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Development of a self-report measure of environmental spatial ability

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Abstract

Environmental spatial abilities are involved in everyday tasks such as finding one's way in the environment and learning the layout of a new environment. Self-report measures of environmental abilities, e.g., asking people to rate their "sense of direction (SOD)," have been found to predict objective measures of these abilities quite highly. In this study, we developed a standardized self-report scale of environmental spatial ability, the Santa Barbara Sense of Direction Scale (SBSOD). The scale proved to be internally consistent and had good test–retest reliability. A series of four validity studies examined its relation to measures of spatial updating and acquisition of spatial knowledge at different scales and acquired from different learning experiences. These studies suggested that the SBSOD is related to tasks that require one to update location in space as a result of self-motion. It is more highly correlated with tests of spatial knowledge that involve orienting oneself within the environment than with tests that involve estimating distances or drawing maps. Self-report SOD is also somewhat more highly correlated with measures of spatial knowledge acquired from direct experience in the environment than with measures of knowledge acquired from maps, video, or virtual environments (VE).

Keywords: Spatial cognition; Sense of direction; Scale; Environmental spatial abilities

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1. Introduction

Environmental spatial abilities are involved in everyday tasks such as finding one's way in the environment and learning the layout of a building or city. Typical tasks used to assess these abilities include recognition of scenes from a learned environment, retracing routes taken, sketching a map of the environment, route distance estimates, and pointing to nonvisible landmarks in the environment (see Evans, 1980; Gärling & Golledge, 1987; Liben, Patterson, & Newcombe, 1981; Spencer, Blades, & Morsley, 1989 for reviews). Individuals differ considerably in their abilities to perform such tasks. However, although environmental tasks have been studied extensively from developmental and experimental perspectives, there has been relatively little research on individual differences in environmental spatial cognition.

One approach to examining individual differences in environmental spatial cognition is to consider how they are related to psychometric tests of spatial ability. These psychometric tests include tasks such as mental rotation of shapes, solving mazes, and finding hidden figures (Carroll, 1993; Eliot & Smith, 1983; Lohman, 1988; McGee, 1979). They involve imagining the manipulation of visual forms in small-scale space rather than imagining one's own changing location and orientation in large-scale space. Research to date suggests that psychometric measures of spatial ability are only weak predictors of environmental spatial tasks (Allen, Kirasic, Dobson, Long, & Beck, 1996; Bryant, 1982, 1991; Goldin & Thorndyke, 1982; Lorenz & Neisser, 1986; Pearson & Ialongo, 1986). Correlations are typically nonsignificant and rarely exceed .3. In factor analysis studies, pencil-and-paper psychometric measures load on different factors than do measures of environmental spatial ability (Allen et al., 1996; Pearson & Ialongo, 1986).

Self-report measures have proved to be a more promising approach to predicting environmental spatial ability. Such a measure was first introduced by Kozlowski and Bryant (1977). These authors simply asked people to rate on a seven- or nine-point scale "How good is your sense of direction (SOD)?" In two experiments, students were told to imagine that they were at a specific location on their campus and to point to various other campus landmarks. The correlations between the pointing error and the self-report item were .49 and .51 for the two experiments, respectively. In a third experiment, participants were classified as having good or poor SOD on the basis of the self-report question and were led through an underground tunnel system. Their task was to point back to the entrance of the tunnel from the end of the route. After four learning trials, the difference in pointing error between the two groups was 30°, in favor of the good SOD participants.

Several subsequent studies have reported high correlations between a single-item self-report measure and the performance of environmental spatial tasks (Montello & Pick, 1993; Prestopnik & Roskos-Ewoldson, 2000; Sholl, 1988; Sholl, Acacio, Makar, & Leon, 2000). Other researchers (Bryant, 1982, 1991; Lorenz & Neisser, 1986; Takeuchi, 1992; Vandenberg, Kuse, & Vogler, 1985) developed self-report scales containing multiple items (e.g., "How well do you judge distances?" and "How good are you at inventing new routes?") and found similar correlations with measures of environmental spatial abilities. For example, Bryant (1982) found a correlation of $-.63$ between a self-report scale and an average error in pointing to landmarks from an imagined position in a familiar environment. Like the objective environmental task measures, self-report measures are only weakly related to psychometric paper-and-pencil spatial tests (Bryant, 1982; Sholl, 1988; Takeuchi, 1992).

Although there is strong support for the correlation of self-report SOD with measures of environmental spatial cognition, there is not complete consistency with respect to this issue. For example, Thorndyke and Goldin (1981) identified people as good and poor cognitive mappers on the basis of tasks such as estimation of distance and direction to landmarks in their local environment. They also administered a "spatial style" questionnaire consisting largely of items similar to those in self-report SOD scales. The questionnaire did not differentiate the good and poor cognitive mappers. Furthermore, Takeuchi (1992) failed to find strong correlations between two self-report factors ("understanding of direction" and "memory for places") and ability to point to landmarks in a familiar environment. Streeter and Vitello (1986) found that a SOD question did not cluster with other questions about map and navigational abilities.

One likely reason for the discrepancies between studies is that researchers have not been consistent in how they measured self-report SOD. Some have used a single item, whereas others have used multi-item scales. Moreover, there is little consistency regarding which items are included in multi-item scales, and researchers often do not even report the items, making comparisons across studies impossible. There is a need for a standardized self-report SOD scale, which can be used by different researchers and can allow comparisons across studies.

Another likely reason for inconsistencies across studies is that different measures of environmental spatial cognition have been used. They have sometimes assessed existing spatial knowledge (such as knowledge of the neighborhood in which a person lives) and sometimes assessed the ability to learn the layout of a new environment. Some studies have measured learning from direct navigation and others have measured learning from maps. Different tasks have been used to assess environmental knowledge, for example, making directional estimates or distance estimates in the environment. Rather than asking whether self-report SOD is related to environmental spatial ability, we believe the appropriate question is to ask which types of knowledge and which spatial tasks are more or less related to self-report SOD.

An important distinction among spatial tasks may be the scale of space at which they are carried out. Montello (1993) and Montello and Golledge (1999) have proposed that because our perceptual-motor systems interact differently with space at different scales, there may be multiple psychological systems for processing spatial information at these different scales (see also Ittelson, 1973; Mandler, 1983). For example, figural space is small in scale relative to the body and is external to the individual. It includes both the flat pictorial space and the space of small manipulable objects. Most existing psychometric tests of spatial ability are at this scale of space. Vista space is projectively as large or larger than the body but can be visually apprehended from a single place without appreciable locomotion. It is the space of single rooms, town squares, small valleys, and horizons. Environmental space is large in scale relative to the body and "contains" the individual. It includes the spaces of buildings, neighborhoods, and cities and typically requires locomotion for its apprehension. Gigantic space (e.g., states, countries, and planets) is larger again and cannot be apprehended from direct locomotion experience. This scale of space is typically apprehended by viewing maps, representations that are themselves figural spaces.

We propose that self-report SOD primarily reflects ability to carry out tasks characteristic of the environmental scale of space. This scale of space is typically apprehended by locomotion and requires one to integrate a sequence of views that change with one's own motion in order to build up spatial knowledge and orient in the environment. We therefore predict that self-report SOD will be most highly correlated with tasks that measure knowledge acquired by direct navigation in environmental spaces. Consistent with this view, tasks that have been found to correlate with self-report SOD include learning a novel environment by walking through it (Montello & Pick, 1993) and measures of orientation in college campuses (Bryant, 1982; Kozlowski & Bryant, 1977; Sholl, 1988), which are typically learned primarily by navigating.[2]

We also propose that self-report SOD is more highly correlated with measures that depend on a configural or survey representation. Consistent with this view, most previous research showing correlations with self-report SOD has examined its relation to ability to point to unseen locations in an environment (Bryant, 1982; Kozlowski & Bryant, 1977; Montello & Pick, 1993; Sholl, 1988; Sholl et al., 2000). This task depends on a representation of the *spatial configuration* of the environment, in contrast with tasks such as scene recognition, which can be accomplished with only visual memory of landmarks, or route retracing, which can be accomplished with only a very simple (perhaps verbal) representation of the sequence and location of turns made on the route.

Finally, a distinction can also be made between pointing to unseen locations from one's current perspective in an environment and pointing from a different (imagined) perspective in the environment. Sholl (1988) found that SOD was related to ability to point to unseen landmarks from an imagined perspective but not from one's current perspective. She concluded that self-report SOD is primarily related to the ability to mentally align egocentric and environmental reference frames. This hypothesis is further examined in the current study.

1.1. Goals of these studies

One goal of these studies was to develop a standardized self-report scale of environmental spatial skills, which we call the Santa Barbara Sense of Direction Scale (SBSOD). In Study 1, we developed the content of the SBSOD and assessed its internal consistency. In Study 2, we

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[2] An environmental scale space, such as a building or campus, could be learned purely from a map. Because a map is itself a figural space, we do not expect learning the layout of an environment *purely* from a map to be correlated as highly with SOD. Although learning by integrating self-motion is not characteristic of the vista scale of space, a path in a vista-scale environment might be learned by integrating over one's own motion, as in studies of dead reckoning in which blindfolded people are lead on a path in a room or a field and asked to point back to their starting location (e.g., Loomis et al., 1993).

assessed its test–retest reliability. A second goal was to study the relation between the SBSOD and measures of spatial cognition at different scales and based on different types of learning experiences. The relation of the SBSOD to these measures also establishes its validity. In Study 3, we examined the relation of SBSOD with pointing to landmarks in environments at different scales. In Study 4, we examined its relation to a blindfolded updating task. In Study 5, we examined the relation of SBSOD with environmental learning from different media. In a final study, we examined its correlation with pointing to landmarks at different scales, in environments that were learned via different media, and the effects of order of administration of the scale and criterion measures.

2. Study 1: initial scale development

2.1. Method

2.1.1. Participants

Forty-one undergraduate students (20 female and 21 male) enrolled in an introductory geography class at the University of California-Santa Barbara (UCSB) participated.

2.1.2. Materials

The scale consisted of 27 items (see Appendix A) taken from previous self-report scales (Bryant, 1991; Kozlowski & Bryant, 1977; Lorenz & Neisser, 1986; Thorndyke & Goldin, 1981) and from statements made by students in a pilot study in which we asked students in a cognitive psychology class to simply list experiences and abilities related to their SOD. Each Likert-type item was a self-referential statement about some aspect of environmental spatial cognition. Participants responded by circling a number from 1 (*strongly agree*) to 7 (*strongly disagree*). The items were phrased such that approximately half of the items were stated positively and half were stated negatively. An example of a positively stated item is “I am very good at judging distances” and an example of a negatively stated item is “I very easily get lost in a new city.” In this and all subsequent studies, all items were scored such that a higher rating indicates a better self-report SOD (i.e., the scoring of positively stated items was reversed).

2.1.3. Procedure

All participants completed the questionnaire in a single group session during an introductory geography class. Completion of the questionnaire was preceded by the instructions printed at the beginning of the scale in Appendix B.

2.2. Results and discussion

Responses to the 27-item questionnaire were included in a factor analysis using squared multiple correlations as communality estimates. The initial extraction of the factors was accomplished using the principal factor method, and this was followed by a varimax (orthogonal) rotation. Five factors were retained for rotation. These factors accounted for

35.7%, 12.2%, 11.2%, 8.1%, and 7.0% of the variance, respectively (total 74.2%). When examining the rotated factor pattern, an item was considered to load on a factor if the given loading was greater than 0.40.

Given the small number of participants in this study, the factor analysis should be considered as very exploratory and was only one criterion used in selecting items for the final scale (high external validity being an equally strong criterion). Nevertheless, it is interesting that 10 items loaded on the first factor and that Item 6 ("My sense of direction is very poor") had the highest loading on this factor. This was the main factor of interest, and given the exploratory nature of the factor analysis, no attempt was made to interpret the other factors. Several items that did not load on Factor 1 had high external validity. Therefore, we adopted the less stringent criterion that any item with a correlation greater than .2 with Item 6 would be retained. These included the 10 items loading on Factor 1 and Items 10, 13, 21, 26, and 27. The final 15-item SBSOD Scale is presented in Appendix B. Coefficient α for the scale was .88, indicating that it has good internal reliability. Item–total correlations ranged from .34 to .75.

The majority of items (10 of 15) that correlated with Item 6 (the "sense of direction" item) were self-reports of the individual's competency in various environmental spatial tasks, such as giving and following directions, remembering routes, remaining oriented in the environment, and using maps. Two items described the individual's feelings about specific environmental tasks. Other items suggested that people with a positive self-rating of SOD place importance on being oriented in their environment and think of their environment in terms of cardinal directions.

Some items that were not related to the central "sense of direction" item described feelings about travel, tendency to explore the environment, and anxiety about getting lost. Bryant (1982) also found that liking to explore and worrying about getting lost were distinct from self-report SOD. The results of our study also indicated that self-report SOD does not seem to be based on self-ratings of encoding visual details (Items 19 and 22), right–left confusion (Item 17), or ability to judge time (Item 12).

3. Study 2: test–retest reliability

3.1. Method

Sixty-one undergraduate students (41 female, 20 male) enrolled in an undergraduate psychology class at the UCSB participated voluntarily. Participants were administered the 15-item SBSOD, shown in Appendix B. The SBSOD was administered to all participants on two different occasions during an introductory cognitive psychology class. The second administration followed the first by 40 days.

3.2. Results and discussion

The correlation between scores on the two administrations of the scale (test–retest reliability) was .91. The correlations between the two administrations for individual items ranged from .42 to .90. The “sense of direction” item (Item 4 in this scale) had the highest test–retest reliability at .90. Consequently, all items were retained and the scale was subjected to validity assessments.

4. Study 3: self-report SOD and pointing to landmarks at different scales

This study assessed the relation of SBSOD to pointing accuracy at different scales of space. Students were asked to point to objects within a room on a college campus (vista space) and to campus landmarks outside the room (environmental space). The campus landmarks were familiar landmarks that the students had probably learned primarily by navigating on the campus. Pointing to these landmarks from within the room required the participants to update their orientation with respect to the landmarks as they moved from the outside location into the room. Because pointing to campus landmarks is at the environmental scale of space and involves updating one’s position as a result of self-motion, we predicted that it would be correlated fairly highly with SBSOD. In contrast, we predicted that pointing to room objects would not be correlated highly with SBSOD because it does not require updating and is at the vista scale of space.

We also contrasted different methods of acquiring pointing responses in this study. A comparison of these methods is the major topic of another paper (Montello, Richardson, Hegarty, & Provenza, 1999) and will not be discussed in detail here.

4.1. Method

4.1.1. Participants

Twenty-four undergraduate students (12 female, 12 male) in an introductory psychology class participated in this study in return for course credit.

4.1.2. Design

Participants pointed to landmarks within the laboratory, landmarks outside the laboratory (campus landmarks), and cardinal directions. They pointed to landmarks either by using a pointing dial or by turning their bodies. Within each of these conditions, half of the time they pointed using a vision-restricting hood and half of the time they pointed while wearing blindfolding goggles that blocked out all visual input.

4.1.3. Materials

A circular pointing dial was used to collect directional estimates for half of the trials. The dial was made of cardboard with a movable radius wire on the top face, which the participant rotated to indicate the direction to the target object on each trial. A single radius line, visible on top of the dial, was used to orient the dial to the participant. Direction estimates were read off the bottom of the dial, which was marked in single degree increments. For the other half of the trials, estimates were collected with a KVH Azimuth 100 digital compass, which was attached to a waist pack worn by the subject.

A vision-restricting hood was used to limit visibility in half of the conditions. This was worn over the head and allowed participants to see straight down around their feet. In the other half of the conditions, participants wore a pair of swimming goggles, made opaque with paint, which completely occluded vision when worn. In all conditions, participants wore a pair of shooter's earmuffs to deaden sound cues. Participants stood on a large piece of short-pile carpet throughout the experiment that had no patterned marks or rectilinear texture.

Participants pointed to 10 different landmarks, including four objects within the testing laboratory, four well-known landmarks on the UCSB campus (landmarks outside the laboratory), and two cardinal directions (north and southeast). The landmarks were chosen so that correct directions were spread fairly evenly around participants' bodies. For further details of the landmarks, see Montello et al. (1999).

4.1.4. Procedure

Participants were first taken to a location outside the laboratory where the directions of the four outside landmarks and the cardinal direction North were pointed out to them. Then, they were taken inside the laboratory and familiarized with the four indoor landmarks. Each participant was tested in four blocks of trials corresponding to the different possible combinations of Visibility and Pointing Method, with order of conditions counterbalanced across participants. All judgments were made from the same starting orientation, corresponding to the cardinal direction East. Participants were allowed to go outside between blocks to refamiliarize themselves with the locations of the outside landmarks. For further details of the procedure, see Montello et al. (1999). After the completion of testing, participants were given the SBSOD.

4.2. Results and discussion

The measure of pointing performance used in this and subsequent studies in this paper was mean absolute error (absolute deviation of pointing direction from correct direction to target) across trials.[3] Note that the measure of pointing accuracy is an error

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[3] Although separation of absolute error into constant and variable error has been advocated for experimental studies (Montello et al., 1999; Schutz & Roy, 1973), we believe that absolute error is the best single measure of individual differences in ability. Absolute error best predicts whether a person would be closest to a correct answer on a given trial, an aspect of performance that requires both low constant error and low variable error, on average. For example, one would not consider a person to have high spatial ability if he or she had a large bias (constant error) in pointing to targets but little variability around this biased pointing direction. Nor would a person be considered to have high ability if his or her estimates always centered on the correct direction but were highly variable.

Table 1
Correlation between SBSOD and different measures of pointing accuracy (Study 3)

Experimental condition	Outside room landmarks	Inside room landmarks
Blindfold pointing	− .46 *	− .13
Blindfold turning	− .22	.00
Hooded pointing	− .48 *	− .23
Hooded turning	− .36	− .39
Overall	− .44 *	− .13

* $P < .05$.

measure (a higher score means less ability) so that a negative correlation with SBSOD is expected.

The correlations of SBSOD with pointing error for inside and outside landmarks are shown in Table 1 (cardinal directions were not included). As predicted, the correlation of SBSOD with pointing to outside landmarks was higher than its correlation with pointing to inside landmarks. Furthermore, this pattern was found for three of the four pointing methods, and in the other case, the difference between measures for inside and outside landmarks was negligible. Only the correlation of SBSOD with pointing to outside landmarks was statistically significant. Although the results of this study are somewhat limited by a small sample size, they are consistent with the view that self-report SOD reflects ability to carry out tasks characteristic of the environmental scale of space and not the vista scale.

The higher correlation with pointing to outside landmarks might reflect the fact that the locations of these landmarks were learned by the participants over time by navigating in the environment, whereas the locations of the inside landmarks were newly learned from a single location in the experimental room. It might also reflect the fact that the participants had to update their location relative to these landmarks as they moved from outside into the location in the experimental room in which they were tested in order to mentally align their egocentric perspective within the room with the frame of reference of the campus. In contrast, when pointing to inside landmarks, no mental egocentric updating was necessary (cf. Sholl, 1988).

5. Study 4: self-report SOD and blindfolded updating

The purpose of this experiment was to assess the correlation of the SBSOD and ability to update location while blindfolded. Participants were lead on paths in an open field while blindfolded and at the end of each path were asked to point back to their starting location. Although this task was carried out in an open field (vista space), it required (blindfolded) participants to integrate their motion on the basis of proprioceptive (kinesthetic and vestibular) cues to remain oriented to the environment. Therefore, we predicted that performance on this task would be correlated with SBSOD.

5.1. Method

5.1.1. Participants

Twenty-five undergraduate students (9 female, 16 male) at the UCSB participated in this study.

5.1.2. Materials

Twelve pathways were marked in an open field. Half of the pathways were 60 ft in length and half were 180 ft. One-third of the paths had three segments and two turns, one-third had six segments and five turns, and one-third had eight segments and seven turns. For half the paths, all the turns were 90°. For the other half, the turns were either 45°, 90°, or 135°. The paths were constructed so that every other turn was to the right or left and so that each path never crossed itself.

The same circular pointing dial used in Study 3 was used to indicate directional estimates in this experiment. Participants again wore the opaque swimming goggles to occlude vision and the shooter's earmuffs to deaden sound cues.

5.1.3. Procedure

Participants were guided along the 12 pathways with the order of the different pathways counterbalanced across participants.[4] At the end of each pathway, participants used the pointing dial to indicate direction to the starting location of the path. After being tested on all 12 pathways, participants were administered the SBSOD as shown in Appendix B.

5.2. Results and discussion

The mean absolute pointing error across the 12 paths was used as an indicator of performance. The correlation between error and SBSOD was $-.40$ ($P<.05$). Again, SBSOD showed a moderate correlation with spatial orientation based on direct experience moving in the environment. While this result is again somewhat limited by a small sample size, it is supportive of the view that SBSOD is related to the ability to update one's location as one moves in the environment. This study showed that updating does not have to be based on visual information and can also be based on proprioceptive information.

No previous study has examined the relation of self-report SOD to blindfolded updating. Two previous studies (Kozlowski & Bryant, 1977; Sholl et al., 2000) studied path integration in environments in which there were minimal visible landmarks (an underground tunnel and a path through a wooded park, respectively), so that updating of spatial

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[4] The order of paths was counterbalanced because another goal of this study was to examine the effects of different path characteristics on blindfolded updating performance.

position was probably primarily based on proprioceptive cues. As noted above, Kozlowski and Bryant (1977) found a significant difference between high and low SOD individuals, which increased with more learning trials on the path. Sholl et al. (2000) failed to find a significant difference between high and low spatial individuals and attributed this to a ceiling effect.

6. Study 5: self-report SOD and learning environments from different media

The purpose of this study was to examine the correlation of self-report SOD with learning via different media, different measures of the knowledge acquired, and paper-and-pencil tests of spatial ability. First, we examined the relation of SBSOD with learning via three different media: direct experience navigating in an environment, viewing a videotape of a route through an environment, and navigating a desktop virtual environment (VE). We have proposed that self-report SOD is most highly correlated with spatial knowledge that is acquired by integrating the sequence of views that one encounters when moving through an environment with proprioceptive (vestibular and kinesthetic) feedback from one's own motion. This describes learning from direct experience. Learning from video and desktop VEs also requires the integration of a sequence of views. However, in these learning situations, one does not physically move, so movement is sensed by vision alone. We therefore predicted that SBSOD would be more highly correlated with measures of learning from direct experience than with measures of learning from video or desktop VEs.

In Study 5, we also examined three different measures of spatial knowledge for each environment learned: pointing to unseen landmarks, estimating straight-line distances to landmarks, and drawing a sketch map of the environment. In contrast to other possible measures of environmental knowledge (e.g., landmark recognition and route retracing), these measures depend at least partially on the ability to derive a representation of the configuration of the route from spatial information learned over time. Estimating the straight-line distance and direction to nonvisible landmarks clearly involves the integration of information learned over time. However, estimating egocentric directions depends on representing one's orientation (heading) and location within the space, whereas estimation of distances depends on a representation of one's location but not orientation. In contrast, drawing a map does not depend on a representation of either one's location or one's orientation in the environment. In fact, although a map is a configural representation of an environment, a relatively accurate map can be sketched even when one's knowledge is not integrated into a configuration, as long as distances and directions are represented and the integration over segments and turns of the route occurs when the route representation is externalized in the sketching of the map.

Finally, in this study, we also examined the relation of SBSOD to two psychometric tests of spatial ability, the Embedded Figures test and the Vandenberg Mental Rotation Test. Previous research has found very weak correlations between self-report SOD measures and paper-and-pencil tests of spatial ability (Bryant, 1982; Sholl, 1988; Takeuchi, 1992). Such tests are characteristic of the figural scale of space, and we propose that tasks at that scale are unrelated to self-report SOD.

6.1. Method

A total of 286 people took part in the study. They were paid $40 for their participation, which took approximately 3.5 h, spread over two sessions. The data from 58 participants were excluded due to missing data. Of the 228 participants included in final analyses, 138 were female and 87 were male (3 did not report their sex). Their mean age was 22.1 years (S.D. = 7.3) and they had been on the UCSB campus 4.1 quarters (S.D. = 4.7) on average.

6.1.1. Tasks and measures

The participants completed the SBSOD, the Group Embedded Figures test (Oltman, Raskin, & Witkin, 1971), the Vandenberg Mental Rotations Test (Vandenberg & Kuse, 1978), and several other psychometric measures that will not be reported in this paper (see Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2001).

6.1.1.1. Spatial learning from navigation directly in a real environment. Participants learned the layout of a route through two floors of a building on the UCSB campus (Ellison Hall) along with the locations of eight landmarks on that route. The experimenter first led each participant through the building, stopping at each landmark to point it out and name it. After traversing the route once, the experimenter again led the participant along the route and at each of the eight landmarks instructed him or her to make straight-line distance and direction judgments to two other landmarks that were not visible from that location. Distance estimates were made directly in feet. Directional estimates were made by means of the same circular pointing dial used in Studies 3 and 4. After completing all estimates on the route, participants drew a sketch map of the route including the locations of the eight landmarks.

6.1.1.2. Spatial learning from navigation in a desktop VE. Participants learned the layout of a single-floor route depicted in a desktop VE along with the locations of four landmarks on that route. The environment was a long hallway with six segments, connected by 90° turns. Participants traversed the route using the forward, right, and left arrow keys on the keyboard. They first spent time in a practice environment to become familiar with the interface. They then traversed the test route twice in response to verbal instructions by the experimenter, who pointed out the four landmarks in the environment as they were encountered. On the third traversal, participants were stopped at each landmark and instructed to make distance and direction judgments to two other landmarks, for a total of eight distance and eight direction estimates. Estimates were collected as for the real-environmental task, and participants also drew a sketch map of the virtual route.

6.1.1.3. Spatial learning from viewing a videotaped environment. Participants learned the layout and locations of seven landmarks in a local building (the Santa Barbara Courthouse) by viewing a videotape. Each landmark was indicated by stopping, pointing the camera at the landmark, and naming it aloud. Participants viewed the video three times. On the third time (the testing phase), the video was paused at each landmark and participants made direction and distance judgments to two of the other landmarks. For each direction judgment, participants were given a circle with a straight line pointing downwards from the center of the circle. They were instructed to point the line towards themselves and to draw an arrow on the circle indicating the direction to the landmark in question. Then, participants drew a sketch map of the video route.

6.1.1.4. Scoring of the environmental learning measures. Three dependent measures were scored for each of the environmental learning tasks: direction estimates, distance estimates, and sketch maps. Direction estimates were scored as the mean absolute error in degrees. Reliability estimates (coefficient α's) for the direction estimation measures were .85 for learning from direct experience, .84 for learning from videotape, and .66 for learning from the VE.

The score for the distance estimates was the correlation of a participant's estimates across trials with the correct distances for these trials. A participant who accurately estimates distances proportionately across trials would therefore receive a high correlation. Correlations of estimated with correct distances were converted to z scores using Fisher's r to z transform for use in the analyses.

We computed the number of "nonmetric" errors based on the sketch maps. These were the number of landmarks omitted from each map, the number of missing or additional segments of the route indicated on the map, and the number of turns indicated on the map that were in the wrong direction. For maps of the routes through Ellison Hall and the Courthouse (each of which traversed two floors of a building), we counted an additional error if the two floors were not aligned correctly on participants' maps. Interrater reliability based on two independent codings of 30 sketch maps was .87.

6.1.2. Procedure

Participants were tested in two sessions. In the first session, they were tested in groups of up to 12 at a time and first completed a demographics questionnaire followed by the SBSOD. They were then administered the Group Embedded Figures and another psychometric test (see Hegarty et al., 2001). Then, all participants were shown the videotape of the Courthouse and performed the spatial learning tests based on this videotape. Finally, participants were administered the Vandenberg Mental Rotation Test and another psychometric test not reported here.

In the second session, participants were tested alone. They first performed a psychometric test (see Hegarty et al., 2001) followed by the test of spatial learning from the desktop VE. Then, they were led out of the laboratory to the entrance of Ellison Hall and performed the test of spatial learning from a real environment. Then, they were tested on several other measures not reported here before being thanked and dismissed.

6.2. Results and discussion

The correlations of the SBSOD with the different measures are shown in Table 2. Note that the measures of direction estimation and map drawing are error scores, so negative correlations of SBSOD with these measures are expected. The correlations of SBSOD with all but one of the measures of spatial learning were significant. As predicted, the correlations of SBSOD with measures of learning from direct experience were higher than its correlation with measures of learning from the video and VE. This is consistent with the view that SOD is more highly related to the ability to learn the layout of an environment by integrating visual and proprioceptive information (i.e., learning from direct experience) than to the ability to learn the layout of an environment from visual information alone (i.e., learning from video or VE).

The correlations of SBSOD were higher with measures of direction estimation than with measures of distance estimation or map sketching, regardless of the learning medium. The higher correlation with pointing to unseen landmarks may reflect the fact that this measure depends on both ability to infer to configuration of the environment from spatial information learned over time and ability to orient oneself in that configuration. Straight-line distance estimation is also a measure of configural knowledge but does not require the ability to orient oneself in the environment. Although it is likely that map sketching also reflects the ability to acquire configural knowledge, route knowledge alone may have been

Table 2
Correlation between SBSOD and measures of learning a complex environment from different media (Study 5)

Measure	Correlation with SBSOD
Learning from direct experience	
Direction estimation (absolute error)	− .43**
Distance estimation (r to z transform)	.36**
Map drawing (nonmetric errors)	− .32**
Learning from video	
Direction estimation (absolute error)	− .33**
Distance estimation (r to z transform)	.25**
Map drawing	− .23**
Learning from VE	
Direction estimation (absolute error)	− .24**
Distance estimation	.08
Map drawing (nonmetric errors)	− .18**
Group Embedded Figures test	.12
Vandenberg Mental Rotations Test	.08

** $P < .01$.

sufficient for accurate performance on the nonmetric measure of map sketching in this study.

Finally, as predicted, SBSOD was not significantly correlated with either of the pencil-and-paper psychometric tests. This is consistent with previous research on self-report SOD (Bryant, 1982; Sholl, 1988; Takeuchi, 1992) and provides evidence for the discriminant validity of the SBSOD in showing that it is not related to tasks characteristic of the figural scale of space.

7. Study 6: self-report SOD as related to scale of space and administration order

We have proposed that a task should correlate with self-report SOD to the degree that it involves environmental knowledge acquired directly. That is, a task that depends solely on directly acquired environmental knowledge or that requires map knowledge to be coordinated with environmental knowledge should correlate more with SOD than a task that depends solely on knowledge acquired from a map. We addressed this question in Study 6 by measuring the correlation of SBSOD with knowledge of the locations of buildings on the UCSB campus to its correlation with knowledge of the locations of cities in the US. Students tend to learn about the locations of campus buildings primarily from direct experience traveling around campus but learn about the locations of US cities primarily from looking at maps (Sholl, 1987). We predict that self-ratings of SOD will correlate more highly with questions about campus buildings than about US cities.

A second issue examined in this study concerns whether self-report SOD reflects a relatively stable trait or self-perception of recent performance on a criterion task. In Studies 3 and 4 and several other studies in the literature, the self-report scale was administered soon after participants performed a criterion task. It is possible that participants rated perceptions of their performance on the just-completed task rather than beliefs about their relatively enduring abilities. We addressed this issue in Study 6 by manipulating whether participants filled out the SBSOD before or after the criterion task.

7.1. Method

7.1.1. Participants

A total of 107 students from an undergraduate geography class participated in return for extra class credit. Of these, 48 were female and 57 were male (2 did not report their sex). Their median age was 19 years, ranging from 18 to 37.

7.1.2. Materials

In addition to the SBSOD scale, participants answered questions testing their knowledge of directions between places. These questions occurred at two scales. *Campus building* questions asked participants to indicate directions between pairs of buildings on the UCSB campus. *City* questions asked participants to indicate directions between pairs of cities in the US. All participants answered 20 questions at each scale. At both scales, questions were of the form "Pretend you are at ___, facing ___. Draw an arrow pointing toward _____." For each judgment, participants were given a circle with an arrow pointing upwards from the center of the circle indicating the heading they were to imagine and then draw an arrow pointing towards the landmark in question. They were instructed to guess the directions if they were not sure of the location of one of the places and to check a box at the bottom of the page if they had no knowledge of the location of one of the places. At each of the scales, 10 different locations (campus buildings or cities) were used to generate the questions.

7.1.3. Procedure

Data were collected in a single group session at the end of class. The SBSOD and direction tests were stapled together as part of a single booklet. The SBSOD scale was administered in two orders, either at the beginning of the data collection or at the end. This was randomly varied: 61 participants completed it at the beginning, while 46 completed it at the end. For the direction tests, participants answered all 20 questions at one scale before they completed the 20 questions at the other scale. The order of the scales was randomly varied (campus questions were answered first by 44 participants). As soon as they finished, participants turned in their booklets at the front of the room.

7.2. Results and discussion

Before turning to the main questions of this study, we address the treatment of missing data. Data were missing for two reasons. First, some participants did not know the location of some US cities or, especially, UCSB campus buildings. Even a person with a good SOD cannot point to a target that they do not know. Therefore, we excluded from the analysis participants who claimed not to know half or more of either the US cities (7 participants) or the campus buildings (19 participants). One person was excluded on both of these criteria, so analyses were based on data from 82 participants. Second, some locations were not well known in general. One campus building in particular was not well known, at least as we referred to it in the test. This building was mentioned in six questions in combination with other buildings, and for these six questions, approximately half the participants stated they did not know one of the buildings involved. We excluded these six questions from the calculation of average error on the campus building questions, so this measure was based on 14 questions. In the resulting data set, the mean number of trials on which cities were not known was 0.3 (S.D. = 1.1) and on which campus buildings were not known was 0.6 (S.D. = 1.6).

The mean score on the SBSOD was 4.7 (S.D. = 1.1) and the mean absolute pointing error was 39.7° (S.D. = 17.4) for city questions and 39.2° (S.D. = 16.7) for campus building questions. Participants who reported a better SOD performed the pointing task more accurately. The correlation between SBSOD and error was $-.52$ ($P < .001$) for the campus-building pointing task and $-.40$ ($P < .001$) for the city pointing task. As predicted, the correlation of SBSOD with campus pointing is higher than with US cities, though this difference does not reach statistical significance according to a test for the difference of dependent correlations [$t(79) = 1.33$, ns]. In fact, average error on building questions was correlated .55 with average error on city questions.

The correlation between performance on the two scales of questions suggests that they tapped into overlapping abilities rather than totally separate abilities. Both tasks require the ability to point to unseen locations from an imagined perspective that is different from one's current perspective. Sholl (1988) also found a relation between SOD and ability to point to landmarks, independently of whether they were campus landmarks or nearby cities. Furthermore, both may require map-acquired knowledge to some extent. The locations of US cities are learned from maps and the locations of buildings on the UCSB campus may also be learned at least partially from maps in addition to direct experience. Therefore, the building task may be best thought of as a task that involves coordinating knowledge gained from maps and direct experience. A test of knowledge gained purely from direct experience may show more separation from a test of map-acquired knowledge than was observed in this study.

We next examined if the relationship between SBSOD and pointing performance depends on whether SBSOD was filled out before or after the pointing tasks. Mean SBSOD was a little lower for those who filled it out first ($n = 41$, mean = 4.5, S.D. = 1.1) than for those who filled it out last ($n = 41$, mean = 4.8, S.D. = 1.0), but this small difference did not reach significance [$t(80) = 1.44$].

Recent self-perception predicts that SOD should correlate more strongly with performance on the criterion tasks for participants who filled out the SBSOD last rather than first. Correlations of SBSOD with pointing error for participants who filled out the SBSOD last were − .42 for city questions and − .36 for building questions. For participants who filled out the SBSOD first, correlations were − .36 for city questions and − .61 for building questions. These results are inconsistent with the recent self-perception hypothesis. Although the correlation with city questions was slightly higher for those who filled out the SBSOD last, the correlation with campus questions was clearly lower for this group. An alternative hypothesis is that self-reports of ability become "self-fulfilling prophecies," causing performance on the subsequent direction task to improve or worsen in order to maintain consistency. This hypothesis would predict higher correlations of SBSOD with both criterion measures when the self-report scale is filled out first, whereas this pattern was only evident for one of the criterion measures (building questions). Therefore, the differences in correlations for the two groups are most likely to reflect differences between the samples in the two conditions rather than a consistent bias due to recent self-perception or self-fulfilling prophesies.

8. General discussion

These studies demonstrate that the SBSOD scale is a useful instrument for measuring the construct of self-report SOD. Large coefficient α's for the scale indicate a high level of internal consistency, and test–retest reliability is also high. An examination of the items that loaded on the SOD factor suggests that when people rate their SOD as "good" or "poor," they are basing their judgments on environmental tasks such as wayfinding, remaining oriented in an environment, learning layouts, using maps to navigate, and giving and following directions. Most of the items that loaded on the SOD factor involved ratings of the individual's own competency on tasks that depend on survey or configural knowledge of environments, whether stored or generated during task performance. Similarly, Prestopnik and Roskos-Ewoldson (2000) reported that SOD is related to use of survey strategies to navigate in the environment but not with use of route strategies.

This research also provides information on the types of objective measures that are related to self-report SOD. It suggests that SOD is related to ability to update one's orientation and location in space with body movement in the environment, an ability that characterizes spatial cognition at the environmental scale of space. The correlation between SBSOD and blindfolded updating in Study 4 indicates that it is related to path integration or the computation of location and heading relative to the starting point on a path (see also Kozlowski & Bryant, 1977). The correlation between SBSOD and pointing to outside landmarks in Study 3 indicates that it is related to the computation of one's location and heading relative to landmarks in the environment. Its correlation with the environmental learning tasks examined in Study 5 also reflects the ability to update one's location relative to environmental landmarks, in this case, the landmarks that one encounters while learning a new environment (see also Montello & Pick, 1993).

This research also suggests that SOD is interpreted quite literally, in that the self-report measure is most highly correlated with measures of environmental knowledge that require one to represent one's current orientation or heading in the environment (Studies 3–5) or imagine taking an orientation in a familiar environment that differs from one's current heading (Study 6). Thus, Study 5 showed that SBSOD was more highly correlated with measures of directional knowledge than with measures of straight-line distance estimation or map sketching that do not depend on a representation of one's heading in the environment.

Several previous studies (e.g., Kozlowski & Bryant, 1977; Montello & Pick, 1993; Sholl, 1988) support the view that self-report SOD reflects the ability to orient oneself in an environment. However, Sholl (1988) has claimed that a relation with self-report SOD is observed only when one points to unseen landmarks from an imagined perspective that is different from one's current perspective, not when one points from one's current perspective. In contrast, in Studies 3 and 5, we found significant correlations of SBSOD with pointing to landmarks from one's current heading. In both cases, the representation of the locations of landmarks in the environment was probably based on mental updating as a result of self-motion. Consistent with Sholl's claim, in Study 3, we found that SBSOD is not correlated with ability to point to locations in one's immediate environment from one's current orientation (pointing to indoor landmarks). This task does not require the ability to update the locations of landmarks or to imagine a different orientation in space.

We predicted that SBSOD would be most highly correlated with measures of environmental knowledge acquired from direct experience in an environment, as opposed to other learning media such as maps, video, or VEs. Our results were somewhat consistent with this hypothesis in that we observed higher correlations with measures of environmental knowledge acquired from direct experience compared with knowledge acquired from video and VE in Study 5 and knowledge acquired from maps in Study 6. However, these correlations were not significantly higher, and measures of knowledge acquired from maps, video, and VE were also significantly correlated with SBSOD. In summary, these results lead us to conclude that SBSOD is more highly correlated with measures of knowledge acquired from direct experience compared with measures of knowledge gained from other learning experiences but that it can be correlated with measures of knowledge derived from these other experiences, especially when that knowledge is well learned. This probably reflects overlapping skills involved in spatial learning via different media and at different scales and overlapping task demands of the measures used to assess the spatial knowledge acquired via different media. Further research is required to examine the similarities and differences between spatial knowledge based on different media (e.g., Richardson, Montello, & Hegarty, 1999).

Consistent with previous research (Bryant, 1982; Sholl, 1988; Takeuchi, 1992), self-report SOD was unrelated to psychometric paper-and-pencil tests of spatial ability. This supports our view that spatial abilities at the figural scale of space are distinct from those measured by self-report SOD.

Some of the correlations with environmental tasks were lower than those reported in previous studies. These results are most likely due to the nature of the environmental tasks rather than to the SBSOD scale per se, because the scale was found to be highly reliable. In particular, correlations with newly acquired knowledge (as measured in Study 5) tended to be lower than those with well-learned knowledge (as measured in Study 6), regardless of how the environment was learned. One possible reason for these relatively low correlations is that participants may not have learned the new environments adequately with the amount of exposure given in these studies. With more exposure to these new environments, we might expect measures of environmental knowledge to be more highly correlated with SBSOD. Consistent with this interpretation, Kozlowski and Bryant (1977) found that differences in performance between high SOD and low SOD individuals increased with exposure to a route through a novel environment when their task was to point back to start after traversing the route.

In general, the correlations of SBSOD with environmental measures observed in these studies are higher than those typically observed between paper-and-pencil tests of spatial ability and environmental measures. In closing, we might ask why self-report questionnaires are so predictive of environmental spatial abilities. Clearly, it would be easy to misrepresent one's ability on such a questionnaire. In fact in other domains such as logic, grammar, and humor, there is evidence that people greatly overestimate their abilities, and self-report measures are thus uncorrelated with performance (Kruger & Dunning, 1999). However, the correlations observed in this study indicate that people are somewhat truthful and accurate in estimating their environmental spatial abilities. One likely reason is that environmental cognitive abilities are exercised on a daily basis and there are real costs in everyday life to having poor environmental cognitive abilities, so that people can easily think of situations in which these abilities have come into play. Given our results and the ease of administration of the SBSOD, we conclude that it can be a very useful instrument for predicting environmental spatial abilities.

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Appendix A

Items included in the 27-item scale in Study 1:

1. I am very good at giving directions.
2. I think it is important to find new routes in the environment.
3. I have a poor memory for where I left things.
4. I like to travel.
5. I am very good at judging distances.
6. My "sense of direction" is very poor.
7. I frequently choose to try new routes when I travel.
8. I do not like to explore.
9. I tend to think of my environment in terms of cardinal directions (N, S, E and W).
10. I very easily get lost in a new city.
11. I enjoy reading maps.
12. I am not very good at judging time.
13. I have trouble understanding directions.
14. I feel very anxious when I get lost.
15. I take shortcuts all of the time.
16. I very easily get lost in an unfamiliar building.
17. I do not confuse right and left much.
18. I am very good at reading maps.
19. I try to remember details of the landscape when traveling in a new area.
20. I do not remember routes very well when driving as a passenger in a car.
21. I do not enjoy giving directions.
22. I tend to think visually, with lots of mental images.
23. It is not important to me to know where I am.
24. I do not worry much about getting lost.
25. I usually let someone else do the navigational planning for long trips.
26. I can usually remember a new route after I have traveled it only once.
27. I do not have a very good "mental map" of my environment.

Appendix B. Santa Barbara Sense of Direction Scale

Sex: F M
Age:_______

Today's Date:_______________
V. 2

This questionnaire consists of several statements about your spatial and navigational abilities, preferences, and experiences. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle "1" if you strongly agree that the statement applies to you, "7" if you strongly disagree, or some number in between if your agreement is intermediate. Circle "4" if you neither agree nor disagree.

1. I am very good at giving directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

2. I have a poor memory for where I left things.

strongly agree 1 2 3 4 5 6 7 strongly disagree

3. I am very good at judging distances.

strongly agree 1 2 3 4 5 6 7 strongly disagree

4. My "sense of direction" is very good.

strongly agree 1 2 3 4 5 6 7 strongly disagree

5. I tend to think of my environment in terms of cardinal directions (N, S, E, W).

strongly agree 1 2 3 4 5 6 7 strongly disagree

6. I very easily get lost in a new city.

strongly agree 1 2 3 4 5 6 7 strongly disagree

7. I enjoy reading maps.
strongly agree 1 2 3 4 5 6 7 strongly disagree

8. I have trouble understanding directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

9. I am very good at reading maps.

strongly agree 1 2 3 4 5 6 7 strongly disagree

10. I don't remember routes very well while riding as a passenger in a car.

strongly agree 1 2 3 4 5 6 7 strongly disagree

11. I don't enjoy giving directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

12. It's not important to me to know where I am.

strongly agree 1 2 3 4 5 6 7 strongly disagree

13. I usually let someone else do the navigational planning for long trips.

strongly agree 1 2 3 4 5 6 7 strongly disagree

14. I can usually remember a new route after I have traveled it only once.

strongly agree 1 2 3 4 5 6 7 strongly disagree

15. I don't have a very good "mental map" of my environment.

strongly agree 1 2 3 4 5 6 7 strongly disagree

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