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Individual differences in the representations of novel environments

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Abstract

The present research investigated individual differences in representations of a novel environment. Thirty-eight participants traversed an unfamiliar route over two floors of a building and drew sketch-maps of the route. Participants also completed a mental rotation task and route knowledge tasks: orientation (pointing to nonvisible landmarks), landmark recognition, route tracing on a floor plan, and route retracing tasks. Based on spatial accuracy, participants' sketch-maps were classified as one-dimensional, two-dimensional, and three-dimensional, and the types of sketch-maps were associated with participants' spatial ability and their performance on route knowledge tasks. Our findings showed that individual differences in visual–spatial abilities predicted the types of environmental representations that adults formed and thus provide evidence against stage/sequential models that attribute differences in environmental representations exclusively to differences in experience.

1. Introduction

Interest in cognitive representations of environments ranges from city planning (e.g. Lynch, 1960; Appleyard, 1969; Antes, McBride, & Collins, 1988) and geography (e.g. Montello, 2002) to spatial cognition and reasoning (e.g. Tolman, 1948; Thorndyke & Goldin, 1983; Tversky, 2003). Since Tolman (1948) found that more general spatial representations of an environment (i.e. beyond chained stimulus-response associations to a goal) guide spatial navigation, considerable research on cognitive representations of environments has focused on the development of such representations with maturation among children (see Piaget & Inhelder, 1967; Siegel & White, 1975) and with experience among children and adults (e.g. Devlin, 1976; Thorndyke & Hayes-Roth, 1982; Aginsky, Harris, Rensink, & Beusmans, 1997). Developmental researchers have suggested that children's abilities to represent environments follow a developmental sequence from concrete, isolated, egocentric representations to abstract, hierarchically integrated, allocentric representations (see Piaget & Inhelder, 1967; Siegel & White, 1975). Furthermore, researchers have suggested that adults' development of representations of environments follows an analogous but experience-based sequence (see Siegel & White, 1975). In the present study, however, we question whether adults' representations necessarily follow such an experience-based sequence, and we instead propose that individual differences in visual–spatial ability predict the types of representations that adults form.

Although there are variations in the definitions, sequential/stage models of the development of environmental representations typically draw distinctions between *landmark* representations (i.e. knowledge of visually distinct objects and scenes in the environment), *route/procedural* representations (i.e. sequentially organized knowledge of locations encountered along the route and actions performed at the locations) and *survey* representations (i.e. spatially organized knowledge of locations and routes) (e.g. Siegel & White, 1975; Thorndyke & Goldin, 1983). According to sequence/stage theorists, children's abilities to represent environments (see Piaget & Inhelder, 1967; Hart & Moore, 1973; Siegel & White, 1975; Moore, 1976) and adults' representations of environments (e.g. Appleyard, 1970; Siegel & White, 1975; Evans, Marrero, & Butler, 1981;

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Thorndyke & Hayes-Roth, 1982) progress in a specific sequence. Siegel and White, for example argued that (1) landmarks are first remembered, (2) actions are associated with landmarks, (3) landmark-action sequence pairings are organized to form routes, (4) an objective frame of reference is established, and (5) the routes are remembered within the objective frame of reference as survey representations. Children's representations then will depend on their specific stage of development, but adults' representations will depend on their experiences (e.g. number of times traversing the routes) in the environment.

To test sequential model predictions of adults' representations, Thorndyke and Hayes-Roth (1982) examined the survey knowledge of employees who had worked at a building 1–2 months, 6–12 months, or 12–24 months and of a group of participants who had no prior experience in the building but who were allowed to study the building floor plan. Survey knowledge of the building was assessed by having all of the participants judge straight-line distances between landmarks (a Euclidean distance estimation task), judge distances between landmarks along specific routes (a route distance estimation task), indicate directions to landmarks from various points in the building (an orientation task), and indicate the location of landmarks relative to two reference locations on an otherwise blank page (a landmark placement task). Thorndyke and Hayes-Roth found that greater experience within the building positively correlated with performance on Euclidean distance, landmark placement, and orientation tasks. Thorndyke and Hayes-Roth also found that survey knowledge could be acquired from studying floor plans (i.e. without direct navigation experience); however, participants who formed the survey representations from studying floor plans were less accurate on the route distance and orientation tasks than employees who had navigational experience within the building.

Although the above data seem to support sequential/stage models (Thorndyke & Hayes-Roth, 1982) and these models are considered a dominant framework for environmental representations (see Montello, 1998), several studies have revealed data that challenge the experience-based sequential/stage progression from landmark- to route- to survey-type representations of environments. Many studies have revealed rather wide individual differences in performance on navigation tasks (e.g. sketch-map, orientation, and backtracking tasks) following relatively little exposure to an environment (e.g. Devlin, 1976; Rovine & Weisman, 1989; Hirtle & Hudson, 1991; Lawton, Charleston, & Zieles, 1996; Aginsky et al., 1997). Devlin, for example found participants who could draw survey-type sketch-maps of a town after residing there for less than 3 weeks. Aginsky et al. examined the environmental representations of participants who demonstrated error-free performance in traversing a route learned in a virtual reality driving simulator, and like Devlin, Aginsky et al. found that after relatively little exposure to the route ($M = 8$ times through), some participants could draw survey-type sketch-maps of the route (whereas others drew landmark- or route-type sketch-maps). Furthermore, Moeser (1988) found that experience in a building did not lead to survey-type representations: Neither first nor third year student nurses drew survey-type sketch-maps of their clinical training building; 6 of 10 first year and 5 of 10 third year nurses drew landmark-type maps, and the others drew route-type maps. Finally, Rovine and Weisman found participants who could draw survey-type sketch-maps of a novel environment after a single traversal of a route through the environment. After walking a route through an unknown downtown area, participants drew sketch-maps of the area, and Rovine and Weisman classified the sketch-maps based on the inter-relations among the paths. They identified five types of sketch-maps: sequential, spatial-mosaic, spatial-linked, incomplete spatial-patterned, and complete spatial-patterned. The fact that complete spatial-patterned sketch-maps (i.e. survey-type sketch-maps) were drawn by participants after only one exposure to an environment challenges the necessity of experience in forming survey-type representations.

Although Devlin (1976), Aginsky et al. (1997), and Moeser (1988) have provided evidence that challenges sequential/stage models, issues regarding the control of experience prevent the unequivocal acceptance of their data as challenges to these models. Devlin and Moeser did not control participants' experience in the environments (e.g. which routes were traversed and how many times), and although Aginsky et al. (1997) had their participants traverse the same route, their data do not address whether all participants formed landmark-type representations after their first exposure to the route and then with additional exposure some participants went on to form survey-type representations. Finding survey-type representations following a *single* exposure to a route through a novel environment, as Rovine and Weisman (1989) found, provides the strongest evidence that survey-type representations do not necessarily follow from a landmark-to-route-to-survey progression. Rovine and Weisman's instruction to draw a map of the downtown area, not just the route traveled, however, may have led participants to spatially structure their drawings based on their knowledge of a typical city. Despite these problems, however, these studies provide some evidence that adults' environmental representations do not necessarily follow a landmark- to route- to survey-type progression.

In contrast to sequential/stage models, we hypothesize that individual differences in visual–spatial abilities (rather than experience alone) predict the types of environmental representations that adults form. In support of our hypothesis, Thorndyke and Goldin (1981), for example found a positive relationship between visual–spatial abilities and environmental representation tasks. Thorndyke and Goldin compared the cognitive abilities of *good cognitive mappers*, those who did well on orientation, route distance, Euclidean distance, and landmark placement tasks, and *bad cognitive mappers*. Good mappers were better than bad mappers on measures of visual–spatial ability (i.e. irregular shape orientation, memory for the locations of buildings on a map, foam board, paper folding, cube comparison, and embedded figures tests), but that they were not better on measures of verbal ability (i.e. synonym recognition and word recall). Other research (see Hegarty & Waller, 2005) also has revealed relationships between visual–spatial abilities and measures of environmental representations using self-to-landmark and landmark-to-landmark distance and orientation judgments (Bryant, 1982; Pearson & Ialongo, 1986; Allen, Kirasic, Dobson, Long, & Beck, 1996; Juan-Espinosa, Abad, Colom, & Fernandez-Truchaud, 2000; Waller, 2000), route-tracing on a cartographic map (Pearson & Ialongo, 1986), and sketch-maps of familiar environments (Moore, 1975).

Although the above examples support the hypothesis that visual–spatial abilities are related to environmental representations, Rovine and Weisman (1989) did not find significant relationships between participants' levels of visual–spatial abilities and the types of sketch-maps that participants drew. Rovine and Weisman (1989) examined the relationship between visual–spatial abilities (Thurstone (1938), Spatial Relations Test and the Embedded Figures Test) and environmental representations of a novel route (the five types of sketch-maps described above treated as an ordinal, map-complexity variable, and the frequency and ordering of landmarks in the sketch-maps), and way-finding performance (route distances and total turns taken when returning to landmarks after having traversed the route). Embedded figures scores were significantly correlated with landmark order accuracy and the way-finding measures; however, neither the embedded figures nor the spatial relations scores were significantly correlated with sketch-map complexity, and spatial relations scores were not significantly correlated with way-finding performance.

There are two potential problems, however, with accepting Rovine and Weisman's findings. First, as noted above, the instruction to draw a map of the downtown area may have affected the spatial structuring of the drawings. Second, Rovine and Weisman sorted the participants' maps based on the depiction of inter-relations among the paths (i.e. the presence of inter-connecting street segments). Thus, for the maps that were given the lowest complexity rank (i.e. the sequential maps), the traversed route segments may have been accurately organized spatially but lacked inter-connecting nontraversed path segments, and changing the classifications of these maps could potentially lead to higher correlations between visual–spatial abilities and the sketch-map measures.

Thus, we designed a study to examine the relationship between visual–spatial ability and representations of a novel environment. In our study, we asked participants to traverse a novel route that covered two floors of a building and then to draw sketch-maps of the route. We used the sketch-maps as a measure of the participants' types of representations of the environment. In order to allow clear classifications of the sketch-map depictions of the participants' environmental representations, the route was designed in an area that had distinct spatial features and distinct landmarks. Thus, in addition to two floors, the route contained several decision points, segments of varying lengths, a loop around a stairwell, and a stairwell with entrance and exit points on opposite sides. The route also contained several landmarks (e.g. bulletin boards, a telephone booth, and an emergency shower) common to science buildings, and we added colorful posters. To provide converging evidence for our sketch-map classifications, we further assessed the participants' knowledge of the environment using orientation and floor plan route-tracing tasks. We also assessed memory for landmarks using a landmark recognition task. We used the Shepard and Metzler (1971) mental rotation test to assess our hypothesis that individual differences in visual–spatial ability predict the types of environmental representations that adults form. Finally, we had participants retrace the route to assess whether differences in environmental representations result in differences in way-finding performance.

Although several measures have been used in the environmental cognition literature to assess environmental representations, we relied on sketch-maps for several reasons. Although correlated with other environmental representation measures, previous research has shown sketch-maps to have unique psychometric properties (e.g. Bryant, 1984). Additionally, sketch-maps yield data that allow for the assessment of landmark-, route-, and survey-type representations, whereas measures like orientation, landmark distance, and landmark placement measures do not. High orientation and distance estimate error, for example, indicate lower understanding of environment configurations, but cutoff points for determining landmark-, route-, and survey-type representations cannot be determined from these data alone. Of course, sketch-maps are not exact measures of environmental representations, and concerns have been raised regarding the treatment of sketch-map data (e.g. the appropriateness of using interval or ratio measurements, the development and application of judgment criteria, see Evans, 1980). Sketch-maps, however, have been shown to have high test–retest reliability and to be valid in that sketch-map measures correlate with other measures of environmental representations but only weakly correlate with graphic skills, although they do correlate with experience interpreting maps (for a review, see Evans, 1980).

2. Method

2.1. Participants

Thirty-eight students (19 males and 19 females) took part in the study. The students were recruited from the psychology participant pool at the Rutgers-Newark campus as well as through sign-up sheets posted around the Rutgers-Newark and New Jersey Institute of Technology campuses. Participants were awarded course credit or monetary compensation for participating.

2.2. Procedure

All participants were tested individually, and the testing lasted approximately 1.5 h. At the beginning of the study, participants completed a demographic questionnaire. Then, the participants completed the computerized spatial ability test—the Shepard and Metzler (1971) mental rotation test.

Next, the experimenter led the participants through the route. At the end of the route, participants completed the orientation task and drew sketch-maps of the route. The experimenter then led the participants back to the starting point and asked the participants to retrace the route from the starting point to the finishing point. After completing the retracing task, participants returned to the starting point and completed the floor plan route-tracing and landmark recognition tasks. Finally, participants were interviewed about cues that they used and difficulties that they experienced during the way-finding task.

2.3. Route description

The experimenter led participants on the route through two floors of the science building at the Rutgers-Newark campus (see Fig. 1). The route was planned on the first floor and in the basement. Both of the floors were not familiar to the participants who took part in the study. Participants received the following instructions: "This is a navigational experiment. You should follow me and pay attention. After we walk this route, you'll be asked to retrace it." Along the route, participants received instructions to remember three places: the door to the lab, the entrance to the building, and the entrance to the second staircase. The experimenter stopped at these places, pointed to them, and said, "Please, try to remember this place," but the experimenter did not explicitly name or label these places.

The route began at the laboratory. From there, the experimenter led the participants around the stairwell and then down the stairwell to the basement. In the basement, the experimenter led the participants through the hallway and then up a second staircase back to the first floor. The experimenter then led the participants down the final leg of the route to the finishing point, which was close to the starting point. The starting point was not visible from the finishing point, however, because of closed double-doors. The route was 376 feet and had 10 turns with two additional turns in each staircase between the first floor and the basement.

The route had several distinct landmarks and spatial features. It was planned on two floors; it contained a loop around the first stairwell; the entrance and exit points for the first stairwell were on opposite sides; the route segments varied in length; and the final heading was back toward the starting point. The route also had different types of landmarks, e.g. bulletin boards, doors to classes, and the entrance to the building (see Fig. 1). Additionally, posters were created and added to the route (e.g. see Landmarks B, C, D, and F in Fig. 1). There were five active and five no-choice landmarks: Active landmarks were located at decision points along the route (i.e. turning points), whereas no-choice landmarks were located along the hallways away from the decision points (see Fig. 1).

2.4. Tasks

Participants completed the following environmental knowledge and visual–spatial ability tasks.

2.4.1. Sketch-map task

For the sketch-map task, participants received the following instructions: "Please draw a map of the route that we just took as accurately as you can. Include as much as you can recall. Artistic abilities are not important." Participants were given a blank sheet of A-3 format paper (27.9 cm × 43.2 cm) and four, different colored markers (black, blue, green, and red) to draw a sketch-map of the route. The experimenter switched the markers during natural pauses when participants began drawing new significant parts of the route (e.g. when the participant finished drawing the loop around the first staircase and began drawing the leg through the basement or when a participant finished drawing the building structure and began drawing the first leg of the route). Switching markers, was used to record the order in which participants drew the segments of route (for an example of the use of this method, see Akshoomoff, Feroleto, Doyle, & Stiles, 2002).

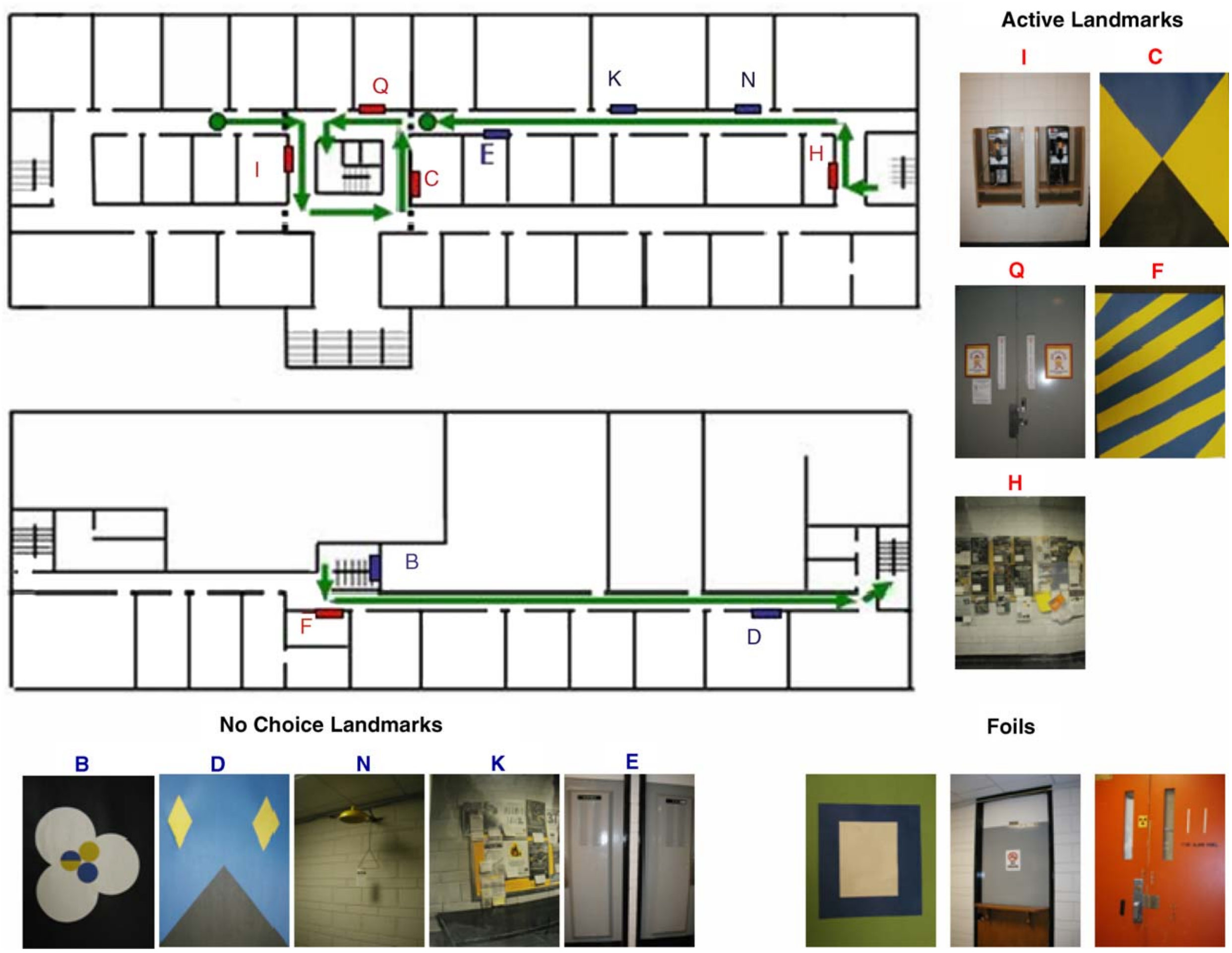

Fig. 1. Floor plans for the two floors of the science building with the route and the landmark locations indicated and with active, no-choice, and examples of foil landmarks used in the landmark recognition task shown.

2.4.2. *Orientation task*

The orientation task was administered to subjects at the finishing point immediately after traversing the route. While seated at a desk facing the inner wall of the hallway, participants indicated the direction to the three locations that were pointed out to them while traversing the route (the lab, the entrance, and the second staircase) and to three locations that were outside of the building (the cafeteria, the bookstore, and the admissions building). For each location, participants were given sheets of paper each with a smaller, filled circle centered within a larger circle. Participants indicated the direction to a location by drawing a straight line from the filled circle, which they were told was their current position, to the outer circle.

2.4.3. *Floor plan route-tracing task*

Participants were given floor plans of two floors of the building (similar to Fig. 1), each on a separate A3 sheet of paper, and they were asked to draw the route on the floor plans.

2.4.4. *Landmark recognition task*

For the landmark recognition task, pictures were taken of 10 objects (active and no-choice) that were on the route and of eight objects (foils) that were not on the route (see Fig. 1). Participants were shown the pictures in a random order, and they verbally indicated whether they remembered seeing the objects along the route.

2.4.5. *Visual–spatial ability test*

To assess visual–spatial ability, participants completed a computerized version of Shepard and Metzler's (1971) mental rotation test. On each trial, participants viewed sample and comparison two-dimensional (2D) line drawings of three-dimensional (3D) geometric figures and judged whether the figures were the same or different. The figures were based on the Shepard and Metzler and Vandenberg and Kuse (1978) figures.

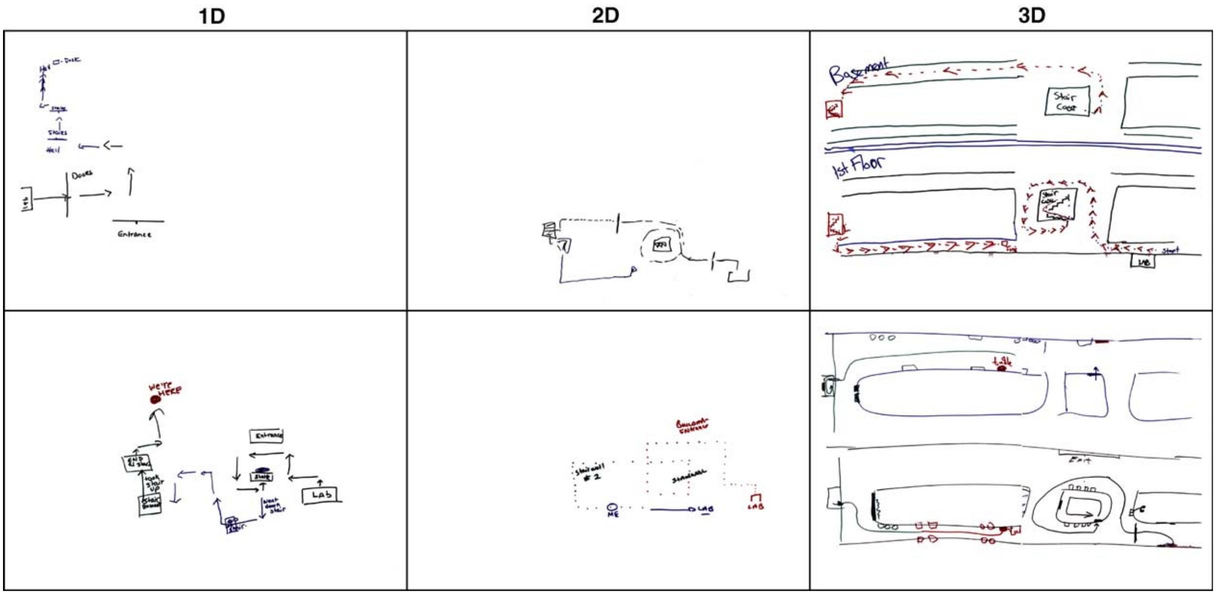

Fig. 2. Examples of the 1D, 2D, and 3D sketch-maps.

Comparison figures were rotated from 20° to 180° (in 20° increments) about the X-, Y-, or Z-axis from the sample figures, and on trials in which the figures differed, the rotated comparison figures were mirror images of the sample figures. Fifty-four (9 angles × 3 axis of rotation × 2 same/mirror image) pairs of figures were used. Participants were instructed to respond as accurately and as quickly as possible, and the computer program recorded accuracy and response time.

2.4.6. Retracing task

For the way-finding retracing task, participants were asked to retrace the route from the beginning to the end. The experimenter followed the participants and recorded the trajectory on a floor plan of the building.

2.4.7. Interviews

During the interviews, participants were asked open-ended questions regarding the way-finding aids that they used (i.e. directional or landmarks cues) to retrace the route. In particular, they were asked: "How did you retrace your steps? What helped you decide where to go and when to turn? Did you use landmarks to find your way? How? Did you have an understanding of how the places that we passed on the route were positioned in relation to one another? How did this help you?" The initial question asked was "How did you retrace your steps?" Some participants gave relatively elaborate responses based on this question alone, and no further questions were necessary. However, some participants required further prompting, and for such cases, the experimenter systematically asked more specific questions until the participant's response indicated what and how directional or landmark cues were used.

3. Results

3.1. Sketch-map drawings classification

All of the sketch-maps were independently analysed and classified by two coders (the first and third authors). When classifying the sketch-maps, the coders used the general criteria that they were to be sorted based on the accuracy of the spatial relations and the topographical features depicted (e.g. main turning points, location and spatial alignment of the route segments, and separation of the two floors), but the number of categories and specific criteria used by the coders used were not restricted. The agreement between the coders was high (96% agreement), and disagreements were discussed until the coders agreed on a classification. Three types of sketch-map drawings were discovered[1] (e.g. see Fig. 2) and labeled as one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D):

(1) 1D sketch-maps (5 males and 11 females): Although participants included some turns, they failed to accurately depict the spatial relations between the segments of the route. In particular, they failed to depict the final segment heading toward the starting point and failed to depict the two separate floors.
(2) 2D sketch-maps (8 males and 3 females): Although participants omitted or incorrectly drew some of the turns, they relatively accurately represented the spatial relations among locations and the overall shape of the route with the final segment heading

[1]The differences in the proportions of males and females drawing each type of map were not significant, $\chi^2(2, N = 38) = 4.614$, $p = 0.10$.

toward the starting point. However, they represented the spatial relations among locations and route segments only within one plane, without separating the two floors.

(3) 3D sketch-maps (6 males and 5 females): Participants relatively accurately represented the spatial relations among locations, and they also represented the vertical alignment of the locations and route segments with respect to the two floors of the building. Although participants may have omitted or incorrectly drawn some of the turns, the main topographical features were present, that is, the heading of the final segment was towards the starting point, the first and last segments of the route were correctly drawn on the first floor, and the intermediate segment of the route was drawn on the basement floor.

Our classification of the sketch-maps was similar to classifications used by other researchers (e.g. Aginsky et al., 1997). Our 1D sketch-maps included elements of both landmark- and route-type maps, because they predominantly consisted of sequential-type route segments connecting some landmarks but did not depict integrated spatial relations. Our 2D and 3D sketch-maps corresponded to survey-type sketch-maps reported in other studies because they preserved the global spatial structure of the environment and spatial relations among locations. In particular, our 2D sketch-maps corresponded to the 2D place-type sketch-maps found by Aginsky et al., and they reflected locations that were connected sequentially while preserving the global spatial structure. Our two-level 3D sketch-maps are new to sketch-map research, and they illustrate the addition of a vertical dimension to survey-type representations, which was found because our route covered two floors. We did not find sketch-maps with landmarks disconnected in space like the 0D place-type sketch-maps found by Aginsky et al., but Aginsky et al. found little difference on the other environmental knowledge tasks between the groups who drew 0D and 1D sketch-maps. Thus, we suggest 0D or landmark-type and 1D or landmark/route-type sketch-maps may represent a single type of representation (see also Montello, 1998).

The presence of 2D and 3D sketch-maps provides evidence that survey-type representations can occur after a single exposure to a route, contrary to the notion that survey knowledge arises only from a landmark-to-route-to-survey experienced-based progression. Thus, our data challenge sequential/stage models of the formation of environmental representations (Hart & Moore, 1973; Siegel & White, 1975).

3.2. Description of additional sketch-map characteristics

Although we classified the sketch-maps based on the spatial relations, we found other characteristics related to the types of sketch-maps. Most of the participants (7 of 11) who drew 3D sketch-maps, compared to few of the participants who drew 2D sketch-maps (2 of 11) and none of the participants who drew 1D sketch-maps (0 of 16), included features in their drawings such as halls and classrooms that they assumed existed in the building but were not visible from the route (e.g. see Fig. 2). χ^2 analysis showed that the relationship between the type of sketch-map and the drawing of assumed features was significant, $\chi^2(2, N = 38) = 14.85$, $p = .001$. Additionally, the drawing sequences were analysed based on the color changes. Most of the participants (8 of 11) who drew 3D sketch-maps drew the basic building structure before drawing in the route, whereas most of the participants who drew 2D sketch-maps (9 of 11) and all of the participants who drew 1D sketch-maps drew the route segments and landmarks sequentially from the remembered start to the remembered finish (e.g. see Fig. 2). χ^2 analysis showed that the relationship between the type of sketch-map and the order of drawing was significant, $\chi^2(2, N = 38) = 18.31$, $p < .001$. The above results suggest that the 3D group incorporated an assumed building structure into their representations and might have relied on an allocentric frame of reference while drawing the sketch-maps in contrast to 1D and 2D groups that tended to draw the maps based on a sequential-type reconstruction of the route and might have relied on egocentric frames of reference.

3.3. Analysis of additional environmental knowledge measures

3.3.1. Orientation task

We compared the three sketch-map groups' orientation errors (mean absolute value of the angular deviation from the correct angle) in estimating the angles to the three landmarks along route and to the three landmarks outside of the building (see Fig. 3). Due

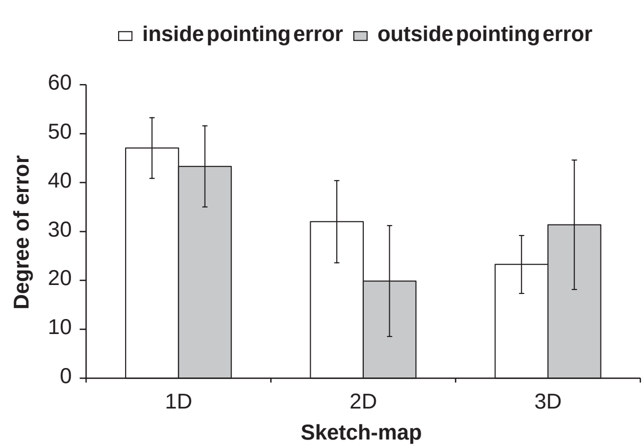

Fig. 3. Orientation error in pointing as a function of the type of sketch-map drawn. Error bars = ±1SE.

to skewness, orientation error was analysed using Kruskal–Wallis *H*. Orientation error to landmarks along the route ($N = 38$) and orientation error to landmarks outside of the route ($N = 31$) were analysed separately because some of the participants were not familiar with the landmarks outside of the route (i.e. they did not perform this orientation task). There were significant differences between the three sketch-map groups in orientation error to landmarks along the route and outside of the building[2] (Inside: $\text{Rank}_{1D} = 26.22$; $\text{Rank}_{2D} = 16.55$, $\text{Rank}_{3D} = 12.68$, $\chi^2(2, N = 38) = 10.79$, $p = .005$; partial $\eta^2 = .158$; and Outside: $\text{Rank}_{1D} = 19.97$; $\text{Rank}_{2D} = 10.07$, $\text{Rank}_{3D} = 14.00$, $\chi^2(2, N = 31) = 6.28$, $p = .043$, partial $\eta^2 = .060$). Follow-up Kruskal–Wallis tests for the locations inside of the building revealed significant differences in orientation error between the 1D and 3D groups, $\chi^2(1, N = 27) = 9.68$, $p = .002$, partial $\eta^2 = .220$, and between the 1D and 2D groups, $\chi^2(1, N = 27) = 4.83$, $p = .028$, partial $\eta^2 = .080$. Orientation error was greater for the 1D group than for the 2D and 3D groups. Follow-up Kruskal–Wallis tests for the locations outside of the building revealed a significant difference in orientation error between the 1D and 2D groups, $\chi^2(1, N = 22) = 5.43$, $p = .020$, partial $\eta^2 = .089$. Orientation error was greater for the 1D group than for the 2D group. Thus, because orientation tasks are considered measures of survey-knowledge (e.g. Bryant, 1984; Juan-Espinosa et al., 2000), the results generally support the validity of our sketch-map classifications by showing that the groups that drew 2D and 3D sketch-maps were more accurate at the orientation task than the group that drew the 1D sketch-maps.

3.3.2. Floor plan route-tracing task

The number of correct turns drawn on the floor plan were calculated and analysed. A one-way ANOVA revealed a significant difference between the three sketch-map groups in the number of correct turns drawn, $F(2, 35) = 3.36$, $p = .046$, partial $\eta^2 = .161$ (see Fig. 4). Tukey's *HSD* revealed a significant difference in the number of correct turns drawn by the 1D and 3D groups, $p = .041$, partial $\eta^2 = .229$. The 1D group drew fewer correct turns than the 3D group. Because route-tracing on maps is considered a measure of environmental knowledge (e.g. Pearson & Ialongo, 1986), the results supported our sketch-map classifications by showing that the group that drew 3D sketch-maps was more accurate at tracing the route than the group that drew the 1D sketch-maps.

[2]The partial η^2 calculated for this test and for the subsequent orientation task multiple comparisons were calculated based on the raw orientation errors, not the ranks of these errors.

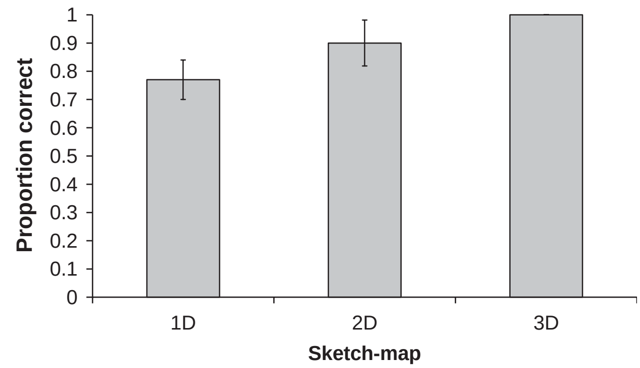

Fig. 4. Floor plan route-tracing accuracy as a function of the type of sketch-map drawn. Error bars = ±1SE.

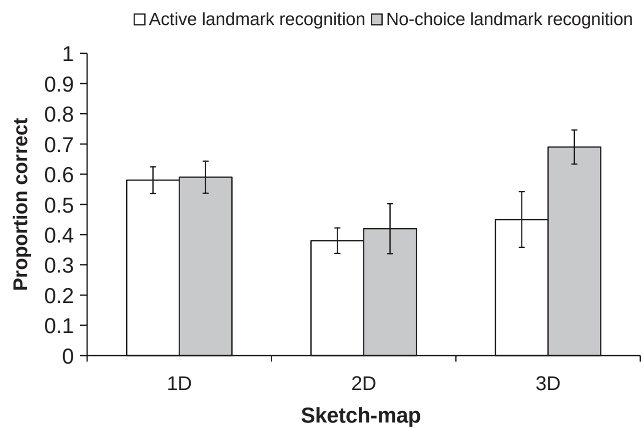

Fig. 5. Proportion of active and no-choice landmarks correctly recognized as a function of the type of sketch-map drawn. Error bars = ±1SE

3.3.3. Landmark recognition

A 3 (sketch-map) × 2(landmark-type) mixed-model ANOVA was performed on the landmark recognition data (see Fig. 5). There were main effects of sketch-map and of landmark-type. There was a significant difference between the sketch-map groups in the proportion of landmarks correctly recognized, $F(2, 35) = 3.85$, $p = .031$, partial $\eta^2 = .180$. Tukey's *HSD* revealed a significant difference in the proportion of landmarks correctly recognized by the 1D and 2D groups, $p = .036$, partial $\eta^2 = .255$, and a marginally significant difference in the proportion of landmarks correctly recognized by the 2D and 3D groups, $p = .078$, partial $\eta^2 = .176$. The 1D ($M = .58$, S.D. $= .16$) and 3D ($M = .57$; S.D. $= .22$) groups correctly recognized more landmarks than the 2D group ($M = .40$, S.D. $= .16$). There was also a significant difference in the proportion of correctly recognized no-choice ($M = .57$; S.D. $= .24$) and active ($M = .48$; S.D. $= .22$) landmarks, $F(1, 35) = 5.21$, $p = .029$, partial $\eta^2 = .130$.

These main effects were qualified by a marginally significant sketch-map by landmark-type interaction,

$F(2,35) = 2.86$, $p = .071$, partial $\eta^2 = .141$. Simple effects analyses revealed a marginally significant difference between the sketch-map groups in the proportion of correctly recognized active landmarks, $F(2,35) = 2.84$, $p = .072$, partial $\eta^2 = .140$, and a significant difference between the sketch-map groups in the proportion of correctly recognized no-choice landmarks, $F(2,35) = 4.11$, $p = .025$, partial $\eta^2 = .190$. Tukey's *HSD* revealed a significant difference between the 1D and 2D groups in the proportion of correctly recognized active landmarks, $p = .068$, partial $\eta^2 = .267$, with the 1D group correctly recognizing more active landmarks than the 2D group. Tukey's *HSD* also revealed a significant difference between the 2D and 3D groups in the proportion of correctly recognized no-choice landmarks, $p = .020$, partial $\eta^2 = .270$, with the 3D group correctly recognizing more active landmarks than the 2D group.

Overall, the results from the landmark recognition task showed that the groups that drew 1D and 3D sketch-maps recognized more landmarks than the group that drew 2D sketch-maps. However, separate analyses for active and no-choice landmarks revealed that the 1D group recognized more active landmarks than the 2D group and that 3D group recognized more no-choice landmarks then the 2D group. Aginsky et al. (1997) also found that the group that drew survey-type maps was more accurate than the groups that drew landmark- and route-type maps at detecting building changes at passive intersections (similar to our no-choice locations in that no turns were made), but Aginsky et al. found that their three groups did not differ at detecting changes at active intersections.

The overall pattern suggests that landmarks serve different functions for the three groups. The group that drew 2D sketch-maps may not have relied on non-interactive landmarks when way-finding, although they did depict landmarks with which they interacted (e.g. staircases and corridor doors) in their sketch-maps. The group that drew 1D sketch-maps may have relied on both active and no-choice landmarks (rather than spatial features) when navigating. Also, the fact that 3D group recognized more no-choice than active landmarks, $t(10) = 3.25$, $p = .009$, partial $\eta^2 = .514$, suggests that this group may have relied on no-choice landmarks while navigating, possibly for updating their position in the environment when way-finding but relied less on active landmarks when making turning decisions.

3.4. Visual–spatial ability test

In support of the hypothesis that the adults' environmental representations are related to their visual–spatial abilities, a one-way ANOVA revealed that there was a significant difference between the sketch-map groups in

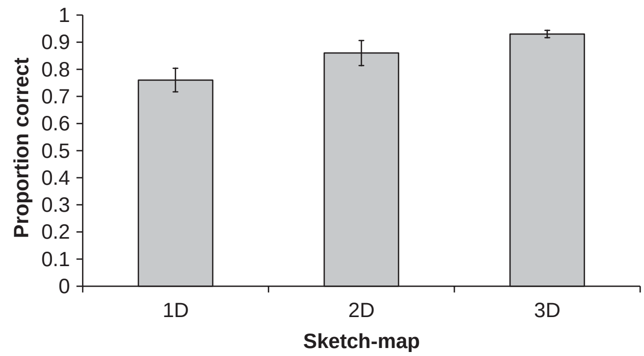

Fig. 6. Mental rotation accuracy as a function of the type of sketch-map drawn. Error bars = ±1SE.

mental rotation accuracy, $F(2,35) = 4.97$, $p = .013$, partial $\eta^2 = .221$ (see Fig. 6).[3] Tukey's *HSD* revealed that the difference between the 1D and 3D groups was significant, $p = .011$, partial $\eta^2 = .268$. The 1D group was less accurate (i.e. showed lower spatial ability) than the 3D group.[4] There were no significant differences in reaction time between the sketch-map groups, $F(2,35) = .258$, $p = .774$, partial $\eta^2 = .015$.

3.5. Retracing task

Performance retracing the route was scored as the number of correct turns (out of 10 possible) divided by the total number of turns made. A one-way ANOVA revealed that retracing accuracy between the sketch-map groups was not significant, $F(2,35) = .428$, $p = .655$, partial $\eta^2 = .024$ (see Fig. 7). Most of the participants (76%; 1D $n = 11$, 2D $n = 8$, 3D $n = 10$) successfully retraced the route without making wrong turns. These results suggest that successful performance in retracing a route does not necessarily involve the development of survey-type representations–the group with landmark/route-type representations performed as well as the groups with survey-type representations.

[3]Due to computer malfunctions, the mental rotation data for five participants were lost. The data for these participants were replaced with the mean accuracy of the other 33 participants. However, the data were also analyzed without replacing these data, and the analyses yielded the same pattern of results, $F(2,30) = 5.22$, $p = .011$, partial $\eta^2 = .258$. Also, there were no significant differences in reaction time between the sketch-map groups, without replacing the missing data, $F(2,30) = .255$, $p = .776$, partial $\eta^2 = .016$.

[4]Consistent with previously reported gender differences in mental rotation ability (see Linn & Petersen, 1985), we found that males ($M = .88$; SD = .13) tended to perform better than females ($M = .79$; S.D. = .17) on the Mental Rotation task, though the difference was only marginally significant, $F(1,36) = 3.034$, $p = .090$, partial $\eta^2 = .078$. There were no differences in reaction time between males and females on the Mental Rotation task, $F(1,36) = .615$, $p = .438$, partial $\eta^2 = .017$.

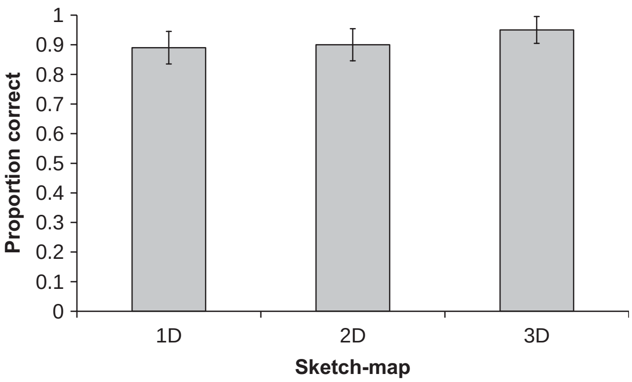

Fig. 7. Retracing accuracy as a function of the type of sketch-map drawn. Error bars = ± 1SE.

3.6. Analyses of interviews

Thirty-five interviews were transcribed (three were lost due to technical problems). All of the interviews were analysed and classified by two coders (the first author and a graduate student) based on the different cues that participants reported as helpful to them while way-finding. The agreement between the coders was high (94% agreement), and disagreements were discussed until the coders agreed on a classification. Two main types of self-reports were identified:

(1) *Landmark-based*: Participants predominantly reported the use of building features, room numbers, and other objects encountered along the route as being most helpful to them for way-finding. Examples from interviews classified as predominantly using landmark-based cues are: "*I used the landmarks that looked like they were put there. The pictures of the triangles, and those three circles and the stripes, and at the end those diamonds…*"; "*I remember the phone, the doors, the classrooms…*"
(2) *Directional-based:* Participants predominantly reported the use of directions, spatial relations and turns as the most helpful for way-finding. Examples from interviews classified as predominantly using directional-based cues are*: "I just knew the general direction of the building and the direction I was taking, I knew which way I was headed…"; "I count turns and directions…"*

Sixteen reports were identified as using predominantly landmark cues and 19 reports were identified as using predominantly directional cues. Most of the participants who drew 1D sketch-maps (77%) reported using predominantly landmark cues, whereas most of the participants who drew 2D sketch-maps (82%) and most of the participants who drew 3D sketch-maps (64%) reported using predominantly directional cues, $\chi^2(2, N = 35) = 8.850$, $p = .012$. The correspondence between the types of sketch-maps and the reported cues supports the categorization of the sketch-maps and also supports our second hypothesis that differences in representations of the environment are related to individual differences in visual–spatial processing: Those who drew relatively spatially accurate sketch-maps, the 3D and 2D sketch-maps, tended to report using directional cues when way-finding, whereas those who drew 1D sketch-maps tended to report using landmarks. Furthermore, a one-way ANOVA also revealed that participants who reported using predominantly directional cues tended to be more accurate on the Mental Rotation task ($M = .88$; S.D. = .15) than participants who reported using predominantly landmark cues ($M = .78$; S.D. = .16), $F(1, 35) = 3.137$, $p = .086$, partial $\eta^2 = .087$, but there were no significant differences in reaction time, $F(1, 35) = 2.682$, $p = .111$, partial $\eta^2 = .075$.

4. Discussion

Our data provide evidence supporting the hypotheses that environmental representations do not necessarily follow a landmark-to-route-to-survey, experience-based progression and that individual differences in visual–-spatial abilities predict the types of representations adults' form of novel environments. Three types of sketch-maps, classified based on the accuracy of the topographical features depicted, were produced after a single exposure to a route. In the 1D sketch-maps, many of the key topographic features were missing (e.g. they failed to depict the legs of the route on two distinctly separate floors, failed to accurately depict the overall shape of the route, and failed to show the final heading back toward the starting point). The 1D maps, however, should not be misinterpreted as showing that these participants did not remember traversing two floors (as illustrated in Fig. 2, some participants who drew 1D maps drew symbols for stairs). The differences in sketch-maps suggest that the groups' cognitive organizations of the elements of the route were qualitatively different. Participants who drew the 1D sketch-maps appeared to have landmark-type representations of the route. During the sketch-map task, they drew the landmarks that they remembered on the sketch-maps and attempted to connect them with line-segments that did not spatially correspond to the actual route-segments. It is possible that more experience traversing the route may have led to survey-type representations for these participants, but Devlin's (1976) and Moeser's (1988) findings question whether such a progression would necessarily occur. In the 2D and 3D sketch-maps, on the other hand, the topographic features of the route were preserved. This finding that participants produced survey-type sketch-maps after a single exposure to the route challenges the sequential/stage models of adults' constructions of environmental representations, which predict that survey knowledge arises only from a landmark-to-route-to-survey progression as a consequence of experience (Piaget & Inhelder, 1967; Hart & Moore, 1973; Siegel & White, 1975; Moore, 1976).

Current neuroscience and working memory research support the idea that differences in environmental representations reflect individual differences in visual–spatial processing and that there are relatively independent systems that process environmental information. Thus, experience is not the only crucial factor underling the differences in environmental representations. Particularly, neuroscience data suggest that there are separate processing systems for spatial and landmark information. For example, dissociation between the representation of visual appearances and spatial relations has been shown in research on perception, memory, and individual differences in imagery (Ungerleider & Mishkin, 1982; Farah, Hammond, Levine, & Calvanio, 1988; Kosslyn & Koenig, 1992; Kozhevnikov, Hegarty, & Mayer, 2002), and reports have shown dissociation between memory for location and memory for objects in a location (Courtney, Ungerleider, Keil, & Haxby, 1996). Additionally, Levine, Warach, and Farah (1985) have argued that topographical disorientation could result from the lesioning of two separate systems (one required for the identification of landmarks and one for the representation of spatial position), and after reviewing the known cases of topological disorientation, Aguirre and D'Esposito (1999) found evidence of selective impairment of spatial orientation and landmark recognition, which suggests that they may involve relatively independent processing sub-systems. Thus, the evidence that suggests that there are separate systems for processing landmarks and for processing spatial positions also challenges sequential models of adults' constructions of environmental representations.

In support of our hypothesis that the types of environmental representations are predicted by individual differences in visual–spatial processing, we found that the group that drew 3D sketch-maps had higher mental rotation ability than the group that drew 1D sketch-maps. Additionally, the group that drew 3D sketch-maps and the group that drew 2D sketch-maps showed less orientation error and the group that drew 3D sketch-maps also showed greater accuracy at tracing the route on the floor plan than the group that drew 1D sketch-maps. Thus, although we did not manipulate the sketch-map types, these data raise the possibility that spatial resources are integral to developing survey-type representations. These data then raise questions about whether navigators with poor spatial ability can form survey-type representations and whether spatial ability training can aid these navigators in developing survey-type representations, which have been shown to be beneficial for successful orienting in an environment and for successful way-finding in impoverished environments.

Although we found a relationship between visual–spatial ability and environmental representations, previous findings have been mixed. Our data are consistent with previous findings that showed relationships between visual–spatial abilities and measures of environmental representations (e.g. Thorndyke & Goldin, 1981) but add to such findings because we relied on sketch-maps of a novel route as assessments of environmental representations. Previous studies in which relationships between visual–spatial abilities and measures of environmental representations were found used orientation tasks (Bryant, 1982; Allen et al., 1996; Waller, 2000), landmark placement tasks (Pearson & Ialongo, 1986; Allen et al., 1996; Waller, 2000), cartographic map route-tracing tasks (Pearson & Ialongo, 1986), and drawing sketch-maps of familiar environments (Moore, 1975). Although orientation, landmark placement, and cartographic map route-tracing have been used to assess environmental representations, as we stated in the Introduction, sketch-maps provide some unique data. Sketch-maps allow for nominal classifications of environmental representations (i.e. classifications as landmark-, route-, and survey-type representations). Additionally, Bryant (1984), for example, showed that sketch-map drawing, landmark placement, and orientation may depend on some shared resources but do not seem to depend on a unified representation. Therefore, finding a relationship between visual–spatial ability and sketch-map drawings combined with the previous findings of relationships between visual–spatial ability and orientation and landmark placement suggest that visual–spatial ability may be an underlying shared resource. Finally, tracing a route in a cartographic map relies on pattern matching and cuing processes, whereas our sketch-map task required relatively prompt-free reconstruction of spatial representations (as suggested above, instructions may bias the organization of sketch-maps). Therefore, sketch-maps also can yield clearer evidence of stored representations than tracing a route on a map.

Regardless of the types of sketch-maps drawn, the groups did not significantly differ in route retracing errors. Of course, caution should be exercised when considering the generality of this result. Several route legibility variables, like route complexity (Weisman, 1981; O'Neill, 1991a, b, 1992) and route angularity (Sadalla & Magel, 1980; Montello, 1991; but see Herman, Norton, & Klein, 1986) have been shown to affect navigation performance. Because of our concern about these issues, we selected a route that had several (10) decision points and atypical (e.g. the entrance and exit points on the center stairwell) and asymmetrical (e.g. the length of the first leg versus the last) route elements, but because the route was through a real built environment, some elements of complexity were constrained (e.g. our route segments were mostly parallel or orthogonal to each other, and we had a finite set of decision points and route segments with which to work). Thus, although the sketch-map, orientation, and route-tracing data show that our route was not "too simple", greater route complexity may have led to greater overall retracing error and differences in retracing error between navigators holding landmark-, route-, and survey-type representations.

Accepting the above limitations, finding that the sketch-map groups retraced the route equally well suggests that survey-type representations were not required for way-finding along our route. However, we found that the 1D group was more accurate at landmark recognition than the 2D group. The 1D group also reported relying on landmark-based route knowledge, over metric-based route knowledge, for way-finding; whereas, the 2D group reported relying on metric-based route knowledge, over landmark-based route knowledge, for way-finding. Interestingly, the 3D group also reported relying on metric-based route knowledge for way-finding, but they recognized more no-choice landmarks than the 2D group. Thus, the interview and landmark recognition data suggest that the 1D group may have navigated by traversing from familiar landmark to familiar landmark and associating landmarks with the turning points. In contrast, the 2D group may have relied on landmarks but instead may have used predominantly directional cues for navigation. Although the 3D group also reported predominantly using directional cues for navigating, they also appear to have used passive landmarks, possibly for updating their position in space with regard to points along the route. Thus, although survey-type representations may facilitate way-finding in visually impoverished environments (e.g. finding a car in a parking lot or finding the way in a forest), in spatially complex environments (e.g. cities with irregular street patterns, buildings with atypically arranged floors), and when tasks are more complex than retracing a single route (e.g. finding detours, finding shortcuts and inter-connections between routes), landmark representations appear as useful for way-finding in environments rich with distinctive landmarks (assuming that the environments are not too spatially complex). Additionally, given that the group showing sequential-type representations generally showed better landmark recognition yet had lower visual–spatial ability, memorizing landmarks for traversing from familiar landmark to familiar landmark and for remembering where to turn may have been used to compensate for poor spatial ability, and measuring behaviors such as head turning (e.g. see O'Neill, 1991a, b; Lawton et al., 1996) or having participants "think-aloud" while retracing the route should provide additional "on-line" support for this claim.

Other research has shown that instructional formats and goals (e.g. to learn landmarks versus to learn spatial configurations) may affect memory for environments and may affect navigational performance (Gauvain & Rogoff, 1986; Magliano, Cohen, Allen, & Rodrigue, 1995; Taylor, Naylor, & Chechile, 1999). As Magliano et al. indicate, however, although people are capable of learning a new environment according to a goal, the degree to which goals can override stage-based processes is unclear from this line of research. For example Taylor et al. (1999) and Magliano et al. found that the goal to learn the configuration of an environment did not lead to less orientation error than the goal to learn routes. Additionally, our data show that navigators spontaneously develop different types of environmental representations, because our participants all were given route goals, and our data suggest that visual–spatial abilities also may constrain the effects of such goals.

Together, the present research provides evidence against stage/sequential models that attribute differences in adults' representations of environments exclusively to differences in experience. Although experience might play an important role in the development of environmental representations, our findings show that individual differences in environmental representations are related to individual differences in visual–spatial processing abilities that high visual–spatial abilities may lead navigators to produce survey-type representations after only a single exposure to a route.

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