	0.25**	0.14	0.08	0.33*	0.10

**$p < 0.01$ (two-tailed).
*$p < 0.05$ (two-tailed).

Table 5
Results of hierarchical multiple regression of efficiency scores of behavioral tasks on NSQ scale scores.

	Route pointing efficiency			Imaginal pointing efficiency			Route-based landmark recognition efficiency		
Predictors	*B*	*SE B*	β	*B*	*SE B*	β	*B*	*SE B*	β
Model 1									
NSQ procedural	−0.16	0.09	−0.17†	−0.20	0.09	−0.22*	0.12	0.09	0.14
NSQ survey-based	0.27	0.08	0.30**	0.04	0.09	0.04	0.16	0.09	0.18†
R^2	0.15			0.06			0.04		
Adjusted R^2	0.13			0.04			0.02		
F (2, 107)	9.44*			3.28*			2.05		
Model 2									
NSQ procedural	−0.14	0.11	-0.15†	−0.18	0.08	−0.20*	0.14	0.09	0.15
NSQ survey-based	−0.03	0.11	−0.03	−0.32	0.11	−0.35**	−0.04	0.12	−0.05
NSQ spatial updating	0.43	0.08	0.47**	0.52	0.12	0.56**	0.30	0.12	0.33*
R^2	0.26			0.21			0.09		
Adjusted R^2	0.24			0.19			0.06		
ΔR^2	0.11			0.15			0.05		
F for ΔR^2	15.17**			20.33**			5.95*		
F (3, 106)	12.18**			9.36**			3.41*		

**$p < 0.01$ (two-tailed).
*$p < 0.05$ (two-tailed).
†$p < 0.10$ (two-tailed).

pattern of significant results were produced using the data collected from the 71 participants in Study 1. With all predictors entered, the spatial updating scale emerged as the sole significant predictor of route pointing efficiency ($\beta = 0.61$, $p < 0.001$) and route-based landmark recognition efficiency ($\beta = 0.41$, $p = 0.024$) while the spatial updating and survey-based scales significantly predicted imaginal pointing efficiency (βs $= 0.94$ and -0.60 respectively, $ps < 0.001$). The procedural scale's prediction of imaginal pointing efficiency was close to significance ($\beta = -0.20$, $p = 0.057$). Using data collected from the 39 participants in Study 2 only, none of the NSQ scales emerged as significant predictors ($ps < 0.05$) when all are entered into the same model. This is because a sample size of 39 is inadequate for assessing the significance of three predictors based on a multiple regression power analysis conducted using conventional parameters: an alpha of 0.05, a power of 0.80, and an effect size of 0.15 (Faul, Erdfelder, Buchner, & Lang, 2013). Hence, the merger of data from all participants across both studies was necessary to provide more power. The combined sample size of 110 was adequate for assessing the significance of three predictors since it exceeded the desired sample size of 76 computed from an alpha of 0.05, a power of 0.80, and an effect size of 0.15 (Faul et al., 2013).

3.3.4.2. Relationship between the sketchmap categories and navigation strategies. To examine the relationship between different types of sketchmaps and navigation strategies, a 3 (Sketchmap Category) x 3 (Navigation 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 Navigation Strategy was the within-subjects factor. NSQ scale scores were transformed into z-scores as dependent measures.

The ANOVA showed a significant main effect of Sketchmap Category, F (2, 59) $= 5.13$, $p = 0.009$, $\eta^2 = 0.15$, but no significant main effect of Navigation Strategy, F (1.29, 75.99) $= 1.88$, $p = 0.17$, $\eta^2 = 0.031$ (Greenhouse-Geisser corrected) with regards to the z-scores of the three NSQ scales. Furthermore, there was a significant interaction between Navigation Strategy and Sketchmap Category, F (2.58, 75.99) $= 9.56$, $p < 0.001$, $\eta^2 = 0.25$ (Greenhouse-Geisser corrected). As shown in Fig. 3, this interaction resulted in a different distribution of NSQ z-scores across the three sketchmap categories for each navigation strategy.

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) $= 14.76$, $p < 0.001$, $\eta^2 = 0.33$; ii) the survey-based scale, F (2, 59) $= 5.33$, $p = 0.007$, $\eta^2 = 0.15$; and iii) the procedural scale, F (2, 59) $= 4.90$, $p = 0.011$, $\eta^2 = 0.14$. All follow-up between-groups comparisons were performed using Tukey *HSD.*

On the spatial updating scale, egocentric-survey map sketchers reported higher scores than both allocentric-survey map sketchers ($p = 0.07$) (marginally significant) and procedural route map sketchers ($p < 0.001$). Similarly, allocentric-survey map sketchers reported higher spatial updating scale scores than procedural route map sketchers ($p = 0.004$). On the survey-based scale, allocentric-survey map sketchers reported higher scores than procedural route map sketchers ($p = 0.033$). Similarly, egocentric-survey map sketchers reported higher survey-based scale scores than procedural route map sketchers ($p = 0.013$). However, the difference in survey-based scale scores between the allocentric- and egocentric-survey map sketchers was non-significant ($p = 0.84$). On the procedural scale, procedural route map sketchers reported higher scores than both egocentric-survey ($p = 0.06$) (marginally

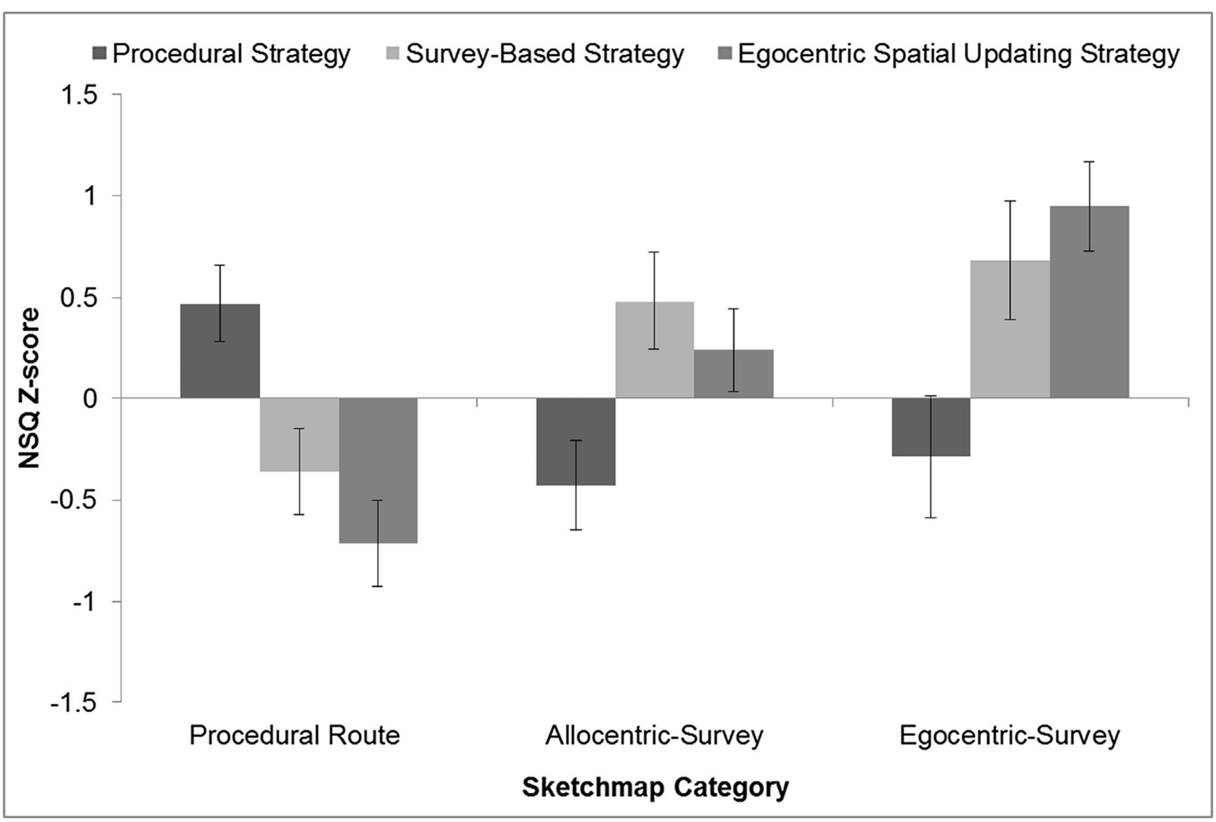

Fig. 3. Sketchmap differences in terms of three types of self-reported navigation strategies. Error bars show ±1 *SEM*.

significant) and allocentric-survey map sketchers ($p = 0.013$). Other than that, the difference in procedural scale scores between the allocentric- and egocentric-survey map sketchers was non-significant ($p = 0.912$).

As for analyzing the differences between the z-scores of the three NSQ scales within each sketchmap category, pairwise comparisons were applied with alpha set at 0.017 (two-tailed) based on Bonferroni correction. Egocentric-survey map sketchers exhibited higher scores on the spatial updating scale than on the procedural scale, t (15) = 2.54, $SEM = 0.49$, $p = 0.024$, a difference that was marginally significant. In contrast, procedural route map sketchers exhibited significantly higher scores on the procedural scale than on both the spatial updating scale, t (23) = 4.72, $SEM = 0.25$, $p < 0.001$, and the survey-based scale, t (23) = 2.88, $SEM = 0.29$, $p = 0.004$. None of the remaining comparisons reached significance, $ps > 0.017$.

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 and the procedural route map sketchers reported the highest scores on the procedural scale. The within-group analyses showed that the procedural route map sketchers depended primarily on the procedural strategy for cognitive mapping.

3.3.5. Gender differences

To investigate gender difference for each navigation strategy, we performed three univariate contrasts between the sexes on all 500 participants. An effect of gender was found for all three navigation strategies: i) spatial updating: F (1, 498) = 43.14, $p < 0.001$, $\eta^2 = 0.080$; with male participants reporting higher scores [*M (SD)* of males = 3.63 (0.40); *M (SD)* of females = 3.45 (0.54)]; ii) survey-based: F (1, 498) = 49.56, $p < 0.001$, $\eta^2 = 0.091$; with male participants reporting higher scores [*M (SD)* of males = 3.29 (0.61); *M (SD)* of females = 2.91 (0.60)], and iii) procedural: F (1, 498) = 18.56, $p < 0.001$, $\eta^2 = 0.036$; with female participants reporting higher scores [*M (SD)* of females = 3.63 (0.40); *M (SD)* of males = 3.45 (0.54)]. To examine whether this pattern of gender differences modulated the significant interaction between Navigation Strategy and Sketchmap Category, gender was entered it as third independent variable together with Navigation Strategy and Sketchmap Category in the repeated measures ANOVA. There was no significant three-way interaction, F (4, 112) = 0.93, $p = 0.449$, $\eta^2 = 0.032$, nor was there any significant two-way interaction between Gender and Navigation Strategy, F (2, 55) = 2.03, $p = 0.141$, $\eta^2 = 0.069$, and between Gender and Sketchmap Category, F (2, 56) = 0.46, $p = 0.636$, $\eta^2 = 0.016$.

Interestingly, these gender differences derived from the total sample of 500 participants were consistent with those derived from the *Wayfinding Strategy Scale* (Lawton, 1994, 1996; Lawton & Kallai, 2002), which showed men reporting a higher use of orientation strategy but a lower use of route strategy than women. They were also consistent with many other previous studies which implicated males to prefer a visuospatial 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).

3.4. Discussion

In Study 2, the NSQ was designed and provided a new self-assessment of egocentric spatial updating strategy that was conceptually differentiated from procedural and survey-based strategies. Based on factor analysis performed on the item ratings collected from a large pool of participants from various academic disciplines, three distinct factors, each composed of items with discriminant loadings, were identified to represent three navigation strategy scales: egocentric spatial updating, survey-based, and procedural. Each scale was shown to have high internal and test-retest reliabilities, and to be significant predictors of imaginal pointing efficiency when entered together into the same regression model.

Prominently, the main findings showed the novel spatial updating scale to have predictive validity in relation to assessments of spatial relationships in a large building complex. In both pointing tasks, the spatial updating scale was found to be the best predictor of their efficiency scores. In the prediction of route pointing performance, it accounted for 11% of variance in R-PDT efficiency scores in addition to the 15% contributed by the procedural and survey-based scales. And notably, in the prediction of imaginal pointing performance, it accounted for a 15% of variance in efficiency scores in addition to a 6% of variance contributed by the procedural and survey-based scales. In the latter case, it is worth noting that the unique variance contributed by the spatial updating scale was two-and-half times of the variance contributed by the two other scales. Together, these findings demonstrate egocentric spatial updating strategy to be a major navigation strategy that is directly relevant for spatial orientation in a large-scale environment.

Furthermore, with respect to the relationship between the three NSQ scales and the three sketchmap categories, egocentric-survey map sketchers exhibited the highest scores on the spatial updating scale in both between-groups and within-group comparisons. Their high scores on the spatial updating scale supported the proposal of egocentric spatial updating as being crucial for the formation of egocentric-survey representation. In addition, 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. Lastly, for the survey-based navigation strategy, the survey-based scale scores of allocentric-survey and egocentric-survey map sketchers did not differ significantly. This non-significant difference could be explained by the survey-based scale being composed of the lowest number of discriminant items among the three scales (i.e., 12 items), making it unable to render a highly discriminant measure of survey-based strategy. The imperfection of the survey-based scale was also testified by the relatively high positive correlation between its scales scores and the spatial updating scale scores [r (110) = 0.72]. This high correlation makes it difficult to confirm the survey-based scale's predictive validity in the presence of the spatial updating scale with respect to the imaginal pointing task. Notably, the strength of the relationships between the two sets of pointing efficiency scores and the survey-based scale scores (shown by the beta coefficients) decreased with the inclusion of the spatial updating scale as the third predictor, and surprisingly became negative in the prediction of imaginal pointing efficiency. Most probably, this reveals a case of suppression in multiple regression whereby the relatively larger effect of the spatial updating scale scores on the two sets of pointing efficiency scores undermined the predictive power of the survey-based scale scores. The prominence of this suppressor effect might also be due to the use of pointing tasks that activated egocentric spatial processing to a greater extent than allocentric spatial processing. Therefore, further studies can be done to improve the validity of the survey-based scale. One way of improving its discriminant validity is by expanding its current number of items with items that are more characteristic of survey-based navigation strategy. And one way of improving its predictive validity is through the use of a *map reading (wayfinding) task* that requires participants to utilize a schematic map and mentally map out interobject relations in finding their way through an unfamiliar route from the start to the end (see Meilinger, Hölscher, Büchner, & Brösamle, 2007; Pazzaglia & De Beni, 2001). Likewise, in consideration that the landmark recognition task might not have offered a direct test of the procedural scale's criterion validity, it can 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 (see Cornell, Sorenson, & Mio, 2003).

Notwithstanding the need for further examination of the survey-based and procedural scales, this study related different levels of egocentric spatial updating strategy use to the formation of route and survey-based representations, and showed that individual differences in the use of this strategy affected the processing of spatial relationships in a building complex. Notably, the high reliability and predictive validity of the spatial updating scale support its potential use in future research as a valid self-report measure in predicting performance on visuospatial tasks that involve egocentric spatial processing.

4. General discussion

This study as a whole investigated whether or not two subtypes of survey-based representations, formed on the basis of differential engagement of the allocentric and egocentric reference frames, can be distinguished from each other using sketchmaps and relevant behavioral tasks, and the association of a self-reported egocentric spatial updating strategy to the acquisition of survey knowledge. Study 1 provided evidence to suggest the two subtypes of survey-based representations can be portrayed in the form of two categories of sketchmaps: allocentric- and egocentric-survey maps. Both categories of sketchmaps exhibited relatively accurate information about the overall spatial layout but the egocentric-survey maps were exceptional for showcasing floor separation and spatial orientation information (i.e., the depiction of the first leg as pointing upwards) that implicate the engagement of the egocentric reference frame or the first-person perspective in the retrieval of spatial information. Notably, the superior performance of the egocentric-survey map sketchers over the allocentric-survey map sketchers in the two pointing direction tasks suggest that the former group engaged egocentric spatial processing to a greater extent. Study 2 supported all of the main findings from Study 1 by showing that egocentric-survey map sketchers reported higher scores than both allocentric-survey map sketchers on a newly developed scale of egocentric spatial updating strategy. Critically, this scale was found to be the best predictor of pointing-to-landmarks performance and route-based landmark recognition when compared to the two other new scales assessing procedural/route and survey-based strategies.

In conjunction, key findings from the two studies showed a significant relationship between egocentric spatial updating strategy use and the formation of egocentric-survey representations, and that differential use of the egocentric spatial updating strategy influenced the processing of spatial relationships in a newly experienced campus environment. It is vital to note that the scale of the environmental or geographical space will limit the application of this strategy. This is because egocentric spatial relations are transient in nature and it will become harder to track and maintain them as the scale of navigable space increases. Based on this reasoning, the egocentric spatial updating strategy is most likely well-suited for computing and updating egocentric spatial relations *within* places that can be navigated over short distances on foot (i.e., buildings, districts or locales of a town or city) rather than *between* places separated by long distances that can only be traversed using a suitable form of transport. In specifying the spatial relationships between arrays of landmarks in a town or city and between various towns and cities, the egocentric spatial updating strategy will be ineffective and has to be substituted by a survey-based or allocentric strategy as several studies have shown that people tend to represent such interrelationships with respect to the northward direction (Frankenstein, Mohler, Bülthoff, & Meilinger, 2012; Meneghetti, Pazzaglia, & De Beni, 2012; Zhang, Mou, McNamara, & Wang, 2014). Nonetheless, the currently documented relevance of egocentric spatial updating strategy for mapping out spatial relations in the confined spaces of a building complex is worthy of greater attention in future research. An acknowledgement of individual differences in the use of this strategy is likely to benefit the development of spatial cognition models that can address the mechanisms of human spatial updating in greater detail.

In the previous literature, path integration (the basic form of 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; for a review). 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, & Golledge, 1993) attribute 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 or to participants' experience with navigating different types of paths which varied in complexity (Klatzky, Beall, Loomis, Golledge, & Philbeck, 1999). Interestingly, this 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. In view that the route pointing accuracy is higher among participants with higher spatial updating scale scores, it is possible that such participants might commit fewer systematic errors than participants 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 egocentric spatial updating, rather than by the experience of navigating various paths alone. Once more, this study suggests that individual differences in egocentric spatial updating should receive greater concern in future research that aim to devise spatial cognition models with greater explanatory power.

Furthermore, the spatial updating items, shown to have high reliability and credible validity, may be applied in future research on the neural correlates of individual differences in spatial navigation that aims to pinpoint the specific neural regions involved in egocentric spatial updating strategy. As previous fMRI research has shown that activation in the precuneus 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, Hegarty, Büchel, & Loomis, 2008), a potential direction for future research can be an examination of the relationship between neural activation in the precuneus and self-reported use of the egocentric spatial updating strategy with regards to selected item ratings and/or the scale score as a whole.

Aside from the theoretical implications highlighted above, in the practical sense, an understanding of individual differences in navigation 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 navigation strategies. Previous research showed that participants who 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 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 navigation 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, 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 egocentric spatial updating strategy because 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 the forward field of view (Aretz, 1991; Rodes & Gugerty, 2012).

Besides identifying drivers with different navigational styles, this study also proposes that the egocentric spatial updating scale can be applied to the selection of professionals whose daily work demands them to rely extensively on egocentric spatial updating for positional and directional awareness. To name a representative few, such professionals include firefighters, naval divers, army rangers, and aviation pilots (see Loomis et al., 1999). The selection of such individuals with relatively high use of egocentric spatial updating strategy 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 egocentric spatial updating in the context of a large-scale environment, and that a major preference for egocentric spatial updating strategy underpinned the formation of a unique subtype of environmental representation—the egocentric survey-based representation. It highlights the egocentric spatial updating strategy as critical for gauging the locations of proximal landmarks and their orientation relative to the navigator's body, and that an understanding of different navigation strategies can contribute to future spatial navigation research, as well as to the improvement of navigational performance and personnel selection.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvp.2016.04.007

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