Title
Revisiting the Relationship between Allocentric-Heading Recall and Self-Reported Sense of Direction

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 34(34)

ISSN
1069-7977

Authors
Burte, Heather
Hegarty, Mary

Publication Date
2012

Peer reviewed

Revisiting the Relationship between Allocentric-Heading Recall and Self-Reported Sense of Direction

Heather Burte (Burte@psych.ucsb.edu)
Department of Psychology, UCSB
Santa Barbara, CA 93106 USA

Mary Hegarty (Hegarty@psych.ucsb.edu)
Department of Psychology, UCSB
Santa Barbara, CA 93106 USA

Abstract

Sense-of-direction (SOD) has been described as a system that tracks the body's facing direction relative to an environmental reference frame (allocentric heading). To study this system, Sholl, Kenny, and DellaPorta (2006) developed a heading-recall task and found that task accuracy correlated highly with self-reported SOD measures. This study attempts to replicate and extend their findings, by increasing task accuracy, and testing alternative hypotheses about factors that could affect task performance. In a heading-recall task, participants estimated allocentric heading from pictures of familiar locations on a college campus. Previous results were replicated, but a weaker relationship between SOD and performance, and a novel relationship between location familiarity and performance were found. These results provide support for a human allocentric heading system but suggest that self-reported SOD potentially measures a range of abilities and not solely the operation of this system.

Keywords: allocentric heading; sense of direction; spatial orientation; spatial memory; head-direction cells; heading-recall.

Introduction

In everyday situations, people describe their ability to accurately navigate through cities or neighborhoods using phrases like 'I have a great sense-of-direction' or 'I lack a sense-of-direction'. Kozlowski and Bryant (1977) transformed these colloquial assessments into a 7-point scale which assessed sense-of-direction (SOD). They found that these assessments were related pointing ability to familiar landmarks and updating one's location while traveling in an underground maze. Kozlowski and Bryant used a single item scale: "How good is your sense-of-direction?" Other researchers have measured SOD in a multi-faceted way. For example, the Santa Barbara Sense of Direction scale (SBSOD) is a 15-item scale that asks people about a variety of environmental tasks, such as giving directions and estimating distances, as well as their "sense-of-direction"(Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002). Hegarty et al. found that this measure of self-assessed SOD is related to several different environmental-scale tasks, including learning the layout of a new place, blindfolded updating, and pointing to familiar landmarks. These environmental-scale tasks require locomotion and integration from multiple viewpoints to acquire and access spatial knowledge. As such, the SBSOD scale was created around the idea that one's SOD is multi-faceted.

Recently, Sholl, Kenny, and DellaPorta (2006) proposed that SOD is single-faceted, and relates to the performance of a head-direction system in humans, similar to that found in animals. The head-direction system in rats was first discovered by Ranck (1984), who identified brain cells that fire when an animal's head is facing a specific direction. The directions that these cells respond to are not directions based on the axis of the body (also called egocentric headings). They respond to the angles between the forward axis of the body and a reference direction that is grounded in the environment (i.e. the animal's allocentric heading). An example of one allocentric reference system is the cardinal directions, but head-direction cells use the environment's intrinsic structure, not cardinal directions.

Sholl, et al.'s (2006) goal was to discover if humans have an allocentric-heading system that is functionally similar to the head-direction system of animals and to elucidate the functional architecture of this system, including its inputs, outputs, organization, representations, and computations. To accomplish that goal, they developed an allocentric-heading recall task in which students were shown a picture of a familiar landmark on their campus, and had to indicate the direction (with respect to the global environment) from which the photo was taken. They found that a person's current facing direction influences their accuracy and decision latency in recalling allocentric headings: when a person's facing direction matches the allocentric direction to be recalled, there is a facilitation effect; and, when the facing direction is 180º from the allocentric direction to be recalled, there is a detrimental effect. According to the author's, one's current body-direction signals interfere with retrieval of allocentric-headings being remembered from other locations, at which one's body-direction signals were different. These results would be predicted if the human allocentric-heading system works similarly to the animal head-direction system. Sholl et al. also found strong correlations between performance on the heading recall task and both Kozlowski & Bryant's (1977) single-item question (K&B) and the SBSOD. They proposed that SOD measures a single-faceted ability, which reflects the operation of a human head-direction system.

To expand upon Sholl et al.'s (2006) findings, the goal of this paper is to replicate Sholl et al.'s findings in a different location, test new hypotheses, and to provide further evidence on the single- or multi-faceted nature of what is measured by self-reported SOD measures.

Allocentric-Heading Recall and SOD

The heading-recall task used by Sholl et al. (2006) was a four-alternative, forced-choice task, using campus pictures as stimuli. The pictures were taken from magnetic north, east, south or west. Magnetic compass directions were used because the intrinsic structure of the Boston College campus is aligned as such (and will also be used in the following experiment as the UCSB campus is similarly aligned). However, while cardinal directions will be used for simplicity in writing this article, it should be noted that cardinal directions were never used in written or verbal instructions, as the task can be completed without using cardinal directions.

First, we will define key terminology used: picture heading is the photographer's orientation when taking the picture; default heading is the orientation of participant before each trial; response heading is the participant's response orientation that s/he moved to, decision latency is the participant's time to decide on a response heading and rotation time is the time taken to rotate from the default to the response heading.

In the heading-recall task, participants were asked to indicate picture heading by rotating in a chair. According to Sholl et al. (2006), when viewing a building, the allocentric-heading of that view is stored in memory and is linked to signals of body-direction. Upon seeing a picture of that building, a person recognizes the building, and then recalls the allocentric-heading from spatial memory. Therefore, participants can rotate in a chair to replicate the picture heading because they can compare their current body-direction to the body-direction signals from their memory and move to face the picture heading. The two main measures of this task were accuracy and decision latency. Participants responded more accurately and faster when the picture heading was consistent with their default heading; therefore, accuracy increased and decision latency decreased with increasing angular deviation between the default and picture heading.

Sholl et al. (2006) found that self-reported SOD was related to accuracy in the heading-recall task, especially at the extremes of the SOD scale, and concluded that SOD measures reflect people's awareness of their own allocentric-heading abilities. In their first experiment, accuracy in heading-recall was correlated .74 with the SBSOD and .68 with the K&B scale. However, the SOD scales were administered at the end of the study and so participants' self-assessed SOD ratings could have reflected an assessment of their performance on this task, rather than a more general assessment of their abilities (cf. Heth, Cornell, & Flood, 2002). Thus, the correlations might be inflated. In our study, participants completed the SOD scales before the heading-recall task.

Another concern is that some of Sholl et al.'s, (2006) participants performed very poorly on the heading-recall task, with only 18/40 participants in Experiment 1 and 10/19 participants in Experiment 2 surpassing a 50% accuracy rate. Low accuracy could reflect failure to understand the task, because the heading-recall task is abstract, unlike everyday directional tasks. In fact, Sholl et al. reported instructional difficulties. Thus, the high correlations with SOD measures may reflect the fact that those with poor SOD were unable to understand the task.

The goals of this study are (1) to replicate the results of the heading task in a new context, (2) to maximize accuracy, (3) to reassess the relationship between self-assessed SOD and allocentric-heading recall, and (4) to test two alternative hypotheses. First, this study serves to replicate the methods used by Sholl et al. (2006) and confirm that their experimental effects are robust with differing campus locations, target pictures and participants. Second, we attempt to maximize accuracy in the heading-recall task by offering more practice trials and feedback to participants in the instruction phase, to ensure that participants understood the task. Third, this study reassesses the relationship between SOD and heading-recall when measures of SOD are taken before the heading-recall task rather than after.

Fourth, two alternative hypotheses were tested. The first alternative hypothesis was that performance on the heading task would be correlated with familiarity. Sholl et al. (2006) found no correlations of performance on the heading recall task with familiarity of the landmarks or distance to target. They used landmarks that had been rated as highly familiar by other students, but did not assess familiarity in the context of their experiment. With regards to familiarity, if one must recognize the target before the allocentric-heading can be retrieved from memory, then familiarity might be related to performance on the heading-recall task. Other studies have found that familiarity predicted directional accuracy on a mental wayfinding task (Prestopnik & Roskos-Ewoldsen, 2000). Therefore, our experimental participants completed a familiarity rating task, to test the hypothesis that familiarity is related to accuracy and decision latency.

The second alternative hypothesis concerns unfamiliar targets or targets for which participants cannot retrieve an allocentric-heading straight from memory. In these cases, people might perform the heading task by imagining walking a route from the experiment location to the target location. In this case, target distance should be correlated with decision latency. This prediction is based on the assumption that mental route taking is an analog process similar to mental rotation (Shepard & Metzler, 1971). Just as participants take longer to mentally rotate with larger angles, so might participants take longer to calculate allocentric-heading with larger distances, if they use a mental walk strategy. Just and Carpenter (1985) found that participants with poor spatial abilities rotated at a slower rate than those with good spatial ability, so the relationship between distance and decision latency might be particularly strong for poor SOD participants. Sholl et al. (2006) failed to find correlations between objective distance and decision latency, but increasing the task understanding of poor SOD participants might reveal these participants' use of the "mental walk" strategy. Therefore, we tested the hypothesis that participants' estimated distances for each landmark would be related to decision latency on the heading-recall task.

Method

Pretesting of Stimuli Twenty students (8 males and 12 females) rated 124 photographs of the University of California, Santa Barbara (UCSB) campus for familiarity and confidence in knowing the location from which the photograph was taken. The photographs were taken from four different headings (facing north, south, east and west). On the basis of this pretesting, 40 photographs (10 from each heading) were selected for the main study. The selected photographs did not differ in familiarity or rated confidence of location across headings. The ratings of familiarity were similar to those reported by Sholl et al., (2006) with the grand mean for the forty photographs being 1.6 on a scale from 1 to 7 with 1 being "Very familiar" and 7 being "Very unfamiliar".

Participants Sixty-one students (29 males and 32 females) participated in the main experiment to fulfill a research participation requirement. Participants were required to have spent at least two full quarters on campus. Each participant was assigned to one of the default headings (N, S, E, or W).

Materials The experiment took place in a room on campus that was aligned with the main axes of the campus (and the cardinal directions). The experimental room had one west-facing window that was open during the experiment. The view directly out that window was of a courtyard and another large (three storey) adjacent building. However, if one stood next to the window, one could see the mountains and ocean (major orientation markers for the campus), and a few major buildings. Therefore, the window afforded excellent views for initial orientation to the campus (when standing by the window), but only basic information while participants were seated at a desk when completing the experimental tasks.

Markers on the floor denoted four cardinal directions (which were also the default and response headings). Experimenters arranged a swivel chair and desk towards the assigned default heading before the participant arrived. Assigned default headings are used to determine if a participant's actual heading differentially affected the retrieval of picture headings.

A trial started with viewing a photograph of campus on a computer. Participants determined the direction (with respect to the campus environment) in which the photographer stood when taking the photograph (i.e., picture heading) and turned in the chair to reproduce that orientation. For example, if the photograph was taken facing south, and the participant's default heading was facing north, the participant should turn 180º to face south. In addition to accuracy in completing this task, latency (time to complete the task) was recorded. Latency was recorded by computer and by the experimenter using a stop-watch, so that decision latency and rotation latency could be separately calculated. Both the computer and experimenter started timing when the picture was shown to the participant. The computer stopped timing when the participant indicated via a button press that s/he was about to turn (decision latency). Then the participant turned and indicated to the experimenter when s/he had finished rotating (total latency). The rotation latency was acquired by subtracting decision latency from the total latency. Participants were asked to rotate using the shortest angle.

Design. The methodology of the study was both experimental and correlational. The experimental factors were picture heading (within subjects) and default heading (between subjects). Participants were randomly assigned to one of the four default headings and completed forty trials, ten for each picture heading. Accuracy and latency were correlated with self-assessed SOD, average familiarity and accuracy of distance estimates.

Procedure Participants were introduced to the experiment, completed a demographics questionnaire, and completed the K&B and SBSOD rating scales. Next, participants were asked to orient to the layout of campus while looking out the window. The experimenter pointed to major points-of-reference (ocean and mountains) and then asked the participant to point towards four major campus buildings, to ensure that s/he was oriented to the global layout of the campus. The experimenter provided feedback, if needed, but most participants oriented and pointed correctly.

Participants were then introduced to the heading-recall task and presented with twelve practice trials in a fixed order. Participants were given feedback, and told the correct answer for any incorrectly answered trials. Next, the forty experimental trials were completed without feedback.

Afterwards, participants completed a distance estimation task, in which they estimated straight-line distances from their current location to the forty photograph locations, using a visually-presented standard unit (20 meters in length). Participants were given two practice distance estimation trials with correct answers provided as feedback. Then the task was completed for all forty photographs without feedback. Finally, participants rated their familiarity with each photograph location on a 7-point Likert scale.

The major procedural differences from Sholl et al. (2006) were that (1) more detailed instructions were provided, (2) more practice heading-recall trials were given, (3) the SOD scales were answered before the heading-recall task rather than after, and (4) distance estimation and familiarity tasks were used to test alternative hypotheses.

Results

Pretest and experimental photograph familiarity The familiarity ratings for pictures from the pretest and from the main experiment correlated significantly, r (38) = .63, p < .001. The mean familiarity in the main experiment was 2.3, which ranged from 1.1 to 3.9 across participants and from 1.1 to 5.3 across pictures. Even though there was a strong correlation between the two familiarity measures, participants in the main experiment rated some pictures as unfamiliar. Four pictures (three east facing and one north facing) had familiarity ratings that exceeded 2.5 *SD* above the mean familiarity and were removed from analyses.

Accuracy To aggregate across default-heading conditions, a new variable called heading disparity was created to denote the angle disparity between the default heading and the picture heading for the four different default headings. For example, if the picture heading is aligned with the default heading, then these responses would be labeled as 0º heading disparity. A 2 (Gender) X 4 repeated measures (Heading disparity: 0º, 90º, 180º, 270º) ANOVA comparing mean accuracy indicated a main effect of heading disparity, F (3,177) = 7.73, MSE = .22, p < .001. The mean correct proportions by heading disparity are shown in Figure 1. Post hoc tests revealed that the 180º condition was the least accurate, the 90º condition was less accurate than the 0º condition and the 270º condition was midway between 0º and 90º. This can be interpreted as an inhibitory effect of having one's body positioned 180º away from the response of one's head-direction system, and is predicted if the human head-direction system operates similarly to that of animals. There were no other main effects or interactions.

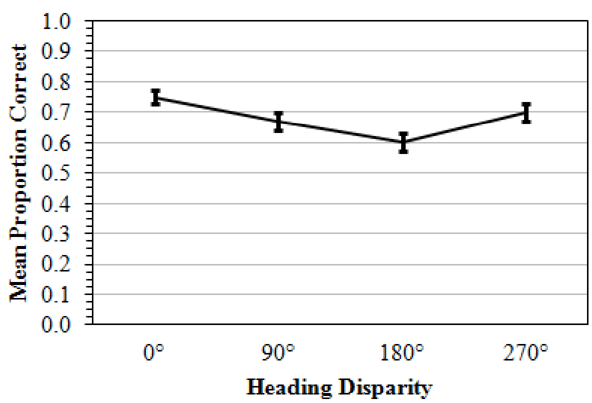

Figure 1: Mean accuracy rate as a function of heading disparity. Error bars are the standard errors of the mean.

To further examine the conditions that lead to the previous analysis, a 2 (Gender: male, female) X 4 (Default heading: N, E, S, W) X 4 repeated measures (Picture heading: N, E, S, W) ANOVA compared mean accuracy. A main effect of picture heading was found, F (3,159) = 20.62, MSE = .45, p < .001, with north-facing pictures (N = 78%) and west-facing pictures (N = 74%) having the highest accuracy, south (N = 66%) with moderate accuracy and east (N = 58%) with the lowest accuracy. The mean proportion correct by picture and default heading is shown in Figure 2. This main effect was qualified by an interaction of picture heading with default heading, F (9,159) = 3.44, MSE = .08, p = .001. Accuracy was highest when picture and default headings were aligned and lowest when the default and picture headings were misaligned by 180º. Supporting the previous analysis, these findings confirm our main finding that your current heading affects the accuracy with which you can recall allocentric-heading. Aligned headings are easier to recall and 180º unaligned heading are harder to recall. There were no other main effects or interactions.

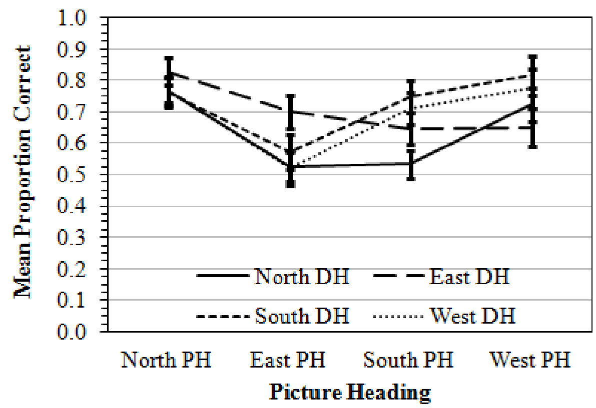

Figure 2: Mean accuracy rate as a function of picture heading (PH) and default heading (DH). Error bars are the standard errors of the mean.

However, there were some qualifications to this result, (1) with north picture headings there was no difference between default headings, and (2) west picture headings were highly accurate for north and south default headings. These finding might have been particular to the campus used as there are large global orientation cues, such as the local mountains when facing North and Isla Vista (an undergraduate housing area) when facing West. In debriefing, some participants reported using heuristics such as determining if the picture heading faced the mountains or Isla Vista.

Rotation time A one-way, repeated measures ANOVA investigated the effects of turn magnitude on rotation times. There was a significant linear trend, F(1,59) =145.23, MSE = 19.42, p < .001, with rotation times of 1.56, 2.10, and 2.36 seconds for rotations 0º, 90º and 180º, respectively. The magnitude of the turn accounted for 71.1% of the variability in turn time, indicating that decision latency was successfully separated from the time to physically turn.

Decision latency Outliers greater than 2.5 *SD* above each participant's mean correct decision latency (3.3% of trials) were recoded to the mean and participants with less than 50% accuracy on the direction task were removed from all decision latency analyses. This was done, as there would be too few decision times to provide a meaningful measure for these participants. Fifty of the 61 participants (82%, 26 male, 24 female) had more than 50% accuracy in the present experiment, in contrast with only 18 of 32 (56%) participants in Sholl et al.'s first experiment. Thus, performance was generally more accurate in the current study.

A 2 (Gender) X 4 repeated measures (Heading disparity: 0º, 90º, 180º, 270º) ANOVA indicated a marginal main effect of heading disparity, F (3,144) = 2.45, MSE = 7.71, p = .07. Post hoc tests revealed the 180º and 90º heading-disparity conditions had longer decision latencies than the 0º condition. While suggestive, this pattern is not exactly what is predicted by the animal model and it is only marginally significant, but interestingly, a similar pattern was observed by Sholl et al. It might be due to the specific environments used in both experiments. The mean decision latency as a function of heading disparity is shown in Figure 3.

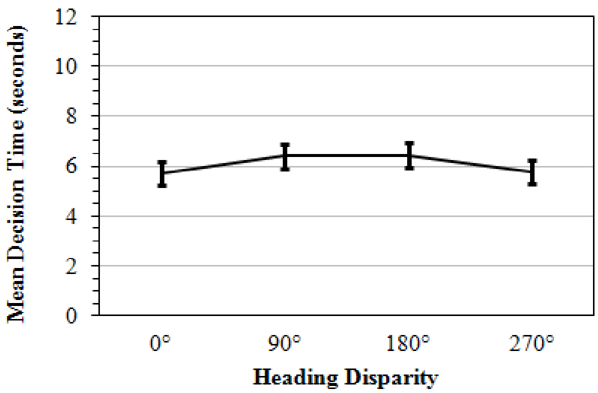

Figure 3: Mean decision latency as a function of heading disparity. Error bars are the standard errors of the mean.

Correlations with Self-Reported Sense of Direction The correlation between the two self-reported sense of direction measures was r (59) =.60, p < .001. Mean accuracy and mean correct decision latency were correlated with participants' SOD measures, as shown in Table 1. Both of the SOD measures were positively correlated with mean accuracy and negatively correlated with mean correct decision latency, as expected. However, the correlations were substantially lower than those found by Sholl et al. (2006), and were significant only for accuracy.

Photograph familiarity Significant correlations between participants' mean familiarity rating (averaged across the 36 pictures) and their mean accuracy on heading-recall were found, r (59) = -.40, p < .001, supporting our familiarity hypothesis. Therefore, as familiarity approaches 1 for 'very familiar', accuracy increases, however, there was no significant correlation between participants' familiarity and decision latency. Correlating mean familiarity per picture (averaged across individuals) with mean accuracy and decision latency per picture resulted in significant correlations (Table 2).

As seen in Table 1, SOD measures were negatively correlated with participants' mean ratings of familiarity of the landmarks, $r_{K\&B}$ (59) = -.34, p < .01, r_{SBSOD} (59) = -.27, p < .05, indicating that participants with good SOD rate their familiarity closer to 1 for 'Very familiar'. Furthermore, if one controls for mean landmark familiarity, correlations between accuracy and the SOD measures drop, to $r_{K\&B}$ (59) = .19, p = .14 and r_{SBSOD} (59) = .29, p < .05. In sum, the only significant correlation after controlling for familiarity is between accuracy and SBSOD. Therefore, the strong correlation between accuracy and SOD is partially due to high SOD participants being more familiar with the buildings shown in the pictures. In contrast with Sholl et al.'s conclusion that SOD reflects only ability to recall the allocentric heading of the picture, we have found that SOD is related to familiarity. Thus failure to recognize the locations from the pictures may be a source of error in this task.

Table 1: Mean Accuracy and Correct Decision Latency Correlations with Sense of Direction Ratings.

	Accuracy [a]	Decision Latency [b]	Familiarity [a]
K&B	.30*	-.13	-.34**
SBSOD	.37**	-.22	-.27*
Accuracy	--	-.03	-.40**
Familiarity	--	.02	--

* p-value < 0.05; ** p-value < 0.01;
[a] N = 61; [b] N = 50

Table 2: Correlations of Familiarity with Accuracy and Correct Decision Latency, with Participants and Pictures as the Unit of Analysis

	Accuracy [a]	Decision Latency [b]
Across participants	-.40**	.01
Across pictures	-.54**	.33*

* p-value < 0.05; ** p-value < 0.01; [a] N = 61; [b] N = 50 across participants; N = 34 across pictures

Distance Estimation To test our mental walk hypothesis, we correlated mean correct decision latency per picture (averaged across individuals) with participants' estimates of the distance to each picture location. The correlation was not significant, r (34) = .23, p = .17, providing no evidence for the mental walk hypothesis.

Discussion

Using a heading-recall task, we replicated Sholl et al.'s (2006) finding that individuals can recall allocentric-directional information from pictures and that their performance is related to SOD. We replicated their finding that the least accurate directional estimates come from heading disparities of 180º and that the longest decisions latencies come from heading disparities of 180º and 90º. These results provide support for the theory that humans have an allocentric-heading system similar to those found in animals. We also replicated a significant correlation between SOD measures and heading-recall measures. However, while our correlations reached significance, they were noticeably lower than those observed by Sholl et al. In addition, we found significant correlations between performance measures and familiarity that Sholl et al. did not find. But we failed to find support for our hypothesis that decision latency would be correlated with estimated distance.

We successfully replicated Sholl et al.'s experimental findings and were also successful in increasing the general accuracy level on the heading-recall task. Thus, people can be quite accurate in providing allocentric-heading for pictures, when adequate training and feedback are provided. Our results demonstrate that the effects replicate across campuses. However, our results also indicate that specific aspects of the local environment, such as the nearby mountain range, may also have affected the accessibility of the views. This study and Sholl et al.'s study were conducted on campuses with structures intrinsically aligned with magnetic compass directions. Using campuses with a less regular structure, or different allocentric reference systems for the pictures, would allow for further testing of the generality of these results.

Our study also attempted to replicate Sholl et al.'s high correlations between SOD measures and heading-recall performance. In contrast we found moderate significant correlations. There are two potential causes for the reduced correlations: administration of SOD measures before the heading-recall task and the increase in accuracy resulting from better instructions and additional practice trials.

With regards to our alternative hypotheses, the hypothesis that heading-recall performance measures would be correlated with familiarity found support. Since recognition is the likely first step in recalling an allocentric-heading, recognizing the view of the location is likely a first step in completing the task. It is possible that poor SOD individuals require more experience with locations than good SOD individuals to attain similar levels of recognition performance. Although Sholl et al. (2006) did not find effects of familiarity, they did not measure familiarity of their experimental participants and we found that the familiarity ratings from our pretest were not perfectly correlated with the familiarity ratings from our experimental participants. In summary, we found that significant correlations between accuracy and SOD are partially due to familiarity. In contrast to Sholl et al.'s conclusion that SOD reflects solely the ability to recall the allocentric heading of the picture, we found that SOD, familiarity and allocentric-heading accuracy are all related.

Our hypothesis that decision latency would be related to distance estimates was not supported. This suggests that people do not accomplish this task by imagining a mental walk to the locations in the pictures, or at least that this mental walk process is not an analog process. On the other hand, in debriefing interviews, many participants mentioned imagining how they would travel past the target location or extrapolating allocentric-heading from the direction of the target location. This, and the fact that global orienting cues (like the mountains) seem to have affected performance, suggests that there may be several strategies employed in this task.

In conclusion, this study has replicated the result that ability to judge the heading from which a picture was taken is related to one's current heading, and provides motivation for further studying the possibility of a human allocentric orientation (or head-direction) system. On the other hand, our results do not support the view that self-reported SOD measures simply reflect the operation of a human head-direction system. Previous studies have found that SOD measures are related to multiple spatial skills, including learning spatial layout and updating, and the correlations we observed between SOD and the heading recall task are similar in size (in the moderate range) to the correlations typically found with these other tasks. Thus it is likely that self-report SOD measures reflect a range of navigation abilities, not just the operation of a head-direction system, and future studies of this system should rely on objective measures of performance, such as the heading-recall task, rather than relying on self-reports as a measure of a human allocentric heading (or head-direction) system.

References

Bryant, J. K. (1982). Personality correlates of sense of direction and geographic orientation. *Journal of Personality and Social Psychology, 43,* 1318-1324.

Hegarty, M., Richardson, A. E., Montello, D. R., Lovelace, K., & Subbiah, I. (2002). Development of a self-report measure of environmental spatial ability. *Intelligence, 30,* 425-447.

Heth, C. D., Cornell, E. H., & Flood, T. L. (2002). Self-ratings of sense of direction and route reversal performance. *Applied Cognitive Psychology, 16*, 309-324.

Just, M. A., & Carpenter, P. A. (1985). Cognitive coordinate systems: Accounts of mental rotation and individual differences in spatial ability. *Psychological Review, 92*(2), 137-172.

Kozlowski, L. T. & Bryant, K. J. (1977). Sense of direction, spatial orientation, and cognitive maps. *Journal of Experimental Psychology: Human Perception and Performance, 3,* 590-598.

Prestopnik, J. L., & Roskos-Ewoldsen, B. (2000). The relations among wayfinding strategy use, sense of direction, sex, familiarity, and wayfinding ability. *Journal of Environmental Psychology, 20*(2), 177-191.

Ranck, J. B., Jr. (1984). Head-direction cells in the deep cell layers of dorsal presubiculum in freely moving rats. *Society of Neuroscience Abstracts, 10*, 599.

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science, 171*, 701-703.

Sholl, M. J., Kenny, R. J., & DellaPorta, K. A. (2006). Allocentric-heading recall and its relation to self-reported sense-of-direction. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*(3), 516-533.