Relating Local to Global Spatial Knowledge: Heuristic Influence of Local Features on Direction Estimates

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ABSTRACT

Previous research has examined heuristics—simplified decision-making rules-of-thumb—for geospatial reasoning. This study examined at two locations the influence of beliefs about local coastline orientation on estimated directions to local and distant places; estimates were made immediately or after fifteen seconds. This study goes beyond well-known effects of alignment, rotation, and orthogonalization. Although residents at both locations widely assume a north–south coastline with ocean lying to the west, it actually runs east–west at the second location with ocean to the south. This created constant errors from the second location not seen from the first. Response delay had very little effect.

Key Words: *cognitive map, spatial knowledge, direction judgments, decision heuristics*

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INTRODUCTION

Knowledge of directions helps people plan spatial activities, navigate efficiently, and assist others in finding their way. People who do not know the direction to their intended destination risk becoming lost, especially if they encounter something unexpected along their travel, such as a detour. For larger areas (smaller cartographic scales), knowledge of directions between places is not as necessary for orientation (Montello 1993), but it still helps in activity planning and is widely considered part of basic geographic knowledge. Having an idea of the directions between places does not mean that idea is correct, however. Someone might be extremely confident that the next town down the road lies to the south when it is actually to the east. This confusion might cause the person difficulty, if, say, he or she orients according to cardinal directions when navigating.

When we have no access to a cartographic map and have to navigate using only our perceptions and our stored spatial knowledge (our cognitive map), what influences our beliefs about directions? This study explored some ways that the local surrounds influence our estimates of directions to places, at various scales from the local to the global, and whether time pressure to answer quickly brings these influences out even more. The study did this by looking at the spatial patterns of constant and variable errors in indicating directions to various targets nearby and far away under two conditions of time pressure. It also compared responses from groups of respondents located in two different places near the coast of California, one on a coastline running nearly north–south and one on a coastline running east–west. The coastline near the first location is aligned with the general orientation of California's Pacific coast, with the ocean to the west, and nearly aligned with the common map orientation in our culture of north–south running vertically. The coastline near the second location stands in stark contrast with most of California's coastline and the typical assumption of that coastline's orientation and the direction to the ocean; it also deviates from the common north-up map orientation.

Being accurate at estimating directions to places depends on the accuracy of two aspects of cognition: accurately knowing the relative locations of places (that is, having an accurate cognitive map), and accurately knowing one's location and heading at the occasion when directions are estimated (that is, having an accurate sense of self-orientation). People can have equivalent knowledge of locations (the first aspect) but differ in expressing that knowledge because of differences in their sense of orientation (the second aspect).

Our study concerned methods and strategies people employ to reason about directions, including the simplified decision-making rules-of-thumb known as heuristics. Past studies have investigated the use of heuristics in geographic spatial thinking. Probably most well known is one by Stevens and Coupe (1978) on the hierarchical reasoning heuristic, by which people recall the relative locations of places by referring to their understanding of the relative locations of the larger (superordinate) spatial units to which those places belong. Their best known example was people's common belief that the city of San Diego is west of the city of Reno (it is east) because, according to Stevens and Coupe, California is mostly west of Nevada.

Tversky (1981) built on the research of Stevens and Coupe by demonstrating the use of two additional heuristics. She referred to the alignment heuristic as people's tendency to infer spatial relationships by assuming (often incorrectly) that geographic units are spatially aligned with each other along vertical and horizontal axes within the graphic space of maps. For instance, the belief that North and South America are aligned along a north–south axis would explain why people often mistakenly think Lima, Peru, lies to the west of Miami. Her second heuristic, the rotation heuristic, refers to people's tendency to infer spatial relationships by assuming (again, often falsely) that the axis of a geographic feature such as a landmass matches that of a surrounding frame of reference, frequently the cardinal directions or a larger feature. For example, since people tend to mentally rotate the axes of San Francisco Bay to coincide with north–south, they often incorrectly report that Berkeley, California, is east of Palo Alto, California. Similarly, Shelton and McNamara (2001) found a preference for views aligned with salient axes in the environment due to the "naturalness of organization" provided by such views.

Glicksohn (1994) replicated the existence of Tversky's rotation heuristic by testing Israeli subjects making judgments about the relative directions between Israeli cities, finding that most respondents internally rotated the country's Mediterranean coastline fifteen degrees counterclockwise, mistakenly imagining the coast to run due north–south. Mark (1992, 316) reported distorted judgments of latitudes for world cities, consistent with the alignment heuristic, but pointed out that other heuristics could also contribute to some of the distorted judgments. For instance, many people think Rome, Italy, is south of New York City, even though it lies slightly north, perhaps in part because Rome enjoys a warmer and sunnier climate than New York City does. Mark observed that people use decision-making heuristics about geographic knowledge because they often lack "access to accurate direct configurational ['map-like'] knowledge of either relative or absolute locations of cities" and so must infer them with heuristics.

Consistent with Mark's proposal, the extensive research program of Friedman and her colleagues (Friedman and Brown 2000; Friedman, Kerkman, and Brown 2002; Friedman 2009) has shown that many cases of distorted latitude and longitude estimates are more conceptual than perceptual in origin. Their plausible-reasoning approach states that estimates will be based on a combination of multiple types of relevant knowledge, including prior beliefs, new information, and the context of the task. This knowledge, in turn, is used by people to organize Earth's surface into regions, which act as heuristics for reasoning about city locations (Friedman and Brown memorably referred to "psychological plate tectonics"). Thus, people tend to assume that Canadian cities (such as Edmonton and Toronto) are more nearly the same latitude than is true, that northern cities in the conterminous United States (such as Seattle and Boston) are similarly more nearly the same latitude than is true, and that Canadian cities are farther north of the northern U.S. cities than is true.

Portugali and Omer (2003) proposed another explanation for the distortions in recalled city locations believed to be caused by the hierarchy and rotation heuristics. Their study suggested that an "edge effect" influenced people's judgment of spatial relationships, causing them to correctly identify the relative locations of cities common to an edge feature such as a coastline while leading them to inaccurately estimate the relative locations of cities that do not both occupy a position along the edge. For instance, subjects accurately determined the direction to Tel Aviv from Haifa because both cities are situated along Israel's Mediterranean coast, but erred when estimating the direction to Jerusalem from Haifa since the former is inland of the coastline edge. Without being anchored to the legible coastline, as Haifa and Tel Aviv are, Jerusalem is left as a "floating point" in the interior. Furthermore, these authors proposed that direction judgments to Jerusalem will be further distorted because as the coast runs south, it bends westward increasingly, biasing mental conceptions of city locations even more. We note that the well-known error Stevens and Coupe (1978) discussed of mislocating Reno relative to San Diego probably relates not just to hierarchical reasoning but to a tendency people likely have to straighten the coastline of California, which actually curves far eastward as it goes south (this curve features prominently in the study we report here).

Another body of research has investigated the heuristics people apply specifically to judge directions between places. Distortions in directional knowledge have been conjectured since at least Griffin (1948, 381), who conjectured that people would tend "to show most turns as right angles." Milgram and Jodelet (1976) noted that people tended to straighten the Seine River when sketching maps of Paris (see also Byrne 1979). Tversky's (1981) work posited that the rotation heuristic will lead people to recall city streets as more nearly aligned with dominant features or the cardinal directions than is true. This causes people to distort directions toward right or straight angles. Moar and Bower (1983) also reported that people estimating directions within a town distorted their estimates toward 90°, so that the sum of three such directions forming the vertices of a triangle added to considerably more than 180°. Sadalla and Montello (1989) showed that vision-restricted people walking pathways in a large laboratory room recalled path turns that were nearly straight or at right angles more accurately than turns that were oblique (diagonal).

Montello (1991, 65) followed up on this work within a street network in a student neighborhood next to the Arizona State University campus. He stopped passersby at one of three locations in this neighborhood, two on oblique streets that violated the dominant cardinal-aligned street grid pattern and one on an orthogonal street consistent with the dominant cardinal-aligned street grid. Respondents used a circular pointing device to estimate directions to three local features and two cardinal directions. Directional errors were greater on the two oblique streets, as predicted. He explained these results as due to the difficulty when traveling on oblique routes in keeping "the orthogonal, body-centered axes used to organize surrounding spatial knowledge coordinated with the orthogonal axes determined by local features or global frames," like the cardinal directions.

Interestingly, Montello (1991) also found that directional estimates were made more slowly at only one of the oblique street locations. They were made just as quickly on the other oblique street as on the orthogonal street. It was determined subsequently that this fast oblique street was actually the busiest of the three streets and the most familiar of the three to respondents. Thus, respondents on this oblique street were just as quick to access their directional knowledge as on the orthogonal street but were just as inaccurate as on the less familiar oblique street. This finding leads one to question how time pressure might influence people's expressions of directional knowledge. If people have less accurate knowledge, will they necessarily have slower cognitive access to that knowledge? If so, forcing them to answer more quickly should cause them to be even less accurate. In contrast, people with less accurate knowledge may feel they know the directions just as well and will access that (mistaken) knowledge just as quickly as people with more accurate knowledge. If so, forcing them to answer more quickly should not affect their response accuracy.

MEASURING AND ANALYZING DIRECTIONAL KNOWLEDGE

Several studies have addressed how best to measure people's knowledge of directions in the environment (Attneave and Pierce 1978; Waller, Beall, and Loomis 2004). Haber *et al.* (1993) compared different methods in a task in which blind adults indicated directions to several surrounding targets specified by sound. They found that methods with the greatest accuracy and lowest variability involved pointing with body parts (such as with an outstretched arm and finger) and extensions of body parts (holding a stick with an outstretched arm). These were modestly, although significantly, better than pointing with a circular dial or drawing directional vectors.

Montello *et al.* (1999) approached the issue by comparing two prominent methods of estimating directions by manually rotating a radius wire on a circular dial or turning one's body while standing to face in the desired direction. They specifically decomposed directional judgments into variable and constant errors. *Variable errors* are the absolute values of the differences between each directional judgment and the mean estimated direction to a particular target across all judgments. Averaged over estimation trials, variable error assesses the unsystematic error of judgment, indicating the variability or, conversely, the consensus of directional judgments. *Constant errors* are the signed (directional) differences between each directional judgment and the correct value to a particular target. Averaged over estimation trials, constant error assesses the systematic error of judgment, indicating bias in one direction or another (i.e., estimated directions clockwise or counterclockwise of the correct direction). Together, variable and constant errors decompose the information contained in absolute errors, which are frequently used in research on directional knowledge (Schutz 1979). *Absolute errors* are the absolute values of the differences between each directional judgment and the correct value to a particular target. Averaged over estimation trials, absolute error assesses the average error of judgment, reflecting both unsystematic and systematic sources of error. In the present study, we analyze our directional data in terms of variable and constant errors, although for some purposes, absolute error is an informative way to analyze directional data (e.g., for quantifying a person's average directional accuracy across trials).

Examining research participants' pointing judgments, Montello *et al.* (1999) found that manually pointing with a dial led to somewhat greater variable error in performance, while turning one's body yielded greater constant error. They concluded that the two methods "produce evidence of different organizational frameworks for egocentric spatial knowledge." In light of this, we had research participants in this study judge directions by both turning their bodies and pointing with a circular dial in hopes of exploiting the values of both methods.

We also note that constant errors in directions are inherently circular variables, not linear; as judgments change angles in a particular direction (such as clockwise), one eventually comes around to the direction from which one started. That is, directions form a circle around an origin or base point. If one computed a standard arithmetic mean of the two vectors 5° and 355°, for example, the result would be 180°, even though it is evident that 0° is the value that accurately reflects the central tendency of the two directions. Although the vectors could be transformed in this example (e.g., by recoding 355° as -5°), such an approach would not be generally applicable and is not exactly correct in all cases. Determining the mean direction of a set of estimates (called *phi*) properly entails the use of *circular statistics* (Batschelet 1981; Mardia and Jupp 2000). Briefly, circular statistics average directions by decomposing each judgment into its sine and cosine values (x and y values, equivalent to longitude and latitude in our data), averaging them separately, and then transforming them back into a single vector. It is worth noting that both variable and absolute errors are linear variables, although the correct calculation of variable errors does require using circular statistics to properly calculate phi, the mean direction. In the study below, we use circular statistics to calculate mean directions.

STUDY

Our review above indicates that there are several possible heuristics people might use to judge directions to places on Earth's surface when they do not have exact locations stored in memory, including hierarchical reasoning, alignment, rotation, plausible-reasoning (including nonspatial factors such as climate), regionalization, edge effects, and orthogonalization. In this study we looked for a different pattern of distorted spatial estimates to support the operation of heuristic assumptions about geographic spatial layout. We investigated not a tendency to straighten, align, or make into a right angle, but a tendency to assume that the adjacent coastline runs north–south when it actually runs east–west, and thereby assume that the ocean itself lies to the west when it is actually to the south. We looked for these patterns by comparing constant and variable errors of directional judgments made from two testing sites. Almost all previous work on this issue has focused on comparing answers to different target locations, for instance, estimating directions to a place in one region as compared to a place in another region. In contrast, our experiment compared answers given to the same targets from two different testing sites, allowing us to investigate how the local geographic surrounds of the base relates to people's understanding of their spatial relationships to other places, both nearby and distant. Also unlike most previous studies on geographic spatial heuristics, we tested participants' knowledge in situ rather than in a lab room, meaning that they were not removed from their surrounding environment. We did this so our participants would have good visual access to the surroundings in a way that would likely help them establish their orientation, without giving them visual access to the coast or ocean. We asked them to indicate directions from their current location and heading to local and distant places around the globe.

Two California university campuses, California Polytechnic State University in San Luis Obispo (Cal Poly) and the University of California, Santa Barbara (UCSB), served as the locations for our testing sites. The campuses are situated about 120 km (75 miles) apart, and both lie near a common edge feature—the Pacific coast (UCSB is on the shoreline and Cal Poly is about 15 km (9 miles) from the ocean). However, this coastline makes an abrupt turn of approximately 90° halfway between these two locations, potentially turning what would otherwise be a reliable line of reference into a source of confusion and error (see Fig. 1). Such confusion likely arises because many people tend to believe that the Pacific coast of the United States runs consistently north–south when it in fact runs predominantly east–west for a good portion of its length in Southern California (including the entire south coast of Santa Barbara County). We believe this confuses people in and around the city of Santa Barbara (including the campus of UCSB) with respect to directional orientation. Someone asked to point west, for instance, may wrongly point south toward the ocean, thrown off by the turn in the primary edge feature. People in San Luis Obispo, including at Cal Poly, would not experience this problem, as the Pacific coast does run primarily north–south near that city. Alternatively, people at Cal Poly may be less likely than people at UCSB to use the coastline as a basis for spatial heuristics, because it is not immediately adjacent to the campus, but we would still not expect them to show the biasing effects of an east–west coastline that people at UCSB might show. This led us to predict that our study participants pointing from Cal Poly would show smaller constant errors than those pointing from UCSB. However, we think most people are unaware of their confusion at the UCSB location, so we did not necessarily anticipate greater variable errors from there. We asked participants at both testing sites to point to various target locations, both nearby and distant. This allowed us to investigate how the spatial layout of the local surroundings relates to people's understanding of their spatial relations to both local and global geography.

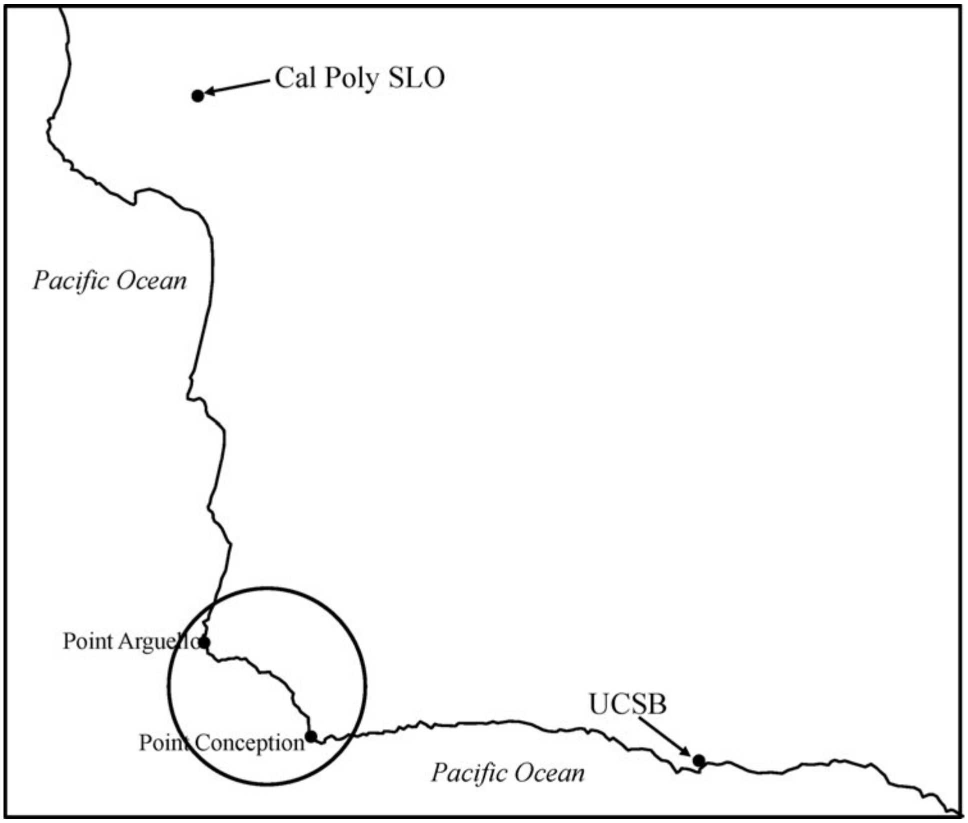

Figure 1. Schematic map of the testing site campuses and coastline in the study area. The 90° bend in the coastline at Points Arguello and Conception is circled. (Redrawn from Google Maps image.)

In our study we also manipulated how much time participants at each site had to indicate directions; half were asked to respond essentially immediately and the other half after a short delay. We expected participants given a delay would indicate directions more accurately. But if participants at UCSB were largely unaware of their mistaken orientation, providing additional time to respond should not have reduced their constant errors much.

METHODS

Design

The study tested two factors. The first was the testing site on the Cal Poly campus or the UCSB campus. This factor was varied between-case, with different participants at each location. The second was time given to answer, also varied between-case. About half of the participants were required to judge directions almost immediately on hearing the target location (the 5-sec. condition); the other half were asked to wait for a brief delay (the 15-sec. condition). Participants were alternately assigned to one or the other time condition when they were tested.

Participants

Two samples of college students participated in the study, one at Cal Poly and the other at UCSB. We solicited participants by stopping students walking past our testing sites at both campuses. We asked everyone who walked by alone if they had five minutes to spare to participate in "a study on people's directional knowledge"; we also avoided asking people who were on a phone or appeared to be in a hurry. In order to obtain more homogenous samples and avoid the extra noise and possible confounding of using more diverse samples at the two locations, we also avoided people who appeared to be staff or faculty. Forty students participated in the study at each campus, for a total of eighty participants; this represented about a 50 percent participation rate for those asked. Participants at each testing site were nearly exactly balanced for sex and time condition: Cal Poly had twenty-one males, eleven in the 5-sec. and ten in the 15-sec. condition, and nineteen females, ten in the 5-sec. and nine in the 15-sec. condition. Participants at UCSB included twenty-two males, eleven in each of the two time conditions, and eighteen females, nine in each of the two time conditions. Sixty-five of the eighty participants were undergraduates in their second, third, or fourth year of schooling, with the remainder being freshmen or graduate students. Also, the vast majority reported a California city as their hometown, with only eight having come from outside the state. However, most students were not from Santa Barbara or San Luis Obispo.

Materials

The locations at which participants were tested were in high traffic areas near the centers of the campuses. As we stated above, neither afforded views of the coast or ocean, although both otherwise had good visual access to the surroundings. A circular trash can with a circular cardboard cutout attached to it served to measure directional judgments; the circular device ensured that no alignment or orthogonal biases would operate in participants' visual field. The cutout had a stiff metal wire attached at the center that rotated around the circle; participants rotated this radius wire to indicate directions. Numerals from 1 to 72 lined the rim of the circle, allowing us to observe and record directions at a resolution of 5°; these numerals were scrambled, however, so they provided participants no clues to directions. In addition, we used a stopwatch to measure time for the delay condition.

Each participant pointed to fourteen different targets, none of which was visible from the study area. The targets progressively increased in distance from the study area throughout the course of the test. Participants were asked to point to the campus library of their respective campus and the downtown district of their respective city in order to test their knowledge of local geography. They also pointed to the campus site of the other study location, as well as to the cities of Los Angeles and San Francisco, to test their spatial grasp of the state of California. Then they pointed to Miami, Honolulu, and New York, familiar U.S. cities that are spread out from one another in direction but are not along the west coast of North America. After that, they pointed to Tokyo, London, Rio de Janeiro, and Sydney, familiar and prominent international cities that are spread out both in terms of direction and distance. Finally, participants pointed to the cardinal directions of north and west.

Procedure

After students were stopped and agreed to participate, we explained and demonstrated the procedure for the study and pointing response. We told them to show us the directions to particular places as they were named, making their best guess if they were not sure, by walking around the trashcan until they faced the direction they believed was correct and then using the radius wire to point in that direction. The dial was always aligned with the value of '57' pointing due north, so as to ensure correct measurement (although participants were not informed that '57' indicated north), but the position and facing direction of the participant at the start of each trial, as well as the initial pointing direction of the radius wire, were not controlled. In the 5-sec. condition, participants were told to "respond as quickly as possible, taking no more than five seconds." In the 15-sec. condition, they were told to "wait to respond until you have thought about it carefully; do not point until after I tell you that fifteen seconds have passed." After participants pointed to a target, we recorded the numeral nearest to their answer (i.e., the closest angle at a resolution of 5°). Each participant responded to all fourteen targets in the same fixed order of increasing distance from the testing location. After all targets were pointed to, participants gave their year of school and hometown.

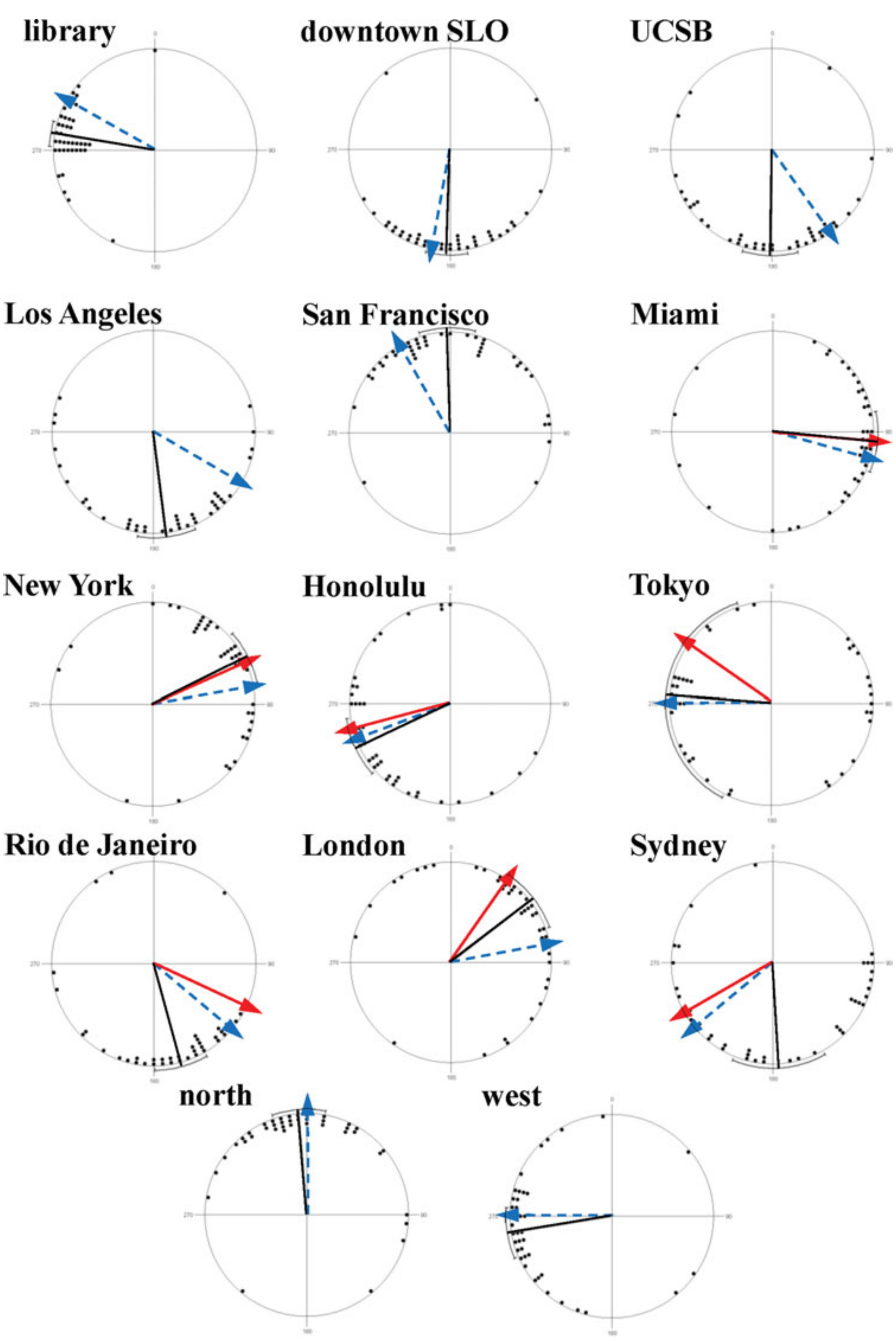

Figure 2. Circular graphs of raw pointing estimates for each target from Cal Poly. Each dot is one participant's answer. The solid black line shows the mean estimate (phi) and its 95 percent confidence interval. The dashed blue vector indicates the correct direction along a rhumb line; the solid red vector indicates the correct direction along a great circle (great circle not shown at shorter distances or for cardinal directions). North is straight up for each circle.

RESULTS

Our analysis strategy was first to examine patterns of constant errors (bias) in pointing to each target from each testing site. After constant errors, we examined patterns of variable errors (noise) in pointing to each target from each testing site. We additionally investigated whether these patterns in constant and variable errors differed as a function of time condition. With both constant and variable errors, we considered whether error increased with increasing distance of the target location from the testing site. Figure 2 shows circular graphs of the raw pointing estimates for each target from the Cal Poly site; Figure 3 shows them from UCSB.

Constant Errors

Phi values (mean estimated directions) are shown in Figures 2 and 3, as are the actual directions to targets. As explained in our section on circular statistics in the introduction, a standard arithmetic mean of vectors expressed from 0° to 360° would not produce the correct mean direction of all the vectors (Batschelet 1981; Mardia and Jupp 2000). Instead, the individual vectors are decomposed into x and y values, averaged, and then converted back into a mean vector direction expressed in degrees. The difference between the mean vector (phi) and the actual vector to the target is the constant error for that target, and the spread of estimates around phi suggests the magnitude of variable error (a measure of variability around the mean).

We defined actual directions to targets as rhumb lines, measured from a conformal map projection, which preserves angles locally. This is not the only way to define actual directions. We could also define them to follow the shortest path between points, which is the great circle (geodesic). The valid choice would be whichever corresponds better to the way people organize their spatial understanding of

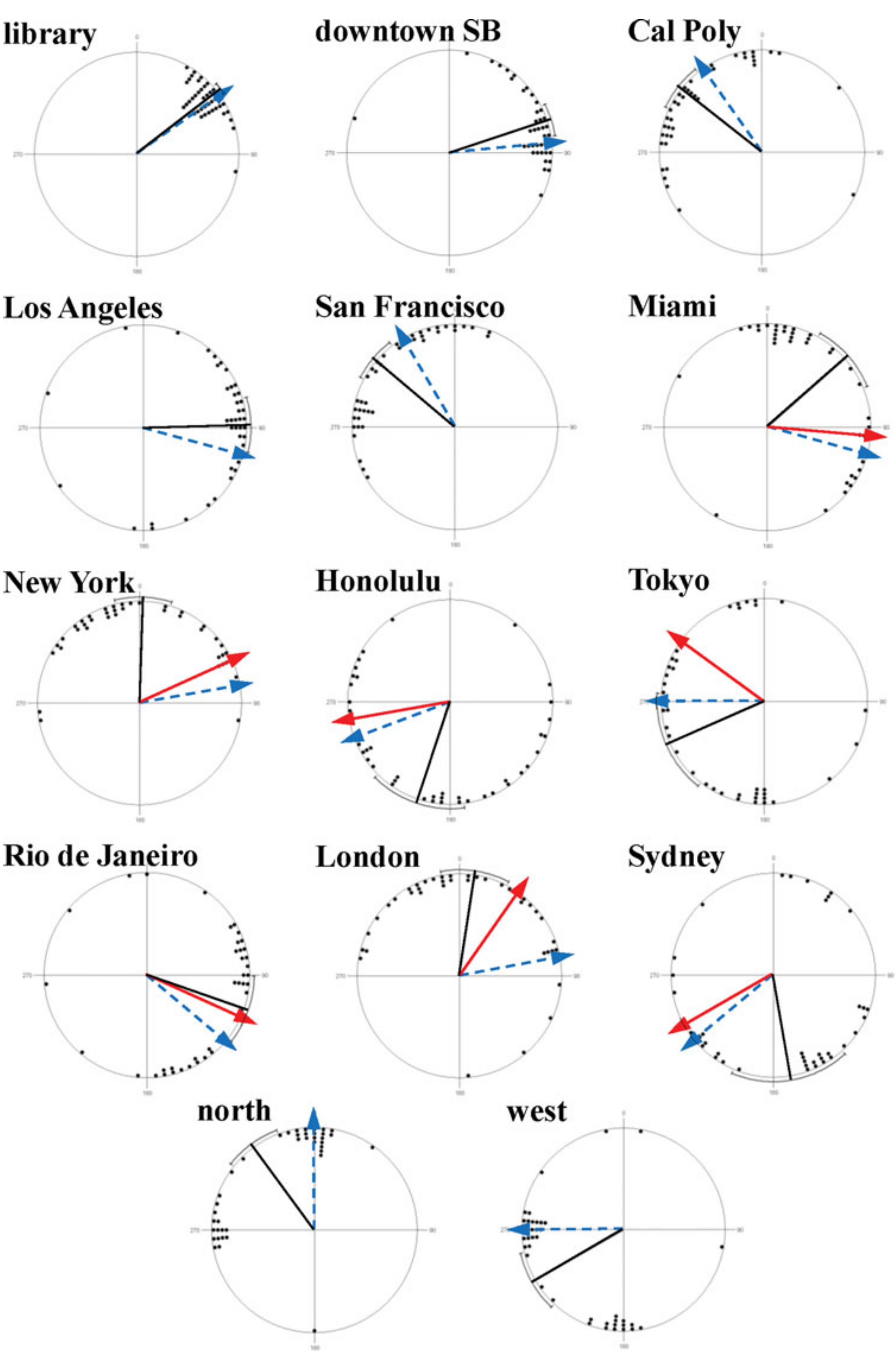

Figure 3. Circular graphs of raw pointing estimates for each target from UCSB. Each dot is one participant's answer. The solid black line shows the mean estimate (phi) and its 95 percent confidence interval; the dashed blue vector indicates the correct direction along a rhumb line; the solid red vector indicates the correct direction along a great circle (great circle not shown at shorter distances or for cardinal directions). North is straight up for each circle.

Earth's surface and reason about directions along its surface. Do they point along rhumb lines, imagining the world according to a rectangular projection such as Mercator? Or do they point along the great circle line, imagining the world in its true near-spherical form? Of course, the distinction is unimportant at short distances, where the two do not appreciably differ, and is not a factor with the cardinal directions. In interpreting our results below, we take the rhumb line bearings as correct, assuming that most of our participants are more accustomed to seeing flat projections than spherical globes and otherwise tend to think of Earth naively as being flat (see Egenhofer and Mark 1995). But we recognize it is ambiguous to interpret our mean estimates as right or wrong in terms of absolute magnitudes, given that the correct answer is ambiguous. To allow the reader to compare the two approaches, we depict rhumb line directions as dashed blue vectors in Figures 2 and 3, and great circle directions as solid red vectors (only for the trials where they can be uniquely defined and differ appreciably from the rhumb lines). We return to this issue in the discussion section.

Before comparing mean directions to actual directions, we established for each target whether the estimates were more concentrated around any single direction than would be expected by chance if the estimates were randomly sampled from a population distributed uniformly around 360°; if the estimates were nonuniform, they would generally be concentrated around phi. This question is addressed by circular statistics with Rayleigh's Uniformity Test (Mardia and Jupp 2000). From Cal Poly, estimates to all targets were significantly concentrated at $p < 0.05$, except the estimates to Tokyo ($Z = 1.39$, $p = 0.25$). From UCSB, estimates to all targets were significantly concentrated at $p < 0.05$.

Given that estimates to nearly all targets concentrated significantly in a single direction, we next asked whether those directions were the correct directions to the targets (with the caveat given above), allowing for random sampling fluctuation, or whether those directions significantly deviated from correct. This was addressed by examining the circular graphs in Figures 2 and 3, which also graphically depict the 95 percent confidence interval for each target's phi. As long as the estimates were significantly concentrated around phi, we could conclude that phi significantly deviated from the correct direction when the latter fell outside the 95 percent confidence interval. In fact, from Cal Poly, phi significantly deviated from correct for eight of the thirteen targets for which there was significant concentration. There did not appear to be any general pattern here, as targets at all scales were pointed to with significant bias. However, both cardinal directions were pointed to without significant bias. Furthermore, whether significantly different than the correct values or not, nine targets had phi values counterclockwise of the correct directions and five had values clockwise. When the directional magnitudes of all constant errors were added, the net constant error across all targets was just 1° clockwise. We also looked for any relationship between the magnitude of constant errors (regardless of direction) and the distance of the target from the testing site (which is undefined for the two cardinal directions). This correlation was only 0.16, suggesting very little relationship.

Pointing estimates from UCSB proved more heavily biased, as phi significantly deviated from the correct direction for all but two of the fourteen targets (and estimates were significantly concentrated for all targets). Only the closest target, the campus library, and one of the distant targets, Tokyo, were pointed to without significant bias (although estimates to Tokyo did have large variation, there was significant concentration around phi, unlike from Cal Poly). So biased pointing occurred mostly at all scales and included the two cardinal directions. In contrast with Cal Poly, the testing at UCSB demonstrated a clear pattern of constant errors: Phi for all fourteen targets fell counterclockwise of the correct directions, with a net constant error across all targets of a substantial 497° counterclockwise (35.5° per target). Also unlike estimates from Cal Poly, the magnitudes of constant errors in pointing from UCSB did correlate with the distance of the target. In this case, the correlation was 0.50, suggesting a moderately strong relationship ($p < 0.05$ for the one-tailed test).

Focusing on the estimates to the two cardinal directions shown in Figures 2 and 3 provides clear evidence consistent with a biasing effect of the local coastline from UCSB but not Cal Poly. When pointing north, thirteen participants from UCSB pointed due west ±10°; only one from Cal Poly pointed nearly west, and no Cal Poly estimates clustered around any other value besides north. Similarly, when pointing west, twelve participants from UCSB pointed due south ±10°; none from Cal Poly did so, and again, no Cal Poly estimates clustered around any other value besides west. Furthermore, of the thirteen UCSB participants who pointed west when attempting to point north, all but one pointed south when attempting to point west. That is, the same participants who were off by 90° on one cardinal direction were off by 90° on the other cardinal direction, supporting the existence of a consistent constant error in their orientation that can be explained by the counterintuitive coastline operating as a heuristic for orientation.

Next we examined whether these patterns of constant errors varied as a function of whether participants pointed within 5 or 15 secs. In circular statistics, the Watson-Williams F-test compares the mean directions of two independent samples (Batschelet 1981). Phi for several of the targets from Cal Poly was significantly different at $p < 0.05$ in the 5- and 15-sec. groups, including estimates to the UCSB campus, Los Angeles, San Francisco, Miami, New York, London, and north. Estimates made quickly, after 5 secs., were more accurate for the first three targets in this list, which are all located in California. Estimates made slowly, after 15 secs., were more accurate for New York and London. Estimates to Miami and north were about equally inaccurate in both time conditions, although in opposite directions from the correct directions. In contrast, no phi values for any targets from UCSB were significantly different at $p < 0.05$ for the 5- and 15-sec. groups (all ps > 0.18).

Variable Errors

Phi values show a group of participants' systematic bias, if any, to point clockwise or counterclockwise of the correct directions to targets, that is, constant error. We next examined the spread of estimates around phi as a measure of unsystematic error, or noise, around the average directions, that is, variable error. We calculated variable error as the mean of the absolute value of the difference between each estimate and that target's phi value across participants, for all estimates within a particular condition (e.g., all estimates to Tokyo made from Cal Poly after 5 secs.). This measure of variability is commonly known in standard linear statistics as the mean deviation.

Table 1 presents the patterns of variable errors in pointing to the fourteen targets from the two testing sites and in the two time conditions. To test the significance of these patterns, we used the multivariate approach to repeated measures to conduct a mixed ANOVA on the variable errors, with testing site and time condition as between-case factors, and target as within-case (that is, participants pointed either from Cal Poly or UCSB, and after 5 secs. or 15 secs., but all pointed to all fourteen targets). Test results for all effects are listed in Table 2. As is customary, we looked first at the three-way interaction of location, time, and target, which was not significant at the 0.05 level. We then considered the three two-way interaction effects. The pattern of variable errors across the targets did not differ significantly at the two testing sites, nor did the pattern of variable errors across the two time conditions differ at the two testing sites. However, the pattern of variable

Table 1. Patterns of variable errors in pointing to the fourteen targets from the two testing sites and in the two time conditions.

	Cal Poly			UCSB			
Targets	**5 secs.**[a]	**15 secs.**[b]	**All**	**5 secs.**[c]	**15 secs.**[c]	**All**	**Both**
Library	15.8	14.8	15.3	7.5	9.5	8.5	11.9
Downtown	26.6	30.5	28.5	18.8	23.0	20.9	24.7
Other Campus	25.5	47.1	35.8	39.5	27.8	33.6	34.7
Los Angeles	27.2	46.1	36.2	27.0	44.8	35.9	36.0
San Francisco	27.9	43.2	35.2	30.2	37.6	33.9	34.5
Miami	21.5	57.6	38.6	43.8	57.2	50.5	44.6
Honolulu	30.0	52.4	40.6	58.2	57.4	57.8	49.2
New York	32.1	38.9	35.3	42.5	41.0	41.8	38.5
Tokyo	71.9	74.3	73.0	54.0	66.8	60.4	66.7
London	38.6	43.0	40.7	53.2	41.5	47.4	44.0
Rio de Janeiro	25.6	48.6	36.5	39.2	57.1	48.2	42.3
Sydney	59.0	55.8	57.5	76.6	50.9	63.8	60.6
North	24.3	45.7	34.5	39.7	48.8	44.2	39.4
West	32.0	35.0	33.4	39.4	49.4	44.4	38.9
All	32.7	45.2	38.7	40.7	43.8	42.2	40.4

Note: [a] $n = 21$; [b] $n = 19$; [c] $n = 20$.

errors across the targets did differ significantly across the two time conditions. Tests of main effects of each factor separately notably indicated no significant differences in the magnitude of variable errors at the two testing sites, but variable errors differed significantly for the two time conditions and, very substantially, across the fourteen targets.

We interpreted these results by examining the patterns of variable errors shown in Table 1 (and graphically depicted in Figs. 2 and 3). Variable errors were greater in the 15-sec. condition than the 5-sec. condition, but this did not hold true for all targets. Likewise, variable errors were greater for some targets than others, but not uniformly for both time conditions. Table 1 shows that variable errors in pointing to the local targets of the campus library and downtown were consistently lower than in pointing to any of the other targets. That is, participants at both Cal Poly and UCSB pointed to local targets with greater agreement than to any other targets. Participant variability in pointing to Tokyo and Sydney was exceptionally high from both sites. Thus, both locations featured a similarly high correlation between target distance and variable error: 0.66 from Cal Poly and 0.78 from UCSB. Considering that randomly pointing to a target would lead to mean variable errors of about 90° provides perspective on the magnitudes of variable error. The variable error in pointing to Tokyo in our sample amounted to 66.7°, which is clearly better overall than random pointing but quite imprecise nonetheless.

Table 2. MANOVA effects tests for the significance of patterns of variable errors in pointing to the fourteen targets from the two testing sites and in the two time conditions.

Effect	***F* score**	***p* value**
Location × Time × Target	1.14[a]	.34
Location × Time	1.59[b]	.21
Location × Target	1.09[a]	.38
Time × Target	2.27[a]	.02
Location	0.76[b]	.38
Time	4.32[b]	.04
Target	18.29[a]	<.0001

Note: [a] $df = 13, 64$; [b] $df = 1, 76$.

DISCUSSION

This study compared the directional knowledge of students at two university campuses under two time conditions, as expressed by pointing judgments the students made from the perspective of the location and heading where they were standing at the time they estimated directions; that is, knowledge was tested in situ. Our results confirm that people from different places can have equivalent cognitive maps but can differ in expressing that knowledge because of differences in their sense of orientation from the two places.

In our study, people's sense of orientation depended in part on referring to the nearby coastline and/or ocean, and was likely also influenced by other local features such as the east–west running Santa Ynez Mountains just north of UCSB and U.S. Highway 101, which is signed as north–south but runs east–west through the Santa Barbara area and nearly north–south by San Luis Obispo. Like other heuristics, these assumptions simplify reasoning but can also mislead.

Our results support the role of self-orientation in directional knowledge that we discussed in the introduction. People can know directional relations between places but estimate them poorly because they are confused or uncertain about their heading when they perform the estimation. As suggested by numerous previous studies, we again demonstrated the role of heuristic assumptions in establishing one's heading in ways that can lead to systematic distortions in geographic spatial knowledge. But, importantly, our coastline/ocean heuristic goes beyond the alignment or rotation of features, as Tversky (1981), Mark (1992), and Glicksohn (1994) discussed; regional membership, as discussed by Friedman and her colleagues (e.g., Friedman and Brown 2000); and orthogonalization, as discussed by Tversky (1981), Montello (1991), and others. In contrast, we demonstrate that the heuristic use of the coastline (or ocean) for judging directions is not just a matter of featural alignment, rotation, or orthogonalization. Our UCSB participants did not straighten or align anything, or make anything into a right angle. A substantial subset of them assumed that a coastline actually running east–west is north–south (or, equivalently, that an ocean actually to the south is to the west). Even more, our results show that the influence of a coastline—as in Portugali and Omer's (2003) edge effect, wherein coastline features are estimated with greater accuracy—can operate to produce *less* accurate responses when the orientation of the coastline is mistakenly understood. Thus, we propose that the edge effect is one of greater certainty, not necessarily greater accuracy.

It is possible that participants at Cal Poly did not use the coastline as a heuristic basis for directional judgments, given that it is not immediately adjacent to the campus. They may have used closer linear features, such as State Highway 1 or California Boulevard, two major roads that run through or next to the campus. These linear features run about 15°–20° northwest–southeast of due north–south. Coincidentally, the coastline of California (ignoring more local perturbations) also runs very close to this orientation. Although constant errors in estimating cardinal directions from Cal Poly do not significantly differ from correct, as they do from UCSB, there is some evidence in the histograms in Figure 2 that participants do mistakenly align one or all of these linear features as being due north–south. This is most clearly revealed in the constant errors pointing to the nonlocal targets in California from Cal Poly: San Francisco is pointed to as if it were due north, while UCSB and Los Angeles are pointed to as if they were due south. Whatever the heuristic basis for judgments from Cal Poly, however, the results clearly differ from those collected at UCSB, providing evidence for a unique pattern of coastline misalignment from UCSB.

Evidence for our conclusion is found mostly in the pattern of constant errors, the systematic tendency for research participants to point either clockwise or counterclockwise of the correct directions to target places. For almost all targets from both testing sites, participants did tend to point in a single direction, even though this direction was often significantly inaccurate. Strikingly, however, these biased estimates were about equally strongly clockwise as counterclockwise from the campus of Cal Poly (total of 1° clockwise over all fourteen targets), but they were very strongly and consistently counterclockwise from the campus of UCSB (total of 497° counterclockwise over all fourteen targets). This difference in net consistent bias at the two testing locations shows starkly that Cal Poly participants as a group are not showing any consistent heuristic bias, while UCSB participants as a group are showing a strong consistent heuristic bias; the fact that the latter is counterclockwise supports the operation of the coastline/ocean heuristic because that is precisely the direction in which the coast turns between the two campuses.

Especially conspicuous were the patterns for the two cardinal direction targets. From Cal Poly, participants pointed to north and west without significant error, their errors unimodally clustered around the correct direction. From UCSB, participants pointed to both north and west significantly inaccurately, with the distributions of their individual estimates bimodally clustered around either the correct direction or 90° counterclockwise, reflecting the 90° coastline turn. Taken together, these results clearly indicate that many people use the local orientation of the turning coastline/ocean and/or the mountains and highway that turn with it to determine their own heading (facing direction), and that they heuristically assume a feature like the coastline runs north–south or that the ocean lies due west along the entire California coast (or United States, North America, etc.) when in fact neither is true. This leads to systematic errors from the south coast of Santa Barbara County, wherein at least a substantial subset of people believe they are facing west as they look at the ocean when they are actually facing south.

These patterns of constant errors did not differ consistently as a function of whether participants responded quickly or after a short delay. Constant errors for several targets did differ from Cal Poly in the two time conditions, but not in any consistent way; mean estimates were more accurate after a longer delay for some targets and less accurate for others. None differed significantly from UCSB. We draw no firm conclusion about this, other than to note that the strong coastline/ocean bias when pointing from UCSB swamps out other biasing influences on directional estimates.

The effects of the coastline/ocean heuristic expresses itself in the pattern of constant errors, not variable errors.

This is a strong argument to support the value of decomposing absolute errors into constant and variable errors when analyzing spatial estimates. The most important result here is that variable errors were about the same from the two testing sites. This suggests that participants did not feel more uncertain about their spatial orientation from UCSB, even though they consistently estimated much less accurately from there. That is a trademark of heuristic reasoning—it simplifies reasoning and reduces uncertainty, even when it sometimes leads to wrong decisions. Uncertainty about directions did increase quite a bit with the distance of the target, with much more agreement across participants for local targets than very distant ones. That is to be expected in any system where unsystematic error (noise) accumulates with extent and is not subject to any corrective influences (such as landmark fixes made at sea by navigators correcting their orientation).

This influence of the coastline, ocean, mountains, and/or highway on reasoning about orientation is in line with Portugali and Omer's (2003) assertion that prominent edges in the environment have a large bearing on people's directional judgments. We conclude that a fairly large set of people along the south coast of Santa Barbara County may observe a sun that appears to rise in the south and set in the north. More likely, we speculate that people in our culture generally do not use the sun to orient themselves, and we consider it an interesting researchable question as to how many of them even understand how to use the sun properly in this way (e.g., to account for seasons, the time of day, and so on).

As explained above, we interpreted our constant errors in terms of actual directions defined as rhumb lines. We justified this based on assuming that it corresponds better to the way lay people in our culture probably organize their spatial understanding of Earth. This is not the only choice one could make for the actual directions, but we maintain that it has little bearing on our general conclusions about the influence of the local coastline and ocean. Whichever actual direction is used, as Figures 2 and 3 show, estimates from UCSB are clearly more counterclockwise than are estimates from Cal Poly, and they clearly display bimodality at UCSB either way. A look at Figure 2 shows that for the seven targets where an appreciably different great circle direction can be identified, no trials with significant bias from the rhumb line are nonsignificant from the great circle at Cal Poly, and vice versa. For only one target with significantly clustered pointing—London—is the mean estimate biased in a different direction from the great circle vector than it is from the rhumb line vector. Figure 3 shows that only one target at UCSB differs with the two ways of defining actual directions: Tokyo shows significant bias from the great circle but not the rhumb line. And no target at UCSB shows estimate bias in a different direction from the great circle vector than from the rhumb line vector; they all still show counterclockwise bias. Research ongoing in our lab examines whether people's directionalestimates match rhumb lines or great circles more closely (accounting for the influence of coastline/ocean heuristics). For our present purposes, the two ways of defining actual directions have no implications for our general conclusions.

We might also ask whether our operationalization of time pressure was adequate. As we have described, giving people 15 secs. rather than 5 secs. did not consistently affect patterns of errors in the responses. It is possible that 5 secs. did not prove restrictive enough; some participants had enough time to change their answer within that time (and we heard a few UCSB students in this condition mention the coastline turn). We thus consider our results as to the effects of time pressure to be inconclusive.

This study clearly demonstrates the influence of dominant features in providing a heuristic basis for geographic orientation and the anchoring of our spatial understanding of Earth's surface, and unlike most previous studies, it does so for knowledge assessed *in situ*. These findings are relevant to basic theories of geographic spatial cognition. They are also relevant to applied issues concerning the determination and maintenance of spatial orientation while moving about. Navigation systems break, make errors, suffer from obscured satellite signals, or are dropped down canyon walls. The need for old-fashioned mental orientation using the sun and local features will not disappear anytime soon.

REFERENCES

Attneave, F., and C. R. Pierce. 1978. Accuracy of extrapolating a pointer into perceived and imagined space. *American Journal of Psychology* 91 (3): 371–387.

Batschelet, E. 1981. *Circular Statistics in Biology*. London: Academic Press.

Byrne, R. W. 1979. Memory for urban geography. *Quarterly Journal of Experimental Psychology* 31 (1): 147–154.

Egenhofer, M. J., and D. M. Mark. 1995. Naive geography. In *Spatial Information Theory: A Theoretical Basis for GIS*, ed. A. U. Frank and W. Kuhn, pp. 1–15. Berlin: Springer.

Friedman, A. 2009. The role of categories and spatial cuing in global-scale location estimates. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 35 (1): 94–112.

Friedman, A., and N. R. Brown. 2000. Reasoning about geography. *Journal of Experimental Psychology: General* 129 (2): 193–219.

Friedman, A., D. D. Kerkman, and N. R. Brown. 2002. Spatial location judgments: A cross-national comparison of estimation bias in subjective North American geography. *Psychonomic Bulletin & Review* 9 (3): 615–623.

Glicksohn, J. 1994. Rotation, orientation, and cognitive mapping. *American Journal of Psychology* 107 (1): 39–51.

Griffin, D. R. 1948. Topographical orientation. In *Foundations of Psychology*, ed. E. G. Boring, H. S. Langfeld, and H. P. Weld, pp. 380–392. New York: John Wiley and Sons.

Haber, L., R. N. Haber, S. Penningroth, K. Novak, and H. Radgowski. 1993. Comparison of nine methods of indicating the direction to objects: Data from blind adults. *Perception* 22 (1): 35–47.

Mardia, K. V., and P. E. Jupp. 2000. *Statistics of Directional Data,* 2nd ed. Chichester: John Wiley & Sons.

Mark, D. M. 1992. Counter-intuitive geographic 'facts': Clues for spatial reasoning at geographic scales. In *Theories and Methods of Spatio-Temporal Reasoning in Geographic Space*, ed. A. U. Frank, I. Campari, and U. Formentini, pp. 305–317. Berlin: Springer-Verlag.

Milgram, S., and D. Jodelet. 1976. Psychological maps of Paris. In *Environmental Psychology: People and Their Physical Settings,* 2nd ed., ed. H. M. Proshansky, W. H. Ittelson, and L. G. Rivlin, pp. 104–124. New York: Holt, Rinehart & Winston.

Moar, I., and G. H. Bower. 1983. Inconsistency in spatial knowledge. *Memory & Cognition* 11 (2): 107–113.

Montello, D. R. 1991. Spatial orientation and the angularity of urban routes: A field study. *Environment and Behavior* 23 (1): 47–69.

———.1993. Scale and multiple psychologies of space. In *Spatial Information Theory: A Theoretical Basis for GIS*, ed. A. U. Frank and I. Campari, pp. 312–321. Berlin: Springer-Verlag.

Montello, D. R., A. E. Richardson, M. Hegarty, and M. Provenza. 1999. A comparison of methods for estimating directions in egocentric space. *Perception* 28 (8): 981–1000.

Portugali, J. and I. Omer. 2003. Systematic distortions in cognitive maps: The North American west coast vs. the (west) coast of Israel. In *Spatial Information Theory: Foundations of Geographic Information Science*, ed. W. Kuhn, M. F. Worboys, and S. Timpf, pp. 93–100. Lecture Notes in Computer Science 2825. Berlin: Springer.

Sadalla, E. K., and D. R. Montello. 1989. Remembering changes in direction. *Environment and Behavior* 21 (3): 346–363.

Schutz, R. 1979. Absolute, constant, and variable errors: Problems and solutions. In *Proceedings of the Colorado Measurement Symposium*, ed. D. P. Mood, pp. 82–108. Boulder, Colorado: University of Colorado.

Shelton, A. L., and T. P. McNamara. 2001. Systems of spatial reference in human memory. *Cognitive Psychology* 43 (4): 274–310.

Stevens, A., and P. Coupe. 1978. Distortions in judged spatial relations. *Cognitive Psychology* 10 (4): 422–437.

Tversky, B. 1981. Distortions in memory for maps. *Cognitive Psychology* 13 (3): 407–433.

Waller, D., A. C. Beall, and J. M. Loomis. 2004. Using virtual environments to assess directional knowledge. *Journal of Environmental Psychology* 24 (1): 105–116.