Area Estimation of World Regions and the Projection of the Global-Scale Cognitive Map

Sarah E. Battersby* and Daniel R. Montello†

*Department of Geography, University of South Carolina
†Department of Geography, University of California at Santa Barbara

For global-scale geographic information, there are relatively few sources that can be used to form or structure a cognitive map. One of the most common sources for this information is maps, the only reference that permits an individual a comprehensive view of the world without having to integrate information from multiple views (e.g., stitching together the two halves of a globe or assembling the pages of an atlas). It has been frequently stated that visual experience with the map projections used for global-scale mapping, specifically the Mercator projection, has a strong influence on the shape and structure of an individual's global-scale cognitive map. In this article, we examine this belief by conducting two studies on the relationship between memory- and inference-derived estimates of land area and the actual land areas of regions on the Earth. Numerical and graphical estimation techniques were used to obtain area estimates. We examined the results for relationships between distortion in estimated area and area as displayed in common map projections such as the Mercator projection, as well as for general trends in the estimation patterns. Nonequal area projections, particularly the Mercator projection, were found not to have much if any influence on the shape of participants' cognitive maps. Instead, we found estimates to be fairly accurate relative to actual area, and that the estimation pattern most clearly reflected standard trends in psychophysical estimation. *Key Words: area psychophysics, cognitive map, Mercator projection, spatial memory.*

对于全球规模的地理信息，一般只有相对较少的来源可以用来组成或构造一副认知地图。最常见的地理信息的来源就是地图，这是允许一个人能够全面地看待世界，而不必把信息从多个视图加以综合（例如，拼接地球的两个半球，或者组装地图册的分页）的唯一参考。以往的研究多次指出，用于全球规模测绘的地图投影，特别是麦卡托投影，造成的视觉体验，对于个人对全球规模的认知地图的形状和结构具有很强的影响力。在本文中，我们对这个信念进行了检验。本文对记忆和推理估算的地球上的陆地面积与实际陆地面积的关系进行了两项研究。在研究中，数值和图形估算技术被用于面积估计。我们研究了扭曲的估计面积和在普通投影地图上，例如麦卡托投影地图上面积估算的关系，以及估计模式的一般趋势。研究发现，非等面积投影，特别是麦卡托投影，对参与者的认知地图的形状认知没有太多的影响，相反，我们发现，估算面积相对实际面积是相当准确的，并且估算的模式很清楚地反映了心物学估算的标准趋势。*关键词：面积心物学，认知地图，麦卡托投影，空间记忆。*

En términos de información geográfica a escala global, relativamente pocas son las fuentes utilizables que hay para formar o estructurar un mapa cognoscitivo. Una de las fuentes más comunes para esta información son los mapas, única referencia que facilita a un individuo la visión comprensiva del mundo sin que sea necesario integrar información a partir de múltiples vistas (por ejemplo, pegando las dos mitades de un globo o ensamblando las páginas de un atlas). Con frecuencia se ha sostenido que la experiencia visual lograda con las proyecciones usadas en cartografía a escala global, específicamente la proyección de Mercator, ejerce gran influencia sobre la forma y estructura del mapa cognoscitivo de un individuo a escala global. En este artículo examinamos este creencia con base en dos estudios centrados en la relación existente entre los estimativos de área derivados de la memoria e inferencia, y las áreas reales que tienen las regiones de la Tierra. Para obtener los estimativos de área se utilizaron técnicas de cálculo numéricas y gráficas. Examinamos los resultados para las relaciones entre distorsión en área estimada y el área como es desplegada en proyecciones cartogtráficas tan comunes como la Mercator, lo mismo que por la tendencia general observada en los patrones de estimativos. Se encontró que las proyecciones conformes o de área desigual, en particular la proyección Mercator, tenían poca o ninguna influencia sobre la forma de los mapas cognoscitivos de los participantes. En cambio, encontramos que los estimativos fueron bastante exactos en términos de área real, y que el patrón de estimativos reflejaba muy claramente las tendencias estándar en cálculo psicofísico. *Palabras clave: área psicofísica, mapa cognoscitivo, Proyección Mercator, memoria espacial.*

Annals of the Association of American Geographers, 99(2) 2009, pp. 273–291
Initial submission, February 2008; revised submission, April 2008; final acceptance, April 2008
Published by Taylor & Francis, LLC.

How do people learn and remember information about the world? Depending in part on the size of the area, there are numerous ways to learn about parts of the world; for instance, through direct experience, verbal descriptions, or static pictorial representations (e.g., a map or "photo tour"). Each of these methods of learning about the world can lead to the development of somewhat different mental representations—cognitive maps—with varying levels of detail and accuracy (e.g., Thorndyke and Hayes-Roth 1982; Montello et al. 2004). Behavioral geographers, psychologists, and other cognitive scientists have studied variations in the detail and accuracy of cognitive maps fairly extensively and at various spatial scales (e.g., Downs and Stea 1973; D. B. MacKay 1976; Baird, Merrill, and Tannenbaum 1979; Golledge 1987; McNamara 1992; Lloyd 1997; Friedman and Brown 2000; Tversky 2000).

In this article, we report two empirical studies of global-scale cognitive maps—mental representations of the layout of the entire Earth surface. We investigate the nature of global-scale cognitive maps specifically by asking research participants to estimate the areas of large regions, mostly countries; because our participants did not look at a map or globe while estimating areas, the estimates are based only on memory and inference. Our goals are twofold. First, we characterize the psychophysical function describing the relationship between estimated and actual region areas on the Earth's surface when the estimates of area are based on memory and inference, rather than directly on perception. Second, we attempt to explain the pattern of distortions in estimated areas we find in our data.

Sources of Spatial Information

There are a variety of potential influences on people's beliefs about global-scale geography, and these differ partially as a function of the size and administrative status of the area. Different regions vary in their familiarity to people, their media coverage, their political or economic influence, their population size, their emotional connotations, their distance from the United States (specifically California), and so on. At the global scale, direct experience (i.e., sensorimotor apprehension of the entire Earth, unmediated by symbolic representations) does not provide the kind of information that could lead to a very comprehensive understanding (Montello 1993). Even in a jet airplane, let alone an automobile, the intermittent views one gets out of the window do not lead to a complete and interconnected understanding of the layout of entire continents or hemispheres. At this scale, various symbolic sources of information are the primary influence on one's beliefs. Examples of these symbolic sources of information include accounts from family and friends, travel writers, media coverage, textbooks and teachers, and so on.

One obvious potential source for people's beliefs about the sizes of regions on the Earth is the depiction of these regions on maps and globes. We are particularly interested in our research in whether exposure to map projections, especially the Mercator projection, has played a significant role in introducing distortions of area into the global-scale cognitive maps of college-age respondents. The Mercator projection is notorious for being widely and inappropriately used in the twentieth century as a map projection for general audiences, including in atlases and wall maps. As we review later, its widespread use has been accused of influencing generations of people's global-scale cognitive maps by creating impressions of areal exaggeration for polar and near-polar landmasses at the expense of tropical and near-tropical areas. In our research, we examine patterns of distortion in participants' estimates of area for evidence of the existence of such a "Mercator Effect" (Saarinen, Parton, and Billberg 1996)—a tendency for estimates of the sizes of polar and near-polar areas to be exaggerated. In lieu of such an effect, we attempt to find alternative explanations for patterns of estimated land areas.

The Mercator Projection: A Mental Imperialist?

The notion that the relative sizes of regions on maps provide a basis for relative sizes in people's global-scale cognitive maps seems likely and is consistent with one of Egenhofer and Mark's (1995, 8) principles of "naïve geography" that "maps are more real than experience." At the global scale, there is little possibility of directly experiencing the sizes of land areas, so global-scale maps are likely to be essential sources of information. Thus, one might argue that they become both a source of information for reality and the reality itself. Unfortunately, at this scale, the representation is always a disfigured version of reality. What's more, the representations people see are not always visually consistent, as there are an infinite number of ways to project global-scale geographic information onto a two-dimensional map. Projection introduces distortion in angles, area, direction, distance, and continuity of the surface. These

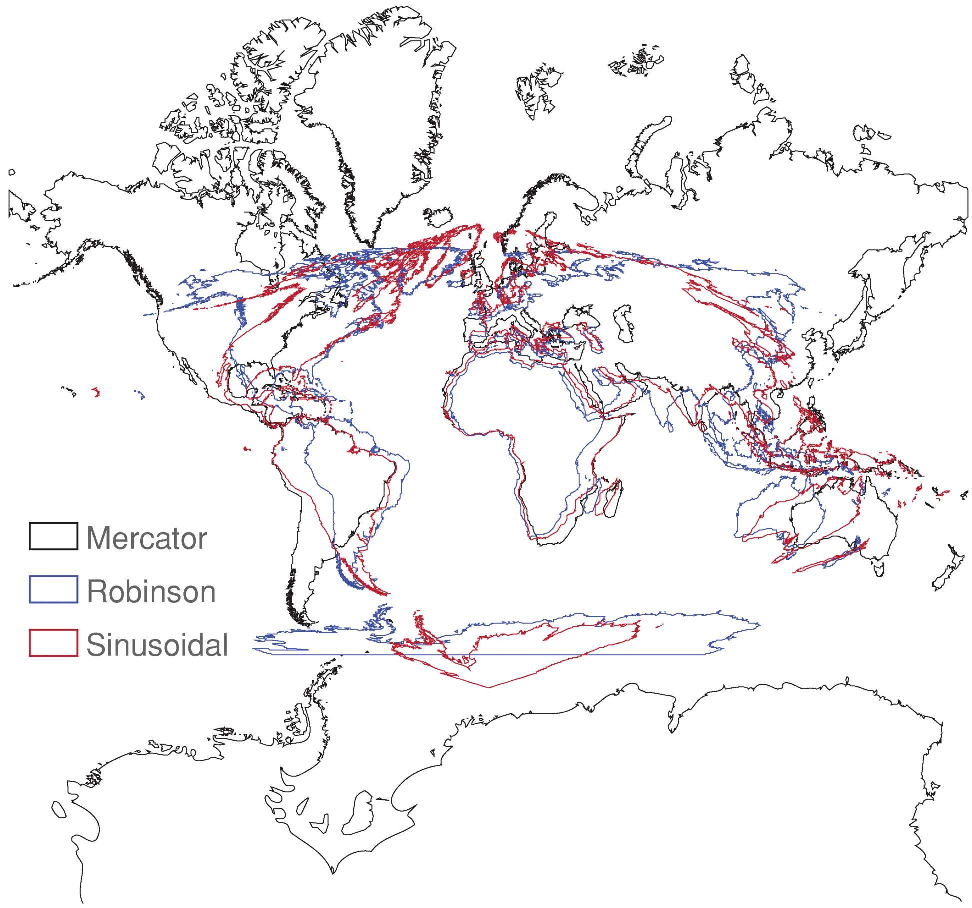

Figure 1. Three common global-scale projections have been aligned and overlaid on one another to illustrate the variety of distortion introduced in the projection process. The sinusoidal projection preserves the true areas of landmasses, whereas the Robinson and especially the Mercator projections exaggerate areas toward the poles.

distortions are more or less pronounced in different geographic areas and at different scales of depiction. This can be examined visually in Figure 1, which depicts the effects of distortion due to map projection at the global scale. As can be seen in Figure 1, differences in the portrayal of landmasses among common projections can be quite pronounced at the global scale. These differences would provide substantially different experiences of global-scale space and, thus, impressions of geographic reality. If impressions from these projections become embedded in people's cognitive maps, they should be reflected in measurements of spatial properties of those cognitive maps.

Whether for good or bad, both geographers and members of the general population seem to be attached to the Mercator projection—either as the classic example of projection distortion or as the most recognized representation of the world. The historical and contemporary story of the Mercator projection is reviewed by Monmonier (2004). Designed by Gerard Mercator in the sixteenth century, the projection served the needs of ocean navigators brilliantly, insofar as all lines of constant compass bearing (rhumb lines) plotted as Euclidean straight lines on the projection. Of course, very few of these rhumb lines represent shortest distances over the Earth's surface and, more to the point of the research reported here, the lines can only plot as straight lines on flat maps if the cartographer greatly exaggerates the sizes of landmasses (as well as oceans, for that matter) as one moves north or south from the equator, toward the poles. In fact, this relative exaggeration of areas toward the poles, relative to areas near the equator, does not really hit its stride on the Mercator projection until about latitude 40–50° (N or S): South Africa, at an average of about 29° S latitude, is depicted at about 131 percent of its area on a Mercator projection, relative to depicted areas at the equator; Switzerland, at about 47° N latitude, is depicted at about 213 percent of its area; Sweden, at about 63° N latitude, is depicted at about 487 percent of its area.

According to Monmonier (2004), the general population did not warmly welcome Rand McNally replacing the Mercator projection for their maps with the Robinson projection. There also appears to be a fondness for the Mercator projection on the part of many geographers but usually because of its suitability as a cartographic whipping child. Many geographers and cartographers have claimed that the Mercator projection strongly distorts the shape of individuals' global-scale cognitive maps (Lloyd 2000; claims recounted in Monmonier 2004). Robinson (the creator of an influential rival projection) claimed about the Mercator that "generations have been exposed to it, and by now the great majority of those who occasionally call up the world in their mind's eye do so with a thoroughly warped image. . . . We have been 'brainwashed' by the rectangular Mercator" (Robinson 1990, 103). Robinson was moved to write this in part because of his enthusiasm for a resolution by the American Cartographic Association that was endorsed by six additional professional organizations of geographers and cartographers. This resolution cautioned us that repeated viewing of any particular projection tends to make it "look right," and that if an individual has had frequent viewing experiences with a rectangular map, such as the Mercator, this will lead to "serious, erroneous conceptions . . . [of] large sections of the world" (American Cartographic Association 1989, 223). Furthermore, they claimed, "world maps have a powerful and lasting effect on people's impressions of the shapes and sizes of lands and seas" (223). As recently as 2002, one writer went so far as to suggest that the Mercator projection had become something of a "master image" for world maps (Vujakovic 2002).

Innumerable classroom anecdotes suggest the distorting power of the Mercator projection, often by citing the exaggerated impressions students reliably have of the size of Greenland (we have found this in our own classroom demonstrations). The territory of Greenland, which ranges from about 60° N to 83° N latitude, is in fact depicted at a whopping 1,645 percent of its area on a Mercator projection. Many people recall the Mercator being the projection of their formative years spent in the classroom (e.g., Saarinen, Parton, and Billberg 1996). Saarinen's work has indicated that there are, in fact, some artifacts of the distortion patterns of the Mercator projection in children's sketch maps of the world (Saarinen 1999). In another sketch map study, Chiodo (1997) found that over 50 percent of participants drew what were classified as "Mercator projection-based" sketch maps. All in all, it seems reasonable to fear that exposure to a particular projection would lead to a cognitive map exhibiting Mercator- or other projection-based distortion. As MacEachren (1995) has written, "if a person's general map schema includes the assumption that relative size on the map corresponds to relative size in the world, she is likely to (mis)interpret the sign-vehicles to mean something that they do not" (315). In other words, if individuals are familiar with the Mercator projection and assume it is an equal-area projection, matching distortion of the areas in the cognitive map should follow.

The history, uses, and geometric and mathematical properties of projections have been well covered in academic literature (Snyder 1993; Yang, Snyder, and Tobler 2000; Monmonier 2004). With respect to the cognitive influences of projections, however, there are many opinions, as we reviewed earlier, but little research measuring estimated areas in global-scale cognitive maps. Some research on the cognitive areas of regions has been conducted by psychologists, but the possible effect of map projections has been overlooked or considered minor. Brown and Siegler (1993) examined the estimation of land area for the one hundred most populous countries in the world. They assumed that "relative size on maps provides a familiar and highly valid clue to relative land areas. . . . People are quite skillful in using this cue" (517). Brown and Siegler's results revealed that actual area was the best predictor of land area, which they assumed meant that individuals gave greater consideration to "true area learned from maps and globes" (519, 521). Of course, these quotes fail to recognize that many maps do not show true areas—most of the commonly used projections for world maps are not equal-area projections.

Psychophysical Research and Area Estimation of Geographic Regions

Map design research has long been focused on how design influences cognition of geographic information. Since Robinson (1952) published *The Look of Maps*, there has been increased interest in examination of maps as communication devices and how design decisions influence quality of communicated information. The focus of and techniques for map design research have varied throughout the years, but the work has always involved observation and measurement of how people read and interpret maps (Montello 2002). In seeking to explain why we see patterns in interpretation (or misinterpretation) of maps, we must first identify what patterns exist. In the work reported here, we focus on patterns of distortion in area estimation and some of the potential causes for these distortions in area estimation.

Questions about area estimation are part of the domain of *psychophysics*, the long-established subdiscipline of experimental psychology that empirically and quantitatively examines the relationship of subjective stimulus magnitudes to their actual physical magnitudes (e.g., see Gescheider 1997). Although psychophysics has long been a standard approach in experimental psychology, its popularity in map design research has varied with research trends; for example, a plethora of studies on proportional symbol interpretation were undertaken in the 1970s and 1980s (Montello 2002). We are now seeing a resurgence of use of this approach for explaining distortions in cognition of geographic information (e.g., Friedman and Montello 2006).

To collect psychophysical area data, individuals are shown a series of stimuli, like polygons or other figures, and they estimate the sizes of the stimuli with one of several specific methods, including ratio estimation and magnitude estimation. Alternatively, they estimate areas from memory of stimuli to which they have previously been exposed. Traditionally, a graph of these data plots estimated areas against actual areas. This *psychophysical function* is summarized by a mathematical equation. Research has revealed that a power function fits psychophysical data quite well, and area estimation is no exception (see Baird 1970 for more specific details on power functions for estimated area).

The psychophysical equation predicts estimated area (A_{est}) as a function of actual area (A_{act}), raised to an exponent β and multiplied by a scaling constant k, as in Equation 1:

$$A_{est} = kA_{act}^{\beta} \quad (1)$$

A straightforward way to determine β and k is to linearly regress the logarithm of A_{est} against the logarithm of A_{act}; the slope will be the power exponent β and the intercept will be the logarithm of the scaling constant k, as in Equation 2:

$$\log A_{est} = \log k + ß \log A_{act} \quad (2)$$

Usually, most interest is in the value of the exponent, which describes the form of the best fitting curve for the function. Research on area estimation has shown that this exponent is generally in the neighborhood of 0.7 to 0.9. For instance, Teghtsoonian (1965) reported that the exponents for estimating the area of squares, parallelograms, irregular small polygons, and several other shapes mostly fell within the range of 0.76 to 0.81. Flannery (1971) reported a series of psychophysical studies on the estimation of graduated circles, reporting an average exponent of 0.87 (for other work on the psychophysics of graduate symbols, see Chang 1980; Griffin 1985). The positive exponent in these functions indicates that estimated area increases as actual area increases (an essential, if modest, check on the validity of the task). The fact that the exponent is less than 1.0 indicates that the function decelerates; perceived area increases more slowly than the actual area of the stimulus. Put another way, as a figure increases in size, its area is increasingly underestimated relative to its actual area. Exactly why this underestimation happens, however, is still a bit of a mystery; Stevens (1970) has proposed that it reflects how the sensory system transforms stimulus intensity into the neural activity necessary to interpret and estimate the area of the feature. Where this compression is introduced also remains unclear, although it has been shown that the process is not restricted to a single stage in the sensory processing system; the resulting compression may be a result of multiple stages in the neural processing system (D. M. MacKay 1963).

An implication of the decelerating psychophysical functions that are almost always found for area estimation is that smaller figures are relatively overestimated in area, whereas larger figures are relatively underestimated. In addition, research has suggested that feature shape, including the complexity of shape, has some minor influence on estimated area, although it is not clear exactly what causes this. In general, less compact shapes are overestimated relative to more compact shapes. Different studies indicate that area estimation may be related to the length of the outside contour or perimeter of a figure (Smets 1970; Martinez and Dawson 1973), whether it is round or square (Krider, Raghubir, and Krishna 2001), or its number of sides (Hitchcock et al. 1962). Studies using regular and irregular geometric polygons present the features in a context-free manner, however, so it is unclear how their conclusions apply to area estimations of geographic regions like countries or contents.

Kerst and Howard (1978) examined area psychophysics for geographic regions. They were specifically interested in the possible difference between estimating area while subjects visually perceived the regions as opposed to when they estimated area from memory. Kerst and Howard had participants estimate the size of U.S. states or world countries relative to the area of a standard reference stimulus. For estimating states, the area of Pennsylvania was the standard; for estimating countries, the area of France was the standard. Each standard region was assigned the value of 100 units of area. For both state and country data, participants estimated area very accurately in a relative sense: $r = 0.96$ for states, $r = 0.88$ for countries. Also, power functions provided a good fit for the data, with exponents of 0.40 for the states and 0.31 for the countries. These exponents, based on estimation from memory, are much smaller than the exponents we reported earlier that are found for perceptual estimation, but we cannot directly attribute these smaller exponents—the greater compression of subjective area—entirely to estimation from memory rather than perception. The perceptual results are mostly based on regular geometric figures, and geographic regions are not usually regular shapes. Additionally, geographic regions are already familiar to people who serve as participants in these studies, based on varying amounts and types of prior experience.

Psychophysical studies of area estimation do not tell us much about what influences subjective area in people's cognitive maps. In particular, they have not looked at the possible influence of exposure to distorted map projections. We reanalyzed Brown and Siegler's (1993) data in an attempt to explore the possibility of projection-based distortions in estimated land areas. In fact, these researchers did find a strong linear correlation of 0.93 between actual and estimated areas in their set of one hundred countries, supporting the notion that people in general have rather accurate beliefs about the relative sizes of these land areas. Their data also revealed the negatively accelerating power function so often found in psychophysical research. Estimated area was predicted by actual area according to the power function in Equation 3:

$$A_{est} = 1.24A_{act}^{0.47} \quad (3)$$

A positive and decelerating function was found, as usual. Like Kerst and Howard's (1978) research, estimation of area from memory led to a much smaller exponent (0.47) than did estimation during perception.

We next tried to get some sense for whether area estimates in Brown and Siegler's (1993) data set might show evidence of distortion similar to that found on a Mercator projection. To do this, we correlated the estimated areas for each country with the absolute values of their mean latitudes. As we discussed earlier, the actual Mercator pattern of increasing area with more polar latitudes is not linear, but it is monotonic, so that this correlation should at least provide some initial support for the influence of the Mercator or other similar projections (i.e., most cylindrical projections). In fact, we found that the correlation of latitude with estimated area in Brown and Siegler's data was 0.31, definitely positive but not very large. Distortions in the estimated areas of countries, however, have been shown to depend in part on their actual areas. An unconfounded analysis of a possible Mercator effect would require countries at different latitudes to have equal actual areas, which is not the case. In Brown and Siegler's study, the correlation of latitude with actual areas was 0.16, indicating that near-equatorial countries tended to be a little smaller than near-polar countries. This indicates that the correlation of latitude with estimated area in their data may have been due in part to the correlation of latitude with actual area. In the studies we present, we attempt to clarify the separate contributions of latitude and actual area to patterns of estimated area. Also, because Brown and Siegler used only populous countries, they left out many regions that are highly distorted by map projections such as the Mercator, including Greenland, Antarctica, and Alaska. We include all of these regions in our studies.

Saarinen and his colleagues (Saarinen 1988, 1999; Saarinen, Parton, and Billberg 1996; see also Pinheiro 1998) have conducted several studies analyzing sketch maps of the Earth that included continents and countries. Among other aspects, these researchers have examined the size of features drawn on these sketches, providing de facto estimates of relative land areas. With a few notable exceptions, participants tended to exaggerate the size of their home continent with respect to other continents. Of note is that participants from Africa, South America, and Australia tended to underestimate the size of their home continent. Regardless of home location, participants tended to overestimate the size of Europe and underestimate the size of Africa. With Saarinen's request that participants sketch countries as well as continents, it is likely that at least some of the area distortion he found resulted from the inclusion or exclusion of feature labels and detailed country borders in regions of differing familiarity. Unlike Brown and Siegler (1993), however, Saarinen and his colleagues did discuss the role of map projections, concluding that some of the patterns in the sketches stemmed from their influence. For example, most of the sketches depicted Europe in the center, even when the sketcher's home continent was far away from Europe. These studies, however, did not quantitatively compare sketch maps to distortions in Mercator projections or any other map projections.

In the research reported in this article, we describe the global-scale cognitive map by characterizing what people believe about the relative sizes of countries and other regions on the Earth. This, in turn, will allow us to examine the fundamental question of whether the cognition of global-scale space is affected by map projections and their attendant distortions, and if so, how. Demonstrating the influence, or lack of influence, of map projections on the content and layout of cognitive maps is important because it would help explain distortions in cognitive maps that have been mostly accounted for in other ways, such as psychophysical scaling effects, nongraphical estimation heuristics, regional effects, or emotional attachment. It would also support, or fail to support, critics of particular projections that have worried about the pernicious influences of projections on our accurate and equitable thinking about the world. This would, in turn, have implications for education in geography, for media coverage of geography, and for the use of geographic information in socially constructive ways.

In our studies, we looked for systematic distortions in one characteristic of map projections—region area. To do this, we had people estimate areas from memory and inference, based on the prior beliefs about areas they brought to the study; there was no prestudy of maps, globes, or lists. We used regions (countries, territories, and one U.S. state) of varying size and latitude to assess the effects of region size and latitude on estimated area, and to look specifically for the influence of map projections, especially the hypothetical Mercator Effect. In our first study, participants estimated areas using a traditional magnitude estimation technique in which they produce numbers to represent the sizes of land areas, relative to the numerical value of a standard region. In our second study, we explored the robustness of our results by having participants estimate areas graphically, by modifying the size of a region relative to the graphical size of a standard region. Our initial hypothesis is that both methods of estimating land areas would show evidence of size distortions resulting from exposure to distorted world maps. If measurements from cognitive maps show patterns of distortion mirroring those in map projections, it indicates two things—people have been exposed to distorted maps (e.g., Mercator) and the exposure has left an indelible mark on their conception of land area. If we do not find these matching patterns of distortion it means that either or both of these could be false; there was no memorable exposure to distorted map references, or exposure to these projections made no lasting impression on the structure of the individual's cognitive map.

Study 1: Numerical Magnitude Estimation of Area from Memory

In our first study, participants estimated the areas of twenty-six regions located around the world. They estimated areas using the psychophysical technique of magnitude estimation. With this technique, participants supply a number they believe represents the magnitude of a quantity relative to the value of a standard quantity, the numerical value of which is called a modulus (see Gescheider 1997). We used the area of the conterminous United States as a standard, to which we assigned the area of 1,000 units as a modulus value. In addition, participants rated their familiarity with each region so that we could test for the effect of familiarity on the estimated areas.

Methods

Participants. A total of 194 students (84 female, 103 male, and 7 who did not specify) from an undergraduate regional geography course took part in the study. One additional male student participated but was excluded from analysis; his area estimates were far outside the range of correct answers, with no estimates less than 1,000, which was the standard's modulus value, and some as high as 200,000 (he might not have understood the task, as English was not his native language). The students were primarily nongeography majors born in the United States (92.8 percent), with a mean age of 21.6 years. They received a small amount of course credit for their participation.

Materials. Participants estimated the areas of twenty-six regions in this study; the regions were all countries, with the exception of two territories (Greenland, Antarctica) and one U.S. state (Alaska). The regions were carefully selected according to several criteria. We wanted regions located across the latitude spectrum, both southern and northern, stretching from the equatorial to the polar zones. Centroids were calculated for each of the regions, and the latitudes of the centroids were used to classify the regions into latitude "bands." We selected regions so there was approximately an even number in each of four bands: 0–20°, 20–40°, 40–60°, and over 60°. Within each of these bands, regions were selected to provide as large a range of areas as was possible, both small and large relative to the size of the conterminous United States. An attempt was made to ensure that the regions selected were likely to be familiar to an average audience of U.S. undergraduate, nongeography majors. We made sure to include Greenland as a test region, insofar as there are many anecdotal reports about exaggerations in the estimated area of this region. The regions are listed in Table 1 and depicted in Figure 2, along with their actual area (in km^2) and "modulus area," each region's area calculated relative to the 1,000 modulus of the conterminous United States.

Although we tried to ensure a variety of sizes of regions within each latitude band, it was not possible to balance this strictly (a difficulty with Brown and Siegler's [1993] stimulus set, as we reviewed earlier). In general, there was a weak tendency for region sizes to increase as absolute latitude increased, so the range of area values is not the same for each latitude band. On our planet at this time in history, the correlation of the area of every individual country in the world to that country's mean absolute latitude from the equator is about $r = 0.20$. The study regions we used matched this relationship; area and latitude are also positively correlated with a value of $r = 0.21$ in our sample.

Participants estimated the area of each region in the study via magnitude estimation. The area of the conterminous United States was used as the standard area; it was given a modulus value of 1,000 units. Participants were instructed to estimate the area of each region by writing down a number of units that represented the area of the region relative to the "area of the conterminous United States (the 'lower 48 states')" as 1,000 units. As an example, they were told that if they thought Canada (not in the stimulus set) was twice the size of the conterminous United States, they would estimate its size as 2,000 units. To control for a possible influence of familiarity with a region on estimation accuracy—more knowledge might lead to more accurate estimates—participants also rated their "knowledge of each region" on a 10-point scale, ranging from 0 (no knowledge) to 10 for (extensive knowledge). No

Table 1. Actual areas and modulus areas for each region in Studies 1 and 2

Region	Area in km^2	Modulus area
Denmark	41,104	5
Switzerland	41,854	5
Austria	82,869	11
Guatemala	109,829	14
Greece	125,515	16
North Korea	122,847	16
New Zealand	267,214	34
Italy	301,101	39
Norway	305,866	39
Vietnam	322,743	41
Japan	370,727	47
Sweden	442,246	57
Spain	503,250	64
Venezuela	913,485	117
Ethiopia	1,134,156	145
South Africa	1,219,930	156
Peru	1,296,605	166
Alaska	1,499,145	192
Mexico	1,953,851	250
Greenland	2,118,140	271
India	3,153,010	404
Australia	7,694,273	985
Conterminous United States	7,809,158	1,000
Brazil	8,493,132	1,088
China	9,366,190	1,199
Antarctica	12,277,658	1,572
Russia	16,897,294	2,164

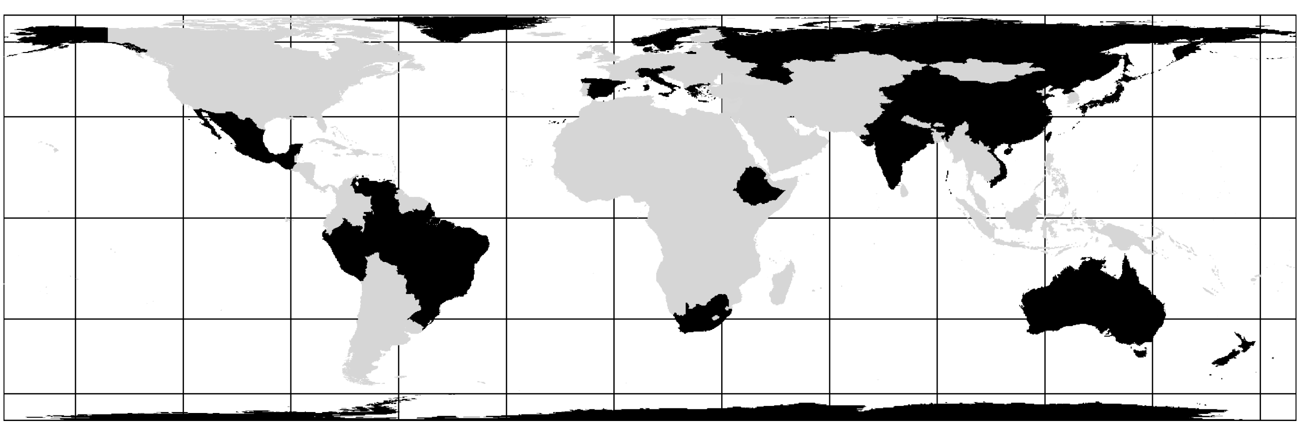

Figure 2. Selected regions of the world (indicated in black). The regions are shown in a cylindrical equal-area projection.

specific mention was made of knowledge about spatial area, map projections, or any other property.

Procedure. Participants were first asked to provide their gender, age, and place of birth. They then rated their knowledge of each region. Instructions for the knowledge ratings, along with the twenty-six region names and rating scales, were printed on one side of a standard 8.5 × 11-inch piece of paper. The regions were printed for each participant in one of ten randomized orders. After completing the knowledge ratings, participants turned the paper over, where the instructions and region names for the area estimation were printed. These were listed in the same random order as for the knowledge-rating task. All estimates were based on the printed names of the regions—no maps or other graphical depictions of the regions were ever shown to participants.

Results

Table 2 presents the mean area estimates, relative to the modulus of 1,000 for the conterminous United

Table 2. Modulus areas, mean estimated areas, and mean knowledge ratings for each region, Study 1

Region	Modulus area	Mean estimated area	Mean knowledge rating
Denmark	5	140	2.1
Switzerland	5	146	3.1
Austria	11	159	2.6
Guatemala	14	118	1.9
Greece	16	179	3.6
North Korea	16	180	2.7
New Zealand	34	193	3.3
Italy	39	177	5.0
Norway	39	205	2.4
Vietnam	41	164	3.8
Japan	47	269	4.6
Sweden	57	184	2.7
Spain	64	264	4.7
Venezuela	117	183	1.9
Ethiopia	145	169	1.9
South Africa	156	393	3.4
Peru	166	165	2.2
Alaska	192	318	4.7
Mexico	250	569	6.2
Greenland	271	520	1.8
India	404	754	3.7
Australia	985	740	4.9
Brazil	1,088	615	3.2
China	1,199	1,409	4.4
Antarctica	1,572	1,225	2.7
Russia	2,164	2,077	3.9

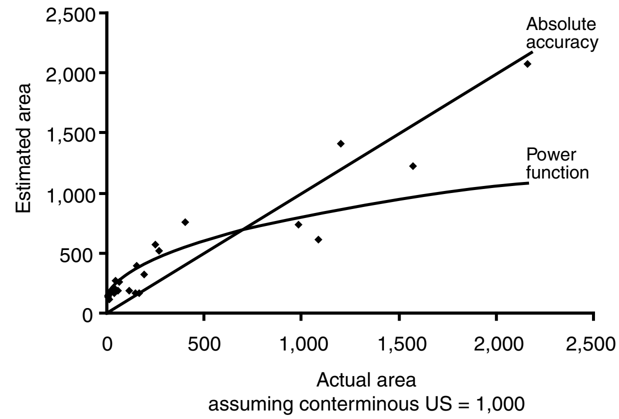

Figure 3. The psychophysical graph plotting estimated areas against modulus areas, Study 1. Absolutely accurate estimation is represented by the straight diagonal line; the best fitting power function is also shown.

States, for each of the twenty-six regions. To analyze the area estimates, we calculated a Pearson correlation coefficient between modulus area and estimated area for each participant, across the twenty-six regions (producing 194 correlations, each based on twenty-six pairs of scores). To calculate a single aggregated correlation to represent the relationship between modulus area and estimated area, we normalized the coefficients using Fisher's r-to-z transformation (see, e.g., Cohen and Cohen 1983), averaged across participants, and then back-transformed to a correlation coefficient.[1] Across participants, the correlation between modulus and estimated area was quite high, $r = 0.82$. This suggests that participants, on average, did a good job of estimating the relative areas of the regions.

To generate the power function equation, we predicted the estimated areas as a power function of the modulus areas separately for each participant. Across participants, the mean of the exponents was 0.56, $r^2 = 0.65$. Figure 3 shows the psychophysical function that plots mean estimated areas against modulus areas.

As a first examination of the potential role of the Mercator projection in causing our patterns of area distortion, we correlated the estimated areas with each region's mean latitude. This correlation, again calculated within participants and then averaged, was positive but small, $r = 0.21$. This suggests a weak tendency for regions further from the equator to be estimated as larger, which is at least roughly consistent with the existence of a Mercator Effect. As we discussed earlier, though, this correlation is confounded insofar as countries at different latitudes differ in actual area, and as our power function results show, estimation patterns apparently depend partially on these area measures. Thus, instead of analyzing the area estimates as provided by the participants, we calculated an index of relative estimation accuracy that attempted to standardize estimated areas for the modulus areas calculated for the regions.

A straightforward approach to calculating relative estimation accuracy might be to simply divide estimated area by modulus area or to divide the difference between estimated area and modulus area by modulus area, but these approaches result in a severely one-tailed index that treats overestimation very differently than underestimation. That is, these approaches allow overestimates to range up to positive infinity, but underestimates have an absolute limit (0.0 in the first case and –1.0 in the second case). So, instead, we calculated relative estimation accuracy differently for over- and underestimates, so that the index would have the same statistical properties for both. If the estimate is larger than or equals the modulus area (i.e., an overestimate or accurate estimate), the index divides estimated area by modulus area. Whether an overestimate or accurate, we then subtract 1.0 so that the index equals 0.0 when estimated area equals modulus area. If the estimate is smaller than the modulus area (i.e., an underestimate), the index calculates the inverse ratio by dividing modulus area by estimated area; 1.0 is then subtracted. Finally, we assign a negative value to this inverse ratio. Calculated these ways, overestimates are positive values for relative estimation accuracy, underestimates are negative, and perfectly accurate estimates are zero as shown in Equations 4 and 5:

$$\text{if } A_{est} \geq A_{mod} \quad A_{rest} = (A_{est}/A_{mod}) - 1.0 \quad (4)$$

$$\text{if } A_{est} < A_{mod} \quad A_{rest} = -((A_{mod}/A_{est}) - 1.0) \quad (5)$$

Thus, an overestimate that is twice the modulus area would have an index of 1.0, and an underestimate that is half the modulus area would have an index of −1.0. Overestimates range up to positive infinity, and underestimates range down to negative infinity.

Table 3 presents relative estimation accuracy for the twenty-six regions, ordered from greatest overestimation to greatest underestimation. Absolute latitudes and the modulus areas are shown for comparison. Examining Table 3 suggests a very weak relationship at most between latitude and estimation accuracy. When we correlated absolute latitude with relative estimated area, we found a positive but very small relationship, $r = 0.17$. There is thus a slight tendency for regions at greater latitudes to be estimated as relatively larger, which is weakly consistent with the existence of a Mercator Effect. The most overestimated regions are found in the latitude range from 39° to 56°: Switzerland, Denmark, Austria, North Korea, and Greece. The most underestimated regions, including Peru and Brazil, tend to be found closer to the equator, but the most underestimated region was Antarctica, at 80°. Russia, at mean latitude 62°, was also underestimated.

Table 3. Relative estimation accuracy, mean absolute latitudes, and modulus areas for each region, Study 1

Region	Relative estimation accuracy	Mean absolute latitude°	Modulus area
Switzerland	26.0	46.8	5.4
Denmark	25.4	56.0	5.3
Austria	14.0	47.6	10.6
Greece	10.1	39.1	16.1
North Korea	10.5	40.1	15.7
Guatemala	7.3	15.7	14.1
New Zealand	4.6	41.8	34.2
Japan	4.5	37.6	47.5
Norway	4.2	64.4	39.2
Italy	3.6	42.8	38.6
Spain	3.0	40.2	64.4
Vietnam	2.9	16.7	41.3
Sweden	2.2	62.8	56.6
Mexico	1.2	24.0	250.2
South Africa	1.0	29.0	156.2
Greenland	0.7	74.7	271.2
India	0.7	22.9	403.8
Alaska	0.2	64.3	192.0
Venezuela	–0.1	7.1	117.0
China	–0.6	36.6	1,199.4
Russia	–0.7	62.0	2,163.8
Ethiopia	–0.8	8.6	145.2
Australia	–0.8	25.7	985.3
Peru	–1.2	9.2	166.0
Brazil	–2.2	10.8	1,087.6
Antarctica	–2.7	80.4	1,572.2

As we noted earlier, however, modulus area was also positively correlated with latitude, $r = 0.21$. When we correlated modulus area with relative estimated area, we found a negative relationship, $r = -0.36$, indicating a moderate tendency for smaller regions to be relatively overestimated, as compared to larger regions. In fact, all of the most overestimated regions were small regions. Switzerland was overestimated by an index of 26.0 and Denmark by 25.4; the next most overestimated regions were Austria, North Korea, Greece, and Guatemala (the latter being found at 16° latitude). In contrast, the most underestimated regions tended to be large regions; Antarctica was underestimated by an index of –2.7 and Brazil by –2.2. The next most underestimated regions were Peru, Australia, and Ethiopia. China and Russia, the other two regions in the stimulus set that are larger than the conterminous United States, were both underestimated in area. Thus, although we found a weak suggestion that regions toward the poles were more overestimated, we found even more so that small regions were overestimated. Given that smaller regions were more common toward the equator, our evidence argues against the existence of patterns of distortion consistent with a Mercator Effect on the projection of the global-scale cognitive map.

To do this, we compared participants' estimates of land areas with the areas as depicted on two common global-scale map projections, the Mercator and the Robinson projections. These projection areas were standardized against 1,000 for the area of the conterminous United States in that particular projection ("Mercator modulus area" and "Robinson modulus area"). Thus, for example, regions more equatorial than the conterminous United States would be relatively smaller on the Mercator projection than in actuality; regions more polar than the conterminous United States (including Alaska) would be relatively larger on the Mercator projection than in actuality. We correlated participants' area estimates for each region with the calculated modulus area of the region as depicted on the two projections; because these correlations compare regions to themselves, these correlations did not require corrections for the modulus areas of the regions. As in our previous analyses, we calculated a correlation across the twenty-six regions for each of the 194 participants, transforming them with Fisher's r-to-z and averaging across participants.

The correlation of participants' estimates with Mercator modulus areas was positive but only moderate, $r = 0.39$. The correlation with Robinson modulus areas was much stronger, $r = 0.77$. Neither, however, was as strong as the correlation reported earlier with standard, unprojected modulus areas, $r = 0.82$. Thus, it does not appear that the Mercator projection has left a discernible influence on the projection of the global-scale cognitive map in our sample of participants. Area estimates of world regions correspond most clearly with the actual areas of the regions.

Finally, we examined knowledge ratings for each region (Table 2). The mean value of all of the knowledge ratings, across all twenty-six regions and 194 participants, was 3.2. This indicates a fairly low level of knowledge on our ten-point scale. Participants felt the most knowledgeable about Mexico, with a mean knowledge rating of 6.2 ($SD = 2.1$). They thought they were least knowledgeable about Greenland, with a mean knowledge rating of 1.8 ($SD = 1.6$). It seems reasonable to expect that region familiarity would predict estimated area, or at least error in estimated area. This does not appear to be the case, however. The correlation of relative estimation accuracy with region familiarity was negligible, $r = -0.10$. Further, the correlation of the absolute value of relative estimation accuracy (i.e., ignoring the direction of over- or underestimation) with region familiarity was also very small, $r = -0.15$. So more familiar regions were estimated more accurately, but only slightly so.

Discussion

On average, our participants did a rather good job at estimating areas of the twenty-six regions presented to them, at least in a relative sense, as indicated by the high correlation of estimated area with modulus area ($r = 0.82$). Our data are fit well by a power function, as is normally found with estimates of area and other stimulus dimensions in psychophysics. The mean exponent of our power function is 0.56 ($r^2 = 0.65$), a positive but decelerating function. This power function exponent is quite a bit smaller than exponents that are found for estimating areas while visually perceiving stimuli (see Baird 1970), but it is about the same value that has been found in studies of area estimation from memory (Kerst and Howard 1978; Brown and Siegler 1993). This small exponent indicates substantial compression of area estimates as the area of the region being estimated increases.

We also find that the tendency to overestimate a region's area correlates only very weakly with increasing latitude (distance from the equator). This is seen most clearly when we calculate relative estimation accuracy, which expresses overestimates as positive ratios of modulus area and underestimates as negative ratios of area. Distance from the equator has only a weak relationship to relative estimation accuracy. Instead, as suggested by the power function, actual area appears to be the strongest determinant of relative estimation accuracy: Small regions are overestimated a great deal; large regions are underestimated, although not as strongly. Given that smaller regions in our stimulus set are more common toward the equator, our evidence argues against the existence of patterns of distortion consistent with a Mercator Effect on the projection of the global-scale cognitive map. The smallest regions are most overestimated, although they are a little closer to the equator on average.

Our strongest evidence against the existence of a Mercator Effect comes when we directly compare area estimates to areas as depicted on two common map projections, the Mercator and the Robinson. Estimates of area are more strongly correlated with actual areas than with either projection areas and, in particular, correlations with Mercator areas are quite weak. Almost 70 percent of the variance in estimated area is shared with variance in actual area, whereas the variance of estimates is only about 15 percent shared with variance in Mercator area. Evidently, the projection of the cognitive map is based on globes, on equal-area projections such as the sinusoidal, or on nonpictorial sources of areal information (e.g., ordered lists of land area) that are accurately interpreted. We return to this point in the General Discussion.

Study 2: Graphical Estimation of Area from Memory

Participants in Study 1 estimated areas from memory, and their estimates were expressed with numerical magnitude estimation. The source (or sources) of our participants' somewhat distorted beliefs about land areas may have expressed itself at any of several steps in the cognitive process of recalling and estimating areas. Participants might have received distorted input information about areas (as from distorted projections), they might have introduced distortion when encoding the information for storage in memory, or they might have introduced distortion when recalling the areas and translating them into numbers for expression as magnitude estimates. In addition, random or nonsystematic errors could have entered at any stage. It is possible in Study 1 that participants erred in the recall and estimation step, insofar as they might have misinterpreted which region they were actually estimating, based as it was on only verbal labels. For instance, a simple addition of two letters could lead to confusion between Austria and Australia, two countries differing greatly in area. Or errors in recall could simply be a result of confusion of a region with a neighboring region. Furthermore, translating recalled areas into numbers is likely to be a complex and error-prone process for some participants; one must figure out the proper ratio of numerical magnitude to 1,000 that is equivalent to the ratio of recalled area to the area of the conterminous United States. We attempted to control for some of these possible confusions in our second study and produce area estimates that more cleanly reflect input and encoding contributions to distortion. To do this, we used a graphical method for obtaining area estimates for geographic regions.

Methods

Participants. A total of thirty-three students (sixteen female, seventeen male) from an introductory undergraduate human geography course took part in the study. As in Study 1, the students were primarily nongeography majors born in the United States (90.9 percent), with a mean age of 20.3 years. They received a small amount of course credit for their participation. Participants from the first study were not allowed to participate in this study.

Materials. Participants estimated the areas of the same twenty-six regions as in Study 1 (Table 1 and Figure 2). Area was estimated graphically with interactive computer displays, programmed on computers that were set up to collect data for this study. On each computer, participants were presented with an Internet browser window showing a Macromedia Flash application that allowed them to graphically scale each region to select its correct size relative to the conterminous United States, the outline of which was shown for each region being estimated. A screen shot from the interface is shown in Figure 4. To use this display, participants modified the size of the test region using a slider bar until they felt that the region was the appropriate size relative to the image of the conterminous United States shown on the screen. A maximum and minimum area value was selected for each region, and these values set the range within which the participants could estimate the area of the regions. The minimum value was assigned to the far left position of the slider bar, and the maximum value was assigned to the far right position of the slider bar. The minimum and maximum values for each region were calculated based on the range of estimates received in the first study; the actual value for each region fell within this range in all instances. The starting size of the image of each region was the median of the minimum and maximum values, set at the midpoint on the slider bar. The range of values provided a wide selection of potential area estimates to the participants while ensuring that there was no consistent "correct" position on the slider bar (i.e., the central point on the slider was not the actual area, nor were either of the extreme values).

After the participant indicated that he or she had set the region to the "correct" size, the Flash application automatically converted the image size to a numeric area measure; the participants did not personally make

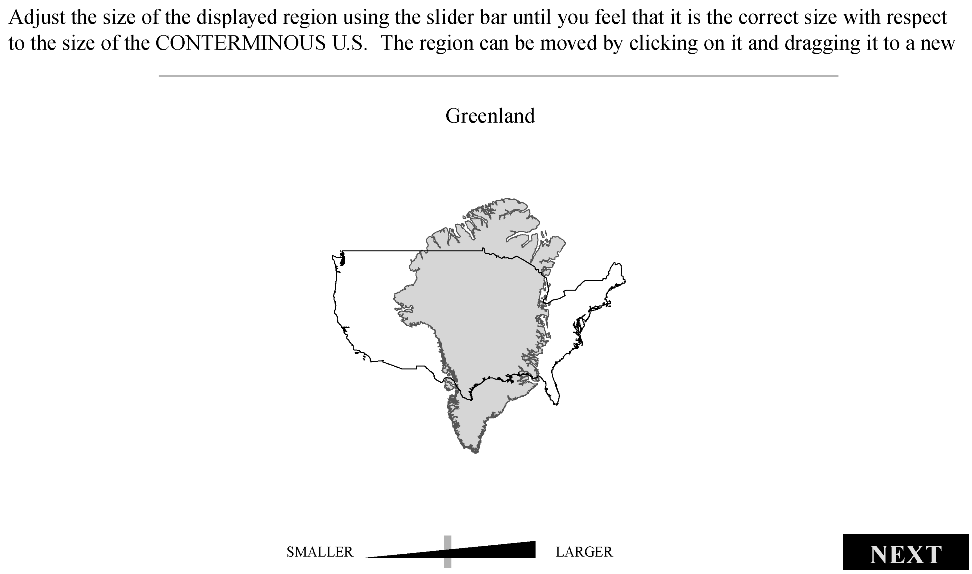

Figure 4. The graphical interface used by participants in Study 2.

any numeric estimates of area. When the area of the regions was calculated based on the size of the image, the numbers were normalized to the same standard used in the first study—the conterminous United States as 1,000 units—so that they could be compared to the results of the first study.

Participants in this study completed the same background surveys as did the participants in the first study. They again rated their knowledge of each region on ten-point scales, ranging from 0 (no knowledge) to 10 (extensive knowledge).

Procedure. After completing the background survey, participants rated their knowledge of each region. They then estimated the area of each region, using the graphical estimation displays. Each participant estimated the area of the twenty-six regions, presented in one of the same ten random orders as in the first study. Unlike Study 1, the regions were presented pictorially as graphical outlines as well as verbally labeled.

Results

The mean area estimates for each region are presented in Table 4. The areas of the estimated region outlines were tabulated by the program and then translated into numerical values equivalent to magnitude estimates relative to the modulus of 1,000 for the conterminous United States, as in Study 1. We again calculated a Pearson correlation coefficient between modulus area and estimated area by aggregating across correlations calculated separately for each participant. Across participants, the correlation between modulus area and estimated area was again quite high, $r = 0.88$. As with magnitude estimation, participants did a good job of estimating the relative areas of the regions.

Table 4. Modulus areas, mean estimated areas, and mean knowledge ratings for each region, Study 2

Region	Modulus area	Mean estimated area	Mean knowledge rating
Denmark	5	114	2.4
Switzerland	5	118	2.9
Austria	11	140	2.6
Guatemala	14	113	2.7
Greece	16	156	3.2
North Korea	16	140	3.8
New Zealand	34	127	2.9
Italy	39	159	4.8
Norway	39	174	2.4
Vietnam	41	113	3.5
Japan	47	115	4.6
Sweden	57	171	2.9
Spain	64	362	4.8
Venezuela	117	234	3.2
Ethiopia	145	181	2.4
South Africa	156	310	3.9
Peru	166	272	3.5
Alaska	192	259	4.3
Mexico	250	439	6.1
Greenland	271	572	2.4
India	404	713	3.9
Australia	985	988	4.4
Brazil	1,088	787	4.1
China	1,199	1,989	4.3
Antarctica	1,572	2,340	2.7
Russia	2,164	3,015	4.2

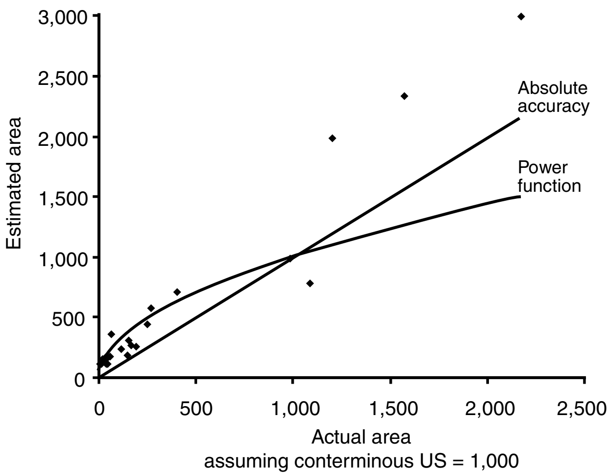

Figure 5. The psychophysical graph plotting estimated areas against modulus areas, Study 2. Absolutely accurate estimation is represented by the straight diagonal line; the best fitting power function is also shown.

We again predicted the estimated areas as a power function of the modulus areas separately for each participant. Across participants, the mean of these thirty-three exponents was 0.56 ($r^2 = 0.63$), again positive and less than 1.0. The psychophysical function that plots mean estimated areas against modulus areas for Study 2 is shown in Figure 5.

We correlated estimated areas for the regions with their mean latitudes. This correlation was again positive but small, $r = 0.27$. Next, we calculated the index of relative estimation accuracy (see Equations 4 and 5) for each region. These are presented in Table 5, ordered from greatest overestimation to greatest underestimation. Absolute latitudes and modulus areas are again shown for comparison. For the most part, the order of the regions is very similar to the order in Study 1. As in Study 1, there appears to be only a very weak relationship between latitude and estimation accuracy. The correlation of absolute latitude with relative estimation accuracy is again positive but very small, $r = 0.18$. The most overestimated regions were again Switzerland, Denmark, Austria, Greece, and North Korea (the order of the last two was switched from Study 1). No regions were as underestimated in Study 2 as in Study 1, but the most underestimated again included Brazil, Australia, and Ethiopia. The clearest difference from Study 1 was that Russia, China, and Antarctica were actually overestimated slightly in Study 2.

Modulus area was again negatively correlated with relative estimation accuracy, $r = -0.31$. This is about the same relationship that was found in Study 1 ($r = -0.36$). This again indicates a moderate tendency for smaller regions to be relatively overestimated, as compared to larger regions. As in Study 1, all of the most overestimated regions were small regions. The most underestimated regions again tended to be large regions, although not as clearly as in Study 1. Like Study 1, actual region size predicted estimation accuracy more clearly than did latitude, arguing against a Mercator Effect on the projection of the global-scale cognitive map.

Table 5. Relative estimation accuracy, mean absolute latitudes, and modulus areas for each region, Study 2

Region	Relative estimation accuracy	PMean absolute latitude°	Modulus area
Switzerland	20.8	46.8	5.4
Denmark	20.5	56.0	5.3
Austria	12.2	47.6	10.6
Greece	8.5	39.1	16.1
North Korea	7.9	40.1	15.7
Guatemala	7.0	15.7	14.1
Spain	4.6	40.2	64.4
Norway	3.4	64.4	39.2
Italy	3.1	42.8	38.6
New Zealand	2.7	41.8	34.2
Vietnam	1.6	16.7	41.3
Sweden	1.9	62.8	56.6
Japan	1.0	37.6	47.5
Greenland	1.0	74.7	271.2
Venezuela	0.8	7.1	117.0
Mexico	0.7	24.0	250.2
South Africa	0.7	29.0	156.2
India	0.6	22.9	403.8
China	0.4	36.6	1,199.4
Russia	0.3	62.0	2,163.8
Antarctica	0.2	80.4	1,572.2
Peru	0.1	9.2	166.0
Alaska	−0.1	64.3	192.0
Ethiopia	−0.1	8.6	145.2
Australia	−0.5	25.7	985.3
Brazil	−1.6	10.8	1,087.6

We next correlated area estimates directly with area as projected by the Mercator and Robinson projections. The correlation of participants' estimates with Mercator modulus areas was again positive, $r = 0.55$, which is larger than in Study 1. So it again does not appear that the Mercator projection has left a discernible influence on the projection of the global-scale cognitive map in our sample of participants. The correlation with Robinson modulus areas was again much stronger, $r = 0.88$, which is exactly the same as the correlation of estimated areas with modulus areas. Thus, we cannot discriminate between an influence of the Robinson projection and veridical areas. In any case, Robinson areas are strongly correlated with actual land areas, $r = 0.95$, so we would expect similar correlations of estimates with the two. In contrast, Mercator areas are correlated much less with actual land areas, $r = 0.53$.

Our results in Study 2 appeared similar to those of Study 1. To evaluate this formally, we compared the estimates in Study 2 to those in Study 1 with a mixed-model analysis of variance. Study served as a between-subject variable (with two levels) and region served as a repeated-measures variable (with twenty-six levels); the multivariate approach was used to analyze the repeated-measures factors. Not surprisingly, the main effect of region was significant, $F(25, 191) = 31.35$, $p < 0.0001$. More important, the main effect of study also reached significance, $F(1, 215) = 6.91$, $p < 0.01$. The mean estimate in Study 1 was 444.1 units (relative to the standard area), smaller than the mean estimate of 542.3 found in Study 2. This difference, though, must be interpreted in light of a significant statistical interaction between study and region, $F(25, 191) = 3.56$, $p < 0.0001$. This interaction means that all regions were not estimated differently across the two studies in the same way; that is, the difference between the estimates of a given region in the two studies was not the same difference found for other regions in the two studies. To interpret this interaction, we compared the estimates for each region across the two studies, in a series of pairwise comparisons. These results are shown in Table 6. Applying a correction for alpha inflation, only seven of the twenty-six region estimates are significantly different in the two studies. In all but one of these comparisons, the estimate from Study 2 is larger than from Study 1. Also, five of the seven are the five largest regions in the stimulus set, and for all five, estimates from Study 2 were larger. Examining Table 6 reveals that the rank ordering of area estimates was quite comparable in the two studies. In fact, four of the five regions with the smallest estimates in Study 1 were in the set of the five smallest estimates in Study 2, and four of the five regions with the largest estimates in Study 1 were in the set of the five largest estimates in Study 2. These results suggested that the two estimation methods produced rather similar estimation patterns, except that the graphic estimation method in Study 2 led to larger estimates for larger regions, as compared to the numerical magnitude estimates in Study 1.

Finally, we again examined knowledge ratings for each region (Table 4). The mean value of all of the knowledge ratings in Study 2 was 3.6 on our ten-point scale, about the same as in Study 1, which suggests that participants in Study 2 were comparable to those in Study 1. As in Study 1, relative estimation accuracy in Study 2 did not correlate much with region familiarity, $r = -0.17$, nor did absolute accuracy correlate much with region familiarity, $r = -0.18$. Again, more familiar regions were estimated more accurately, but only slightly so.

Table 6. Paired comparisons of mean estimates in Study 1 versus Study 2, for each region, ordered from smallest to largest area

Region	Study 1	Study 2	*t* test
Denmark	139.9	113.8	1.05
Switzerland	147.2	117.8	0.96
Austria	159.3	140.3	0.59
Guatemala	118.7	113.1	0.29
Greece	174.7	155.7	0.61
North Korea	166.2	140.2	0.54
New Zealand	189.5	126.9	1.75
Italy	173.6	158.8	0.62
Norway	203.6	173.8	0.98
Vietnam	159.6	113.5	1.41
Japan	261.5	114.5	2.73**
Sweden	179.6	171	0.3
Spain	256.3	361.7	−1.78
Venezuela	182	233.7	−1.88
Ethiopia	168.4	180.5	−0.47
South Africa	385.9	310.2	0.87
Peru	163.7	272.3	−3.34***
Alaska	321.7	259.3	1.09
Mexico	554.4	438.6	1.16
Greenland	524.1	572	−0.59
India	765.7	713.5	0.34
Australia	740.1	987.6	−3.17**
Brazil	612.2	787.2	−1.99*
China	1,424.20	1,988.60	−2.75**
Antarctica	1,241.00	2,339.60	−5.72****
Russia	2,047.50	3,015.30	−2.32*

Note: Bonferroni corrections are applied to adjust the significance probabilities as a protection against alpha inflation. * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$. **** $p < 0.0001$.

Discussion

Our participants estimated the areas of world regions using a graphical estimation method quite similar to their estimates using magnitude estimate in Study 1. The estimates were again accurate, at least in a relative sense, with a correlation of estimated and modulus areas of $r = 0.88$. The exponent of the power function fit to these estimates was 0.56, similar to that found in Study 1 but a little larger. The exponent was larger because estimates of the largest regions were not as small as in Study 1; there was again a strong tendency for participants to overestimate the areas of small regions, but large regions were not particularly underestimated. Ironically, this reduced compression of larger areas in Study 2 may have occurred because of the perceptual compression during graphical estimation that would not have occurred during numerical estimation in Study 1. In Study 2, participants would have adjusted the graphical size of large regions upward to make them appear "correct" in size, compensating for compression occurring during visual perception. Relatively small differences in the nature of the psychophysical function aside, however, there was again little or no relationship of area estimates with absolute latitude in Study 2.

When area estimates were correlated with modulus areas as projected by the Mercator projection, we again found little support for the existence of a Mercator Effect on the projection of global-scale cognitive maps. Estimates did correlate as well with the Robinson projection as with actual areas, but given the very strong correlation between Robinson and actual areas, this provides no evidence for the effect of the Robinson projection. Thus, the results of Study 2 show that area estimates are fairly similar across very different methods for externalizing the cognitive map, contrary to the idea that externalization methods drive the results of research on cognitive maps (e.g., Kitchin 1996). This suggests, in turn, that any distortions people have about region areas are mostly not determined by the process of externalizing those areas in the form of numbers (in magnitude estimation) or adjusted picture sizes (in graphical estimation). As we discuss further later, beliefs about region areas must stem primarily from a combination of the nature of input information, memory encoding, and memory decoding.

General Discussion and Conclusions

Not only are cognitive maps stretched and warped representations of reality, so are all map projections. At extremely large scales (small scales cartographically), globes and map projections are the only practical methods for examining the overall picture of the Earth's surface. Because map projections provide the only continuous view of Earth's surface—even a globe must be rotated and mentally "stitched" together—most people have become familiar with the general layout of Earth using distorted representations of it. Because of this, it has been suggested that the distortion in map projections strongly influences the shape of an individual's global-scale cognitive map. According to critical claims over the past several decades, the most dramatic such influence—some would say insidious—has been that of the Mercator projection. The Mercator projection has been recalled by many as the projection of the world maps hanging on classroom walls (e.g., Saarinen, Parton, and Billberg 1996), deemed a "master image" (Vujakovic 2002), and listed as a likely influence in distorting the shape of global-scale cognitive maps (Lloyd 2000). This very over- and misused projection during much of the twentieth century radically exaggerates the areas of polar landmasses relative to tropical and subtropical lands and would have a noticeable and distinct influence on the measured shape of cognitive maps—if internalized in an unmodified form.

In fact, we began this work believing that any distortions in areas on the global-scale cognitive map would come primarily from visual representations (i.e., maps) that the participants in our studies were familiar with previously, and that Mercator may be one of these familiar visual representations. This proved not to be evident. As the area estimates in both of our studies were highly correlated with the modulus areas of the regions, and not with areas from the common Mercator or Robinson map projections, it appears that the areas of regions as represented in the cognitive map approximate the actual areas of the regions relatively well. We did find that Greenland, an "indicator" country for Mercator estimation patterns, was a bit overestimated in both studies, although not nearly as much as many smaller countries, including several that are in or near the tropics. In contrast, Antarctica is the most polar region in our stimulus set (indeed, on our planet) and is radically exaggerated in size on a Mercator projection, but it was the region most underestimated in Study 1 and was barely overestimated in Study 2. Alaska is another region that is greatly exaggerated in size on a Mercator projection, but it was estimated nearly perfectly in both studies.

Thus, we found no evidence for a Mercator Effect in our studies, which would lead to increasing estimates of area as landmasses become more distant from the equator. Nor did we find any other clear patterns of distortion corresponding to particular geographic variables (e.g., distance from the United States). If our participants were, in fact, making their area estimates based on a single unified global-scale "map in the head," either they have been exposed mostly to equal-area projections or to globes (which are nearly always equal area) or they were adept at compensating for areal distortion on map projections when forming or using their cognitive maps.

If our participants were primarily exposed to equal-area (or near equal-area) projections or globes, this, in itself, would indicate that the pervasiveness of the Mercator projection is not as common as it may have been in the past; if so, the Mercator has had little opportunity to influence cognitive maps for the generation of students participating in these studies. Although Monmonier (2004) has given the example that it is still possible to encounter the Mercator projection in classrooms, an informal survey conducted by the authors has indicated that Mercator projections are not common for modern-day classroom world maps, at least according to the products offered by several educational supply companies. For instance, Rand McNally notes in their Maps & Globes catalog for K–12 educators that their world maps use an "educationally sound Robinson projection." On the other hand, Internet mapping and navigation programs are among the most common source of exposure to maps in the early twenty-first century. In fact, Google uses the Mercator projection for its online maps, and Rand McNally uses a similar non-equal-area projection for its maps. So although our evidence clearly shows that the Mercator and other non-equal-area projections (such as the Robinson) have not had undue influence on the cognitive maps of the college-age participants in our studies, it does not appear that a lack of exposure to such projections explains this.

As for the notion that participants were particularly adept at compensating for distortions introduced in map projections, these distortions are complicated even for experts to understand, let alone American college students (e.g., Downs and Liben 1991; Anderson and Leinhardt 2002). Furthermore, such a compensation begs the question of how people could form accurate mental representations of area—it would require at least implicit accurate knowledge of land areas for accurate compensation to occur. We do not therefore find the compensation explanation to be feasible. Instead, we believe it is likely that our participants did not make their estimates based on a single unified global-scale map in the head that mirrors distortion in commonly seen map projections. People store multiple representations about different parts of the world, and these representations contain content derived from multiple sources. Furthermore, when externalizing these representations, such as when estimating areas, people draw on a variety of belief sources and inferences to arrive at their externalization (e.g., Friedman and Montello 2006). These sources include a variety of different map projections, map formats, map scales, and globes. They also include nonpictorial sources such as the amount of coverage of a region in news stories or the political or economic power of a region.

Based on this, we believe that when estimating areas from memory, it is likely that people use more of an atlas-style representation, rather than a single global-scale map representation. When thinking about space and place, information is often derived from multiple sources, with the relevant parts assembled into a single active representation useful for the task at hand. When recalling information about global-scale spaces, it is not necessary for individuals to use a single global-scale representation to answer questions about characteristics such as the area of regions. Considering that estimates in these studies are based on relative area and a modulus region that is, with one exception, on a different continent, it appears that participants used a "cognitive atlas" as a reference rather than a single map including all of the regions between the modulus and the region being estimated. Use of an atlas-style representation in itself could introduce the pattern of over- and underestimation that we found due to the fact that atlases often compress large regions and expand small regions to fit onto a single page. This would lead to a pattern similar to what was seen in our participants' estimates—large regions tended to be more underestimated and small regions tended to be more overestimated.

On the other hand, our results of underestimated large stimuli and overestimated small stimuli are also in line with those often seen in psychophysical estimation exercises generally, not just those investigating area as a property. From this it could be said that people really use a global-scale, "single sheet" cognitive map that is equal area and that their area estimates are only influenced by standard psychophysical estimation trends (i.e., the data being well fit by a power function with a positive exponent less than 1.0). Although we can still question whether the patterns we found result from the estimation process, the geographical structure of the cognitive map, or a combination of these factors, we have shown that there is no distinct connection between distortion in map projections and the way individuals estimate land areas. In particular, there is no apparent Mercator Effect warping the size of our cognitive maps. Area estimates of world regions correspond most clearly with the actual areas of the regions.

Acknowledgments

Portions of this research were presented in talks by the authors at the Association of American Geographers meetings in 2004 and 2005. We would like to express our thanks to Reginald G. Golledge and Mary Hegarty at the University of California, Santa Barbara, for their invaluable feedback. We would also like to express our thanks to the students who participated in our studies.

Note

1. We note that this approach to calculating correlations across the twenty-six regions—calculating individual correlations for each participant and then averaging over participants—more accurately reflects the expression of relationships for each participant than would aggregating variables across participants and then correlating (i.e., averaging estimated areas for each region and correlating the mean estimates with variables such as modulus area). The approach of averaging across participants before correlating can produce strongly misleading correlations, including artifactually weak or strong relationships, or even relationships in the opposite direction (this is convincingly demonstrated by Ewing 1981).

References

American Cartographic Association. 1989. Geographers and cartographers urge end to popular use of rectangular maps. *American Cartographer* 16 (3): 222–23.

Anderson, K. C., and G. Leinhardt. 2002. Maps as representations: Expert–novice comparison of projection understanding. *Cognition and Instruction* 20 (3): 283–321.

Baird, J. C. 1970. *Psychophysical analysis of visual space*. Oxford, UK: Pergamon.

Baird, J. C., A. A. Merrill, and J. Tannenbaum. 1979. Cognitive representation of spatial relations: II. A familiar environment. *Journal of Experimental Psychology: General* 108 (1): 92–98.

Brown, N. R., and R. S. Siegler. 1993. Metrics and mappings: A framework for understanding real-world quantitative estimation. *Psychological Review* 100 (3): 511–34.

Chang, K.-T. 1980. Circle size judgment and map design. *American Cartographer* 7 (2): 155–62.

Chiodo, J. J. 1997. Improving the cognitive development of students' mental maps of the world. *Journal of Geography* 96 (3): 153–63.

Cohen, J., and P. Cohen. 1983. *Applied multiple regression/correlation analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Downs, R. M., and L. S. Liben. 1991. The development of expertise in geography: A cognitive-developmental approach to geographic education. *Annals of the Association of American Geographers* 81 (2): 304–27.

Downs, R. M., and D. Stea. 1973. *Image and environment*. Chicago: Aldine.

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, 1–15. Lecture Notes in Computer Science 988. Berlin: Springer.

Ewing, G. O. 1981. On the sensitivity of conclusions about the bases of cognitive distance. *The Professional Geographer* 33 (3): 311–14.

Flannery, J. J. 1971. The effectiveness of some common graduated point symbols in the presentation of quantitative data. *Canadian Cartographer* 8 (2): 96–109.

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

Friedman, A., and D. R. Montello. 2006. Global-scale location and distance estimates: Common representations and strategies in absolute and relative judgments. *Journal of Experimental Psychology* 32 (3): 333–46.

Gescheider, G. A. 1997. *Psychophysics: The fundamentals* (3rd ed.). Mahwah, NJ: Erlbaum.

Golledge, R. G. 1987. Environmental cognition. In *Handbook of environmental psychology*, ed. D. Stokols and I. Altman, 131–74. New York: Wiley.

Griffin, T. L. C. 1985. Group and individual variations in judgment and their relevance to the scaling of graduated circles. *Cartographica* 22 (1): 21–37.

Hitchcock, L., D. R. Brown, K. M. Michels, and T. Spiritoso. 1962. Stimulus complexity and the judgment of relative size. *Perceptual and Motor Skills* 14 (2): 210.

Kerst, S. M., and J. H. Howard. 1978. Memory psychophysics for visual area and length. *Memory & Cognition* 6 (3): 327–35.

Kitchin, R. M. 1996. Methodological convergence in cognitive mapping research: Investigating configurational knowledge. *Journal of Environmental Psychology* 16 (3): 163–85.

Krider, R. E., P. Raghubir, and A. Krishna. 2001. Pizzas: Pi or square? Psychophysical biases in area comparisons. *Marketing Science* 20 (4): 405–25.

Lloyd, R. 1997. *Spatial cognition: Geographic environments*. Dordrecht, The Netherlands: Kluwer.

———. 2000. Self-organized cognitive maps. *The Professional Geographer* 52 (3): 517–31.

MacEachren, A. M. 1995. *How maps work: Representation, visualization, and design*. New York: Guilford.

MacKay, D. B. 1976. The effect of spatial stimuli on the estimation of cognitive maps. *Geographical Analysis* 8 (4): 439–52.

MacKay, D. M. 1963. Psychophysics of perceived intensity: A theoretical basis for Fechner's and Stevens' laws. *Science* 139 (3560): 1213–16.

Martinez, N., and W. E. Dawson. 1973. Ranking of apparent area for different shapes of equal area. *Perceptual and Motor Skills* 37 (3): 763–70.

McNamara, T. P. 1992. Spatial representation. *Geoforum* 23 (2): 139–50.

Monmonier, M. 2004. *Rhumb lines and map wars: A social history of the Mercator projection*. Chicago: University of Chicago Press.

Montello, D. R. 1993. Scale and multiple psychologies of space. In *Spatial information theory: A theoretical basis for GIS*, ed. A. U. Frank and I. Campari, 312–21. Berlin: Springer-Verlag.

———. 2002. Cognitive map-design research in the twentieth century: Theoretical and empirical approaches. *Cartography and Geographic Information Science* 29 (3): 283–304.

Montello, D. R., D. Waller, M. Hegarty, and A. E. Richardson. 2004. Spatial memory of real environments, virtual environments, and maps. In *Human spatial memory: Remembering where*, ed. G. L. Allen, 251–85. Mahwah, NJ: Erlbaum.

Pinheiro, J. Q. 1998. Determinants of cognitive maps of the world as expressed in sketch maps. *Journal of Environmental Psychology* 18 (3): 321–39.

Robinson, A. H. 1952. *The look of maps*. Madison: University of Wisconsin Press.

———. 1990. Rectangular world maps—No! *The Professional Geographer* 42 (1): 101–4.

Saarinen, T. 1988. Centering of mental maps of the world. *National Geographic Research* 4 (1): 112–27.

———. 1999. The Eurocentric nature of mental maps of the world. *Research in Geographic Education* 1 (2): 136–78.

Saarinen, T., M. Parton, and R. Billberg. 1996. Relative size of continents on world sketch maps. *Cartographica* 33 (2): 37–47.

Smets, G. 1970. When do two figures seem equal in size? *Perceptual and Motor Skills* 30 (3): 1008.

Snyder, J. P. 1993. *Flattening the Earth*. Chicago: The University of Chicago Press.

Stevens, S. S. 1970. Neural events and the psychophysical law. *Science* 170 (3962): 1043–50.

Teghtsoonian, M. 1965. The judgment of size. *American Journal of Psychology* 78 (3): 392–402.

Thorndyke, P. W., and B. Hayes-Roth. 1982. Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology* 14 (4): 560–89.

Tversky, B. 2000. Remembering spaces. In *The Oxford handbook of memory*, ed. E. Tulving and F. I. M. Craik, 363–78. Oxford, UK: Oxford University Press.

Vujakovic, P. 2002. Mapping the war zone: Cartography, geopolitics, and security discourse in the UK press. *Journalism Studies* 3 (2): 187–202.

Yang, Q. H., J. P. Snyder, and W. R. Tobler. 2000. *Map projection transformation: Principles and applications*. London and New York: Taylor & Francis.

Correspondence: Department of Geography, University of South Carolina, Columbia, SC 29208, e-mail: battersby@sc.edu (Battersby); Department of Geography, University of California at Santa Barbara, Santa Barbara, CA, 93106–4060, e-mail: montello@geog.ucsb.edu (Montello).