Orientation and Perspective Dependence in Route and Survey Learning

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Three experiments investigated the role of egocentric orientation in subsequent memory for layouts learned via route (ground-level) and survey (aerial or overview) perspectives. Participants learned virtual environments from text descriptions (Experiment 1) or visual presentation (Experiments 1–3). In all experiments, scene recognition for route and survey images revealed a cost for switching perspective from study to test. In addition, recognition performance was facilitated when the test view matched the observer’s learned orientation but only for the same-perspective recognition test. Experiment 3 demonstrated orientation dependence in judgments of relative direction, with a strong emphasis on initial heading. Together, these results suggest that establishing a reference system for representing spatial information is dependent on specific characteristics of the learning situation.

Implicit use of spatial memory can be seen in many daily activities such as walking through a building or driving from home to work. In other situations people may explicitly appeal to spatial memory, for example, when asked to give directions. Whether implicitly or explicitly, people use spatial memory for many common tasks. Therefore, it is important to ask how the human brain accomplishes the storage and retrieval of such information and to inquire into the nature of the memory representations involved. The key question addressed here is the role different types of encoding play in shaping our memory for spatial information.

Examples of encoding effects on representation can be seen in demonstrations of orientation dependence, in which memory for layout is accessed according to the encoding orientation. Much effort has been expended trying to understand what reference systems might be used in memory representations of spaces (for review see Shelton & McNamara, 2001a). A growing body of work suggests that memory representations of large, room-sized spaces are orientation dependent when learned from a single viewpoint (Rieser, 1989; Roskos-Ewoldsen, McNamara, Shelton, & Carr, 1998) and from multiple viewpoints (Diwadkar & McNamara, 1997; Shelton & McNamara, 1997, 2001a).

Shelton and McNamara (2001a; see also Mou & McNamara, 2002; Werner & Schmidt, 1999) outlined a framework for understanding orientation-dependent performance in spatial memory. According to this framework, spatial learning involves encoding locations by first establishing a spatial reference system—in essence, establishing a principal reference vector—a conceptual “north” for the space. Establishing the principal reference vector in space is akin to establishing the top of an object; it provides an intrinsic reference system within which locations can be defined, producing preferred orientations for retrieval of spatial information (Rock, 1973). The process of selecting from the large number of possible intrinsic reference systems appears to be driven by the experiences one has with the space, including egocentric viewpoint (Shelton & McNamara, 2001a), nonvisual perspective taking (Shelton & McNamara, 2001b; Shelton & McNamara, in press), and instructions (Mou & McNamara, 2002).

Much of this research has involved learning of individual, room-sized, or tabletop displays from ground-level vantage points within or just outside the display. However, many familiar spaces are larger than individual rooms, and individuals’ experiences with them extend beyond ground-level navigation. For example, when learning a new city, we might use maps, guidebook descriptions, or computer-derived maps from such programs as MapQuest in addition to just wandering around. The present study investigates how different types of spatial information affect the representation of spatial information in memory. Using the spatial reference system framework as a guide, we explored the difference between learning from ground-level navigation (route-based learning) and learning from an aerial or map-like perspective (survey learning).

Route and survey learning are analogous to two of the most common sources of spatial information: navigation and maps. These two sources differ on a number of potentially important dimensions. Route learning involves learning a space from the perspective of a ground-level observer within the space. It requires updating of local orientation through turns, and the global structure of the space must be inferred from the information available in successive views. In contrast, survey learning involves a perspective external to the space. The space can be viewed from a fixed...
orientation, and the properties of the global structure are more easily accessed. Previous studies comparing these two types of learning have come in two forms: those that used visual navigation and maps and those that used text descriptions.

Comparisons of route-level navigation and map learning have yielded a variety of behavioral results (Moeser, 1988; Streeter, Vitello, & Wonsiewicz, 1985; Thorndyke & Hayes-Roth, 1982). For example, Thorndyke and Hayes-Roth have shown that extensive navigation leads to survey-like knowledge that is equivalent to the knowledge available from map learning. This equivalence suggested a hierarchical relationship between route and survey learning, with survey information as the automatic result of extensive learning. However, when Moeser (1988) compared nursing students with 2 years of experience in a hospital with naive participants who studied only floor plans, the results were not equivalent. Naive participants were able to perform significantly better than the nursing students on judgments of distance and pointing directions, suggesting that the nursing students were not showing survey knowledge despite extensive experience. These results suggest that the development of survey knowledge with experience is not necessarily automatic (see also Taylor, Naylor, & Checchile, 1999). Both of these studies were concerned with the cumulative effects of route learning. To that end, they compared extensive route learning to limited map learning, making the direct comparison of the two types of learning less conclusive.

One way to gain control over the amount of route or survey learning is to use text descriptions followed by text-based questions about the spatial layout (e.g., Ferguson & Hegarty, 1994; Langer, Keenan, Wetzel, Jacques-Griffin, & Chiszar, 1996; Perrig & Kintsch, 1985; Taylor & Tversky, 1992; Tversky, 1991). Such texts rely on spatial language as the vehicle for route and survey perspectives (e.g., right–left vs. north–south). An alternative method is to present participants with visual information from the visual perspectives of maps and navigation. Participants in the present study learned virtual environments in the form of movies filmed from either a route (ground-level) or a survey (aerial) perspective. (In Experiment 1, we also included text descriptions for comparison.) Following encoding, participants were asked to recognize scenes from the route and survey perspectives that were taken from a variety of different orientations. In Experiment 3, participants were also asked to make judgments about the relative locations of the objects from imagined perspectives. To assess potential differences, we considered route and survey learning in terms of the spatial reference system framework. According to the model, learning a space first requires the selection of a system of reference. Many factors could contribute to the reference system selection. We considered two critical factors, orientation (heading during encoding) and perspective (route vs. survey), as well as their interaction.

For route learning, the previous studies of orientation dependence provide strong evidence for reference system selection based on egocentric orientation (e.g., Shelton & McNamara, 2001a). As such, we expected to see the establishment of a principal reference vector for the route learning conditions based on egocentric orientation during learning. Notably, route learning (both visual and text) involves changes in local orientation throughout the encoding experience, with new route legs described or shown from different orientations. The principal reference vector could therefore be established for the entire environment or for each leg of the environment. Previous work on real, virtual, and imagined environments has suggested that performance is best for the initial orientation (Palj, Levine, & Kahan, 1984; Richardson, Montello, & Hegarty, 1999; Wilson, Tlauka, & Wilbur, 1999), suggesting that a principal reference vector may be established initially and maintained over changes in orientation throughout the route. However, when dynamic scenes are viewed from multiple perspectives over time, recognition of still images is fastest and most accurate when the viewpoint of the still image matches the perspective one had at the particular time point in question (Garsoffky, Schwan, & Hesse, 2002), supporting a changing principal reference vector.

For survey learning, it is possible that survey information might be represented in an orientation-free reference system, with no explicit establishment of a principal reference vector. For purposes of presentation, however, survey information must be presented in some orientation. In the survey movie condition of the present study, orientation is defined by the north-as-up orientation from which a map is typically viewed. If a principal reference vector is established, it should correspond to this learned orientation. In the text condition, no such orientation is required. This condition may, in theory, provide an orientation-free learning condition. However, if comprehending the survey text involves the construction of a mental map of the space, we would again suggest that “viewing” the map requires an orientation. Given the use of cardinal directions in the survey text, we would predict that north-as-up might emerge as the preferred orientation, thereby providing the principal reference vector required by the reference systems framework. Differences between the survey visual and text conditions in Experiment 1 might provide additional information about the potential mental models available for spatial information.

In addition to orientation, the perspective in which the space is viewed (route or survey) could have an influence on the behavioral performance. In particular, one of the critical questions in the previous work on text descriptions focused on switching perspectives. We manipulated the relationship between study and test perspective by testing scene recognition for both route and survey images following each type of learning. The performance for same perspective (e.g., route study–route test) compared with the performance for different perspective (e.g., route study–survey test) allows us to assess whether perspective switching has an overall cost or different costs for route and survey learning. In addition, the interaction of orientation and perspective switching can also be evaluated.

The goal of the present study was to determine what factors influence the memory representation of space for route and survey learning. Experiment 1 was designed to evaluate orientation and perspective effects as a function of the perspective (route vs. survey) or the mode of presentation (text vs. visual). To our knowledge, this is the first experiment to fully cross route and survey perspectives with visual and text-based presentation. Experiment 2 was designed to replicate the visual conditions in Experiment 1 using a within-participant block design to reduce the likelihood that effects of perspective were due to uncertainty or bias. Experiment 3 extended the question of orientation dependence to judgments of relative direction, which do not require visual presentation from the route and survey perspectives at test.
Experiment 1

In Experiment 1, participants learned modified versions of Taylor and Tversky’s (1992) fictional environments in one of four learning conditions: route movie, survey movie, route text description, or survey text description. Following encoding, participants performed scene recognition. Scenes were taken from both route and survey visual conditions and from a variety of different orientations within the space. According to the spatial reference system model, both route and survey learning should require the establishment of a principal reference vector in the space. As such, we should observe preferred orientations in each of the conditions. Although there are no obvious theoretical predictions about differences between the visual and text-based presentations, previous research has shown better performance for map learning compared with either route or survey texts (see Perrig & Kintsch, 1985).

Method

Participants

Forty-eight participants (24 female, 24 male) volunteered in return for credit in introductory psychology at Vanderbilt University. Participants were randomly assigned to one of four groups on the basis of the four learning conditions identified below, with the constraint that each group contain equal numbers of male and female participants.

Materials

Four learning conditions were developed by crossing route and survey information with text and visual presentation: text-survey, text-route, visual-survey, and visual-route.¹

Text descriptions. Text descriptions were slightly modified versions of those used by Taylor and Tversky (1992) for the Zoo and the Convention Center. The route descriptions described the display from the vantage point of an observer walking through the display and were described in second person. Survey descriptions referred to the space as a map, with cardinal directions used to identify relative locations. Each text description was converted to hypertext mark-up language (html). This allowed the text to be linked to icons representing the individual items. This addition was necessary given that the memory test involved visual recognition of the space. For consistency, the environments were rotated so that the starting position of the route descriptions reflected the north-as-up orientation. This required minor modifications in the directional terms for each text; care was taken to maintain the coherence of the texts.

Visual environments. Visual conditions were adapted from the maps used by Taylor and Tversky (1992) for the Zoo and Convention Center. Using the maps as templates, we constructed virtual environments in Virtus WalkThrough Pro (Version 2.b, Virtus Corporation, 1990). Each environment measured approximately 110 feet × 130 feet (330 m × 390 m) in virtual space and was designed to be visually distinct with no overlap of landmarks. Two navigation movies were recorded for each environment, one from the ground-level perspective and one from an aerial perspective. The route movie was recorded from the perspective of a 6-foot (1.8 m) tall observer walking through the environment. The route began at the entrance to the environment (always in the southwest corner), and consisted of four route legs joined by turns (walk north, turn right, walk east, turn right, walk south, turn right, walk west, turn left to face entrance again). The survey movie was taken from the perspective of an aerial observer (70 feet [210 m] above ground level in virtual space) looking straight down. The path began in the southwest corner and then panned north, east, south, and west without any changes in heading. Approximately 20% of the environment was visible in a given frame of the survey movie, with at least one wall visible throughout. The nature of the two perspectives did not allow us to equate the objects visible from frame to frame, but the number of exposures to landmarks was kept similar by following the same paths in both perspectives. Each movie lasted 1 min.²

Recognition stimuli. The recognition task required participants to distinguish route and survey images of the correct environment from route and survey images of reorganized distractor environments. The recognition task used still frames of the virtual environments taken from the ground level or aerial perspectives for route and survey recognition, respectively. The still frames were taken from orientations corresponding to eight different orientations ranging from 0° to 315° in 45° clockwise increments. The 0° heading was arbitrarily defined to correspond to the orientation of the first leg of the route movie (which was the same as the fixed orientation of the survey movie). The same orientations were captured from the four different legs in the display, yielding 64 images (32 route and 32 survey). For a given route or survey trial, only a subset of the environment could be seen. For each environment (Zoo and Convention Center), five distractor environments were constructed by randomly switching the locations of certain icons in the environment. The distractor images were taken from the same set of orientations as described above, again yielding 64 images per distractor environment (32 route and 32 survey).

Procedure

Encoding. Participants were instructed to learn the environment for a spatial memory test. For the text conditions, participants viewed the html documents in Netscape Navigator 4.0 (Netscape Communications Corporation, 1998) on a Macintosh computer and were instructed as to how to click to view icons. For the visual conditions, participants viewed the virtual environments in Virtus Player (Virtus Corporation, 1994) and were briefly instructed on how the movie would proceed. Participants were required to view or read for a minimum of 10 min in all conditions. After 10 min, they were allowed to continue viewing or reading for up to 5 additional minutes (15 min maximum). Taylor and Tversky (1992) found that participants spent an average of 6–8 min learning text descriptions. Additional time was allotted here because the text conditions required participants to click to see the icons. The approximate length of time spent learning was recorded.

Scene recognition. Following the learning phases, participants performed scene recognition. Images were approximately 12 cm (4.7 in.) high by 14.2 cm (5.6 in.) wide and were presented individually in the center of a black screen on a Macintosh computer using PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993). Images remained on the screen until the participant responded with a key press (“c” for target images and “b” for distractor images). After each keypress, the screen was blank for 1,000 ms before the next image appeared. The recognition test consisted of 640 trials, presented in five blocks of 128 trials. Each block contained one instance of each of the 64 target trials and 64 distractor trials. Trials were randomized within each block, and participants were allowed short breaks between blocks. Participants were instructed to respond by pressing the appropriate key to indicate whether the presented image came from the learned environment, regardless of perspective, or from one of the distractor environments. They were also informed that images were taken from several orientations and were shown one example each of route and survey recognition. Participants were asked to respond quickly but accurately. Both accuracy and response latency were recorded.

¹ Examples of all learning conditions are available at http://www.psy.jhu.edu/~ashelton/stimuli.
² Across the route and survey movies, we opted to keep the length of the movies, rather than the pace, constant in order to maintain similar time spent learning. Given the use of overlearning and recent work on self-terminated learning (Shelton & Clark, 2003), it is unlikely that the difference in pace had a significant impact on overall performance.
Map drawing. After completing the recognition test, participants were given a blank sheet of paper and asked to sketch the environment they had learned. No particular orientation was required for the map drawing. The open-ended response was used to encourage participants to draw their map from the most accessible orientation.

Results

The amount of time spent on learning was recorded and submitted to an analysis of variance (ANOVA) with terms for sex, modality (text vs. visual), type of perspective (route vs. survey), and environment (Convention Center vs. Zoo). The analysis revealed that only the main effect for modality was significant, $F(1, 8) = 30.14$. In addition, the main effect of leg of route was significant, $F(3, 24) = 7.00$, as well as the interaction between leg of route and type of recognition, $F(3, 24) = 28.11$, indicating a cost for perspective switching. In terms of orientation effects, the main effect of orientation was significant, $F(7, 56) = 4.70$, as was the interaction between orientation and type of recognition, $F(7, 56) = 4.58$. An interaction contrast again indicated that recognition was fastest for trials oriented with $0^\circ$ (corresponding to the initial orientation of the text description) in route recognition but that no such advantage was observed in survey recognition, $F(1, 56) = 28.65$. In this case, survey recognition was slower overall and did not benefit from the “learned” or initial orientation. This pattern mirrors the effects seen in the survey text condition, suggesting a strong adherence to the particular type of information provided at encoding.

For the route movie, the main effect for recognition type was significant, $F(1, 8) = 28.11$, indicating a cost for perspective switching. In terms of orientation effects, the main effect of orientation was significant, $F(7, 56) = 4.70$, as was the interaction between orientation and type of recognition, $F(7, 56) = 4.58$. An interaction contrast again indicated that recognition was fastest for trials oriented with $0^\circ$ (corresponding to the initial orientation of the text description) in route recognition but that no such advantage was observed in survey recognition, $F(1, 56) = 28.65$. In this case, survey recognition was slower overall and did not benefit from the “learned” or initial orientation. This pattern mirrors the effects seen in the survey text condition, suggesting a strong adherence to the particular type of information provided at encoding.

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In addition to the aforementioned analyses, the response latency data were combined and subjected to a grand analysis, the results of which supported all effects described above. The primary finding was the perspective-switching effect evidenced by the interaction between study and test perspective (Figure 1), $F(1, 32) = 76.85$. The survey and route conditions did not differ except in

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these higher order interactions that confirmed effects from the individual analyses. Surprisingly, no differences were observed for text learning versus visual learning conditions aside from the differences in orientation effects, suggesting that participants could effectively learn the environments from either modality.

Participants’ reproductions of the learned environment at the end of the experiment were also examined for quality and choice of drawing orientation. The degree of distortion in the sketch maps was measured with bidimensional regression and a distortion index (Waterman & Gordon, 1984). The quality of reproduction varied greatly (distortion indices ranged from 8% to 39%) due to apparent individual differences. Analyses revealed no significant effects or interactions for quality. The majority of participants in all conditions drew their maps from the orientation corresponding to a 0° orientation, which corresponds to the north-as-up orientation evident in the reference vector and to then use that orientation to build a representation. In the route movie and survey conditions, the route involved turns such that the ego-centric orientation was different for each leg of the route, allowing either initial orientation or orientation within each leg to dominate the representation. In the route text, orientation dependence specific to the initial orientation was observed. Participants were fastest at recognizing scenes from the 0° orientation in all legs of the route. This adherence to initial orientation suggests that participants were essentially adopting this orientation as they read the text in order to learn the spatial locations. In both cases, this advantage for 0° was limited to recognition of survey images. The route recognition trials were equivalent across all orientations and were slower than survey trials.

Results for the two route conditions also support this orientation dependence; however, the two conditions (text and visual) differed with regard to the preferred orientation. In the route movie and route text conditions, the route involved turns such that the egocentric orientation was different for each leg of the route, allowing either initial orientation or orientation within each leg to dominate the representation. In the route text, orientation dependence specific to the initial orientation was observed. Participants were fastest at recognizing scenes from the 0° orientation in all legs of the route. This adherence to initial orientation suggests that participants in the text condition tended to establish a single principal reference vector and to then use that orientation to build a representation (much like the north-as-up orientation evident in the survey text group).

The route movie condition revealed a different pattern of results, however. Participants in the route movie condition were fastest on

### Discussion

The goal of Experiment 1 was to examine the role of egocentric orientation in route and survey learning. The results clearly support effects of egocentric orientation, perspective switching, and the interaction of orientation and perspective effects.

Neither route nor survey knowledge provided sufficient information for participants to show viewpoint-independent performance in scene recognition. Participants tended to be best at the type of recognition consistent with their learning condition. That is, participants who learned a route text or movie were faster on route recognition than on survey recognition, whereas participants who learned a survey text or movie were faster on survey recognition than on route recognition. Second, participants tended to be fastest at particular egocentric orientations within the display as well. In the survey text and movie conditions, participants performed best on trials oriented with 0°. For survey movie learners, this corresponded to the orientation in which they viewed the environments. For survey text learners, no specific orientation is mandated by the description. Instead, 0° corresponds to the north-as-up orientation. Therefore, it appears that participants were essentially adopting this orientation as they read the text in order to learn the spatial locations. In both cases, this advantage for 0° was limited to recognition of survey images. The route recognition trials were equivalent across all orientations and were slower than survey trials.

Table 2

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Note. Response latencies in boldface indicate best performance.

Figure 1. Mean response latency as a function of encoding and recognition perspectives in Experiment 1. Error bars are confidence intervals corresponding to ±1 standard error of the mean as estimated from the analysis of variance.
the learned orientation for a given leg of the route. This result appears to contradict previous work showing a preference for initial orientation (Palij et al., 1984; Richardson et al., 1999). However, one critical difference between the earlier work and the current work was the use of scene recognition. In scene recognition, the retrieval cue is the visual stimulus, whereas tasks involving pointing to unseen targets do not provide direct visual stimuli for retrieval. This difference may influence the degree to which a person appeals to the specific aspects of an experience. For example, the initial orientation may be more readily accessible without the visual cues, whereas the memory for the direct visual experience may be more accessible for recognizing a scene. This issue is addressed in Experiment 3 through the use of judgments of relative direction instead of scene recognition.

Overall, the results of Experiment 1 suggest that both perspective and orientation play an important role in the establishment of a principal reference vector. In both route and survey conditions, a principal reference vector emerged as a function of the orientation experienced (visual) or implied (text). That this orientation only showed a benefit when the test was also in the perspective of encoding suggests an additional egocentric component to the spatial memory. The spatial information appeared to be encoded in both perspective-specific and orientation-dependent representations. This added dependence on perspective could not be attributed to the strict visual match between study and test because it was evident in the text conditions, in which the visual information during encoding was equivalent for route and survey. In terms of spatial reference system effects, this pattern suggests that the reference system established for representing space is tied to the perspective from which the space is viewed (ground-level or aerial).

Experiment 2

In Experiment 1, two potential sources of bias may have contributed to the perspective-switching effects. First, participants were exposed to only one type of encoding and may have lacked a more general understanding of what the alternative perspective might be. Second, recognition trials were presented randomly, intentionally preventing the participants from adopting a perspective over a series of trials. Experiment 2 was a within-subject block-design version of the visual conditions used in Experiment 1. If the perspective-switching effect observed in Experiment 1 resulted from lack of exposure to alternative perspectives or to the uncertainty of the trial order, then we expected a reduced effect in Experiment 2. In contrast, if the perspective-switching effects reflected fundamental differences in the underlying representations resulting from route and survey encoding, then we expected to replicate the effect.

Method

Participants

Twelve participants (6 male) volunteered in return for credit in introductory psychology at Stanford University.

Materials

Encoding. Three new virtual environments were created with the same software and conventions as in Experiment 1: a Convention Center, a Market Square, and a City Park. Each environment measured 110 feet × 130 feet (330 m × 390 m) in virtual space, and contained 10 large landmarks (as in Experiment 1) and 7 small landmarks in addition to fixed features such as external walls and sidewalks. Movies for route and survey perspectives were recorded with the same procedures as used in Experiment 1, except that the pace through the environment was speeded slightly making each movie 46-s long.

Recognition stimuli. Recognition materials were devised for the new environments with the same conventions as used in Experiment 1. We created 32 route images and 32 survey images for each environment and its distractors. Each test consisted of 128 trials representing one instance of each target image and 64 unique distractor images (32 route, 32 survey), separated into route and survey test blocks.

Procedure

Encoding. Participants learned two different environments simultaneously. They were instructed to learn the two environments as well as possible. Movies were presented seven times each, in an alternating order with PsyScope (Cohen et al., 1993). During the first pass through each movie, the experimenter pointed out the various items in the environment as they appeared in the movie. Following the first pass, participants were given an opportunity to ask questions before the remaining repetitions. Pilot work indicated that participants could accurately reproduce the environments completely after four repetitions. Additional presentations were used to ensure overlearning. The three environments were used an equal number of times in each perspective (route or survey), and order was counterbalanced such that half the participants began with the route movie.

Scene recognition. Following encoding, participants took a short break (2–3 min). Testing always began with the environment that appeared first during the encoding. Pilot work suggested that this would make little difference given the alternation of the movies during encoding. Participants were instructed that they would see images of the environment they learned from either the route or the survey perspective. Examples of each type of image (route target, route distractor, survey target, survey distractor) were provided as part of the instructions. The testing then proceeded in alternating blocks of route and survey images, with eight blocks of each perspective. Each route and survey test block contained eight trials (four target and four distractor), and each trial was presented in the middle of a black screen for 2,750 ms followed by a 250-ms blank screen. Participants were instructed to respond as soon as they felt confident about their answer within the 3,000-ms interval allotted for each trial. This fixed trial interval allowed us to control the timing of each block and the total test time for each environment. The 3,000-ms interval was chosen on the basis of the response time data from Experiment 1. Failure to respond within the time limit resulted in an error. Between blocks, a fixation cross appeared in the center of the screen for 5 s to alert the participant to the changing test.

Following the first recognition test, the participant was instructed on the second test and shown examples. The second test format was identical to the first. Block orders within test were counterbalanced such that half the participants always began with a same-perspective block (route block first following route encoding; survey block first following survey encoding), and half began with a different-perspective block (survey block first following route encoding; route block first following survey encoding). Responses and response latencies were measured.

Map drawing. After the recognition tests had been completed, participants were given two blank sheets of paper and asked to sketch the environments they had learned. Again, no particular orientation was required for the map drawing. In addition to recording the map distortions and choice of orientation, we also classified participants in this experiment according to the type of strategy used during the map drawing. The experimenter recorded the order of item placement to determine whether the map-drawing strategy was sequential or hierarchical. The sequential strategy was defined as drawing the map as a path corresponding to the
movie. The hierarchical strategy was defined as placing central and then peripheral features out of sequence, filling in by quadrant, or both.

Results

Participants showed greater variability in scene recognition accuracy compared with Experiment 1. False alarm rates for all participants in all conditions were around 6% (two false alarms per condition), whereas hit rates varied from 75% to 100%. Error rates (misses) for each participant were analyzed in a repeated measures ANOVA with factors for encoding (route and survey) and test (route test and survey test). Results revealed a significant interaction between encoding and test, $F(1, 11) = 31.11, p < .001$. Participants made fewer errors when perspectives were the same from encoding to test than when the test required a perspective switch (Figure 2). This result replicates the response latency data observed in Experiment 1. Mean correct response latencies were computed for each participant and each condition and submitted to an ANOVA with factors for encoding perspective, test perspective, leg, and orientation. In addition, separate ANOVAs were performed on route and survey encoding to verify the presence/absence of critical interaction. Figure 2 and Table 3 show the replication of the two key results from Experiment 1. First, the cost associated with switching perspectives was observed in the interaction between encoding and test perspectives, $F(1, 77) = 492.24, p < .001$. Second, the four-way interaction of encoding perspective, test perspective, leg, and orientation, $F(21, 231) = 2.23, p < .001$ suggested that the effect of orientation on route and survey tests following route and survey encoding showed the same patterns as in Experiment 1. For route encoding, the effect of orientation interacted with the particular leg of the path, but primarily when recognizing route images. Statistically, this pattern was supported by a test by leg by orientation interaction for route encoding, $F(21, 231) = 2.34, p < .001$. For survey encoding, participants responded faster to the 0° orientation (regardless of leg) compared with other orientations, but primarily when recognizing survey images, as evidenced by the test by orientation interaction for survey encoding, $F(7, 77) = 4.05, p < .001$.

Distortion indices for map drawing did not differ significantly for route ($M = 23.58\%, SD = 5.85$) and survey ($M = 21.28\%, SD = 4.87$) encoding, $F(11) = 1.07, p = .31$. In addition, the choice of orientation for all participants in both the route and survey condition was 0°. This alignment reflects initial orientation for the route encoding and the orientation maintained throughout the movie in the survey encoding. With regard to map-drawing strategies, all participants drew the route environment in a sequential manner (notably, 6 of the participants actually turned the page to draw each subsequent leg). For the survey environment, 8 participants used a hierarchical strategy, whereas the remaining 4 used a hybrid between the sequential and hierarchical strategy (placement of central features out of sequence, followed by each quadrant in the order they appeared in the movie).

Discussion

Experiment 2 replicated the effects of perspective and orientation in the visual conditions of Experiment 1. Despite a predictable trial order, blocking of trial type, and experience with the general format of both route and survey perspectives prior to test, performance was better when there was a match between study and test perspective than when perspectives were mismatched, with additional facilitation for the specific orientation in which the environment was learned. Again, survey encoding led to best performance at the 0° orientation when tested in the survey perspective, whereas route encoding led to best performance at the orientation that was learned in a given leg of the route. These results support the claim that the spatial information was encoded according to a principal reference vector that was established by both the encoding perspective and egocentric orientation(s).

Experiment 3

Experiment 3 tested the effects of orientation following route and survey encoding using judgments of relative direction (JRDs) in addition to scene recognition. JRDs require participants to imagine the environment and make judgments about relative positions of objects. This task has two important features. First, unlike scene recognition, JRDs do not require visual presentation of the environment during the test. As such, participants cannot rely upon visual similarity between study and test stimuli. Second, JRDs do not specify a route or survey visual perspective. Therefore, JRDs allow a more direct test of whether route and survey encoding lead to differences in accuracy and/or response latency, independent of the perspective-switching that is required in scene recognition.

Method

Participants

Twelve participants (6 male, 6 female) volunteered in return for extra credit in psychology courses at Johns Hopkins University.

Materials

Encoding and scene recognition involved the same movies and images, respectively, as in Experiment 2. Additional materials were created to test JRDs. For each environment, the 10 large objects were used to construct
trials consisting of a two-object heading (“Imagine you are at the First Aid and facing the Carousel”) and a target (“Point to the Clocktower”). As in scene recognition, the initial heading (route) and the fixed heading (survey) were arbitrarily labeled 0° for the purpose of classifying imagined headings. Eight different imagined headings were used ranging from 0° to 315° in 45° increments. Due to the structural limitations of the environments, heading labels reflected ranges rather than specific headings. A given trial was classified into a heading category if it was within 15° of the category label (e.g., 45° headings ranged from 30° to 60°).

In addition, trials were identified as belonging to one of the four legs in the environment. This assignment was primarily based on the initial object in the heading and verified by a group of pilot participants who labeled trials as belonging to a particular leg after viewing the environments from both the route and survey perspectives. Finally, trials were labeled according to the pointing direction of the target object (straight ahead = 0°): front (315° to 45°), right (45° to 135°), back (135° to 225°), and left (225° to 315°). From all possible trials for a given environment, 64 trials were selected to have 8 trials at each imagined heading. For each imagined heading, trials were selected to represent all four pointing directions and all four legs. Because of the limited number of trials and constraints of the environments, pointing directions and leg were not completely counterbalanced; however, pointing directions and legs were evenly distributed across headings and across different environments.

Procedure

Encoding. Movies were presented in PsyScope as in Experiment 2.

JRDs. Following encoding, participants took a short break (2–3 min.). Testing always began with the JRDs for the first environment presented during encoding. Participants were instructed on the JRD task and given practice trials involving buildings on the campus. The participant initiated each trial with a mouse click, and the heading and target statement appeared (“Imagine you are at the First Aid and facing the Carousel. Point to the Clocktower.”) along with a simulated pointer and dial (e.g., Shelton & McNamara, 1997). Using the mouse, participants positioned a line on the dial to reflect the direction of the target from the imagined heading. The participant clicked the mouse to indicate the correct position and end the trial. The 64 trials were presented in random order. Following the first JRD test, participants were given a JRD test on the second environment.

Scene recognition and map drawing. Following the two JRD tests, participants took a short break (2–3 min.). Then they were given two scene recognition tests and the map drawing test, following the same procedures as in Experiment 2.

Results

Scene recognition effects observed in Experiments 1 and 2 were replicated (Table 4). Error rates and response latencies revealed an encoding by test interaction, \( F(1, 11) = 16.04, p = .002 \) and \( F(1, 11) = 370.13, p < .001 \), indicating a perspective switching effect (Figure 3). In addition, the overall interaction of encoding perspective by test perspective by leg by orientation was again significant, \( F(21, 231) = 2.14, p = .003 \). For route encoding, the test by leg by orientation interaction was significant, \( F(21, 231) = 3.13, p < .001 \), supporting the preference for the within-leg orientation for route recognition only. For survey encoding, the test by orientation interaction was significant, \( F(7, 77) = 13.80, p < .001 \), indicating

Note. Response latencies in boldface indicate best performance.
an advantage for the $0^\circ$ orientation in all legs for survey recognition only.

The primary dependent measure in JRDs is the angular error of the judgment. Angular error was measured by taking the difference between the actual direction (measured to within 1–2° of the exact heading) and the direction indicated by the participant. The absolute angular errors and response latencies were submitted to separate ANOVAs with factors for sex, encoding perspective, test perspective, leg, and orientation. Although qualitatively similar to angular error, the results of response latency had higher variability and showed no significant effects. Only effects of angular error are indicated below. As shown in Table 5, only the main effect for orientation was significant, $F(7, 70) = 13.96, p < .001$, and not the interaction between encoding and orientation or the interaction between route leg and orientation for route encoding ($F_s < 1$).

Overall, participants were more accurate imagining the $0^\circ$ orientation than the other orientations, $F(1, 70) = 10.28, p < .002$, regardless of type of encoding or route leg.

The same analysis was performed with signed errors, but did not reveal reliable effects. This absence of effects was taken as evidence that the errors were not due to systematic biases but to more general inaccuracy of representation.

Map drawing distortion indices for route ($M = 28.32\%, SD = 5.15$) and survey ($M = 26.35\%, SD = 7.35$) encoding were not significantly different, $t(11) = 0.77, p = .46$. In addition, the choice of orientation for all participants in both the route and survey condition was $0^\circ$. All participants drew the route environment in a sequential manner. For the survey environment, one participant used a clear sequential strategy, seven used a hierarchical strategy, and the remaining three used hybrids of sequential and hierarchical strategies (e.g., placement of central features out of sequence, followed by each quadrant in the order in which it appeared in the movie).

**Discussion**

Experiment 3 provided a contrast between JRDs and scene recognition following route and survey learning. Whereas the
scene recognition results replicated Experiments 1 and 2, the results from JRDs were consistent with previous studies indicating an advantage for initial perspective in environments learned with turns (Palij et al., 1984; Richardson et al., 1999). The broader implications of this difference are discussed in greater detail in the following discussion.

General Discussion

We considered how spatial reference systems are established in memory under different types of encoding conditions by investigating the differences between the two perspectives (route and survey) and how those perspectives were influenced by egocentric orientation in space. The results suggest that both perspective (routes and survey) and egocentric orientation influence encoding and retrieval. In addition, we found that the effect of orientation is dependent on the type of task one has to perform. Below we explore how these results inform us about the differences between route and survey learning as well as their implications for a more general approach to spatial memory.

In scene recognition, we observed two different types of experience-dependent facilitation. First, scene recognition consistently revealed a benefit in speed (Experiments 1–3) and accuracy (Experiments 2–3) for recognizing images presented in the encoding perspective, regardless of egocentric orientation. Second, there was an added benefit for speed of response when the test image matched the egocentric orientation during encoding. This facilitation of egocentric orientation only occurred within the same-perspective recognition test.

One of the critical aspects of the orientation effect in scene recognition was the specific pattern of interaction with encoding perspective. The facilitation for the particular viewpoint one had within a given leg of the route suggests that rather than one preferred view (principal reference vector), the preference changed with the changing orientation in space. This interaction may reflect the establishment of multiple reference vectors for the space; however, additional evidence suggests that it may instead reflect lower level visual matching processes. For example, the results from the route text (which also incorporated multiple egocentric orientations) indicated a single preferred orientation for scene recognition based on the initial orientation. This difference between route movie and route text conditions suggests that the residual effects of changing orientation were specific to the visual encoding.

The results of Experiment 3 further suggest that these effects are not only specific to visual encoding but also to visual testing. When the same route movie condition was tested with JRDs, the effects of orientation were very different from those observed in scene recognition. For the JRDs, which did not require explicit use of visual information, the benefit was observed for initial orientation regardless of what leg of the route was tested. This benefit for initial perspective is consistent with previous studies (Palij et al., 1984; Richardson et al., 1999) and supports the claim that scene recognition and JRDs appeal to different aspects of memory.

This discrepancy between scene recognition and JRDs has been observed in previous studies. For example, Shelton and McNamara (in press) instructed participants to learn a spatial display by viewing the display from one orientation and describing the display from a different, imagined orientation. Participants were tested on both scene recognition and JRDs to determine which view(s) would be most accessible in memory. Scene recognition results indicated strong facilitation for the visually perceived orientation compared with all novel orientations, whereas JRD results showed best performance for headings corresponding to the described orientation, intermediate performance for the visually perceived orientation, and poorest performance for novel orientations.

Results such as these indicate that multiple representations (or multiple components of a representation) may be formed during spatial learning (see McNamara, 2003). One system appears to represent object-to-object relations that allow for a coherent representation of the entire environment. A second system may store the visual experience of the environment, much like the eidetic memories observed in other animals (Collett & Cartwright, 1983; Collett, Cartwright, & Smith, 1986). The object-to-object system would require specification of positions in a standard reference system; that is, it would require a principal reference vector. Alternatively, the degree to which the eidetic memory system would exhibit view preference would depend on which views were directly experienced (and represented). Learning conditions that
involved multiple views (orientations) might exhibit a single preferred view when accessed via the object-to-object system but multiple preferred views when accessed via eidetic memories.

In the present experiments, scene recognition was likely supported by both the object-to-object system and the visual memory system. With regard to the particular effects we observed, the facilitation for same-perspective recognition could be produced by the visual overlap between encoding and test perspectives. Images in the egocentric orientations viewed during encoding would have even greater visual overlap and would thus receive added benefit. The mechanism for this visual facilitation may be akin to that proposed to explain scene priming (Sanocki & Epstein, 1997), in which viewing a scene once can facilitate distance judgments when the scenes are presented again with target probes added. Although the time course of scene priming has not been extended to long-term memory, perceptual priming has been shown to last up to 48 weeks for picture naming (Cave, 1997). If participants are primed to perceive the same-perspective images (and even more so, the same-orientation images), then they might be quicker to access the object-to-object representation needed to determine the veridicality of the spatial organization within those images, producing the observed perspective-switching effect. Alternatively, the visual overlap for same-perspective and same-orientation images may allow participants to appeal to only the visual representation and base the judgment on image matching (e.g., Bühlhoff & Edelman, 1992; Edelman & Bühlhoff, 1992; Poggio & Girosi, 1990).

JRDSs, on the other hand, may have been supported primarily by the object-to-object system. The task is not dependent on perceiving the spatial layout and then making a decision about it. Instead, it relies on directly accessing spatial relationships and using them to accurately determine relative directions. If a principal reference vector has been established for the space, then headings corresponding to this facilitation would be most accurately accessed. Other visually experienced headings would not be facilitated because they do not help with access to the reference system needed to determine relative direction information. Our results (and those of previous studies noted above) indicate that initial orientation can provide this principal reference vector.

In the introduction, we suggested that route and survey information, and the real-world correlates of navigation and maps, differ along many potentially important psychological dimensions. We observed some of the effects of having a dynamic versus a fixed orientation, primarily in the scene recognition results, but other differences may also affect memory representation. For example, route encoding requires making more inferences about the global properties of the space, whereas survey encoding provides more information about the global constraints (direct views of corners, wall continuation, etc.). Similarly, route encoding has a much greater reliance on maintaining the sequence of events, whereas survey encoding can use the global properties to help organize locations. Although we observed very few differences between the route and survey learning (other than the perspective-switching costs in scene recognition), the reliance on sequence was suggested by the map-drawing strategies. Maps of environments learned as route movies were drawn sequentially, whereas maps of environments learned as survey movies were more spatially driven, with central elements placed first followed by peripheral elements in quadrants (top to bottom or left to right) or vice versa. This hierarchical strategy for the survey encoding was surprising given that the survey movie is presented in the same sequential manner as the route movie.

Although a systematic investigation of these properties was well beyond the scope of the present study, it is likely that they have important influences on the way space is encoded. Differences between route and survey encoding have been observed in neuroimaging (Shelton & Gabrieli, 2002). When participants were scanned during the encoding of route and survey movies (as in Experiment 3), the results indicated that survey encoding recruited a subset of the regions recruited by route encoding. The additional brain regions associated with route encoding suggested processes such as integration of spatial information and larger mnemonic loads. In the present study, it is possible that these additional processes for route encoding actually supported the equivalence on our behavioral tasks. As such, if we manipulated the amount of time spent on learning, we might find differences in performance for route and survey.

Spatial skills are known to vary widely in the normal adult population (e.g., Hegarty & Kozhevnikov, 1999; Just & Carpenter, 1985; O’DeKirk, Wyatt, & Ellis, 1993; Schwartz & Philippe, 1991), and one hallmark of spatial skill variability has been sex differences (e.g., Cutmore, Hine, Maberly, Langford, & Hawgood, 2000; Eals & Silverman, 1994; Vandenberg & Kuse, 1978). In the present experiments, however, we did not observe any significant effects of or interactions with sex. One possibility is that real-world tasks like those used here are unaffected by differences in commonly tested spatial skills. Alternatively, the gender differences simply may not manifest themselves in this paradigm due to the overlearning discussed above or to the use of different strategies. Research has demonstrated individual differences in spatial strategy preference during navigation (Lawton, 1996; Pazzaglia & De Beni, 2001), but the different strategies appear to be efficient for successful navigation (Denis, Pazzaglia, Cornoldi, & Bertolo, 1999; Passini, 1984). Gender differences may be occurring in the present study in the form of different strategies that allow for equivalent learning. Further investigation of individual differences in the present paradigm might help delineate potential sex differences (e.g., Shelton & Gabrieli, in press).

The present study focused on understanding how different encoding experiences shape our spatial representations. To our knowledge, we provide the first clear evidence for orientation-dependent reference systems in encoding space from route and survey perspectives. This orientation dependence could best be characterized as establishing a principal reference vector to which spatial relationships could be anchored. Moreover, we found that information about a spatial layout could be accessed via different component representations, depending on the requirements of the memory task. In a previous article, we suggested that space was represented in multiple representations based on experiencing multiple views of a space (Shelton & McNamara, 1997). The results of

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4 For the text conditions in Experiment 1, this explanation would require that participants were using some sort of imagery to support the mental model in a specific perspective (route or survey). Notably, participants reported imagining themselves in the environment or viewing an aerial map in the route and survey text conditions, respectively.
the present study indicate that multiple representations of a different kind are formed, corresponding to different components of experience. Although this finding complicates the task of characterizing spatial representations, it also provides a foundation for understanding discrepancies among encoding conditions and memory tasks. In addition, it brings to the forefront the multifaceted nature of spatial learning. In the environments of everyday life, spatial learning involves learning what is in the environment, where those things are, and surely much more. Differentiating these components, their interactions, and integration is one of the next steps in building a more comprehensive model of spatial memory.

References


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