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Updating Geographical Knowledge: Principles of Coherence and Inertia

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In 2 experiments, the authors investigated how representations of global geography are updated when people learn new location information about individual cities. Participants estimated the latitude of cities in North America (Experiment 1) and in the Old and New Worlds (Experiment 2). After making their first estimates, participants were given information about the latitudes of 2 cities and asked to make a second set of estimates. Both the first and second estimates revealed evidence for psychologically distinct geographical subregions that were coordinated, in an ordinal sense, across the Atlantic Ocean. Further, the second estimates were affected by the nature of the physical adjacency between regions (e.g., the southern U.S. and Mexico) and by accurate location information about distant, but coordinated, subregions (e.g., the southern U.S. and Mediterranean Europe). The data provide support for a framework for making geographical estimates in which people strike a balance between 2 principles: the need to keep their knowledge base coherent, and the inertial tendency to resist changing the knowledge base unless it is necessary to maintain coherence.

People acquire knowledge about the world across the lifespan. This simple fact implies that new knowledge is acquired in the context of prior knowledge and that the content, and perhaps the structure, of the knowledge base changes to reflect this learning. Obviously, the capacity to integrate new knowledge with old is an extremely important one, for without it, we could not adapt to the changing physical, social, and intellectual environment. Yet little is known about how newly acquired facts affect our understanding in complex, real-world domains. The present study was motivated by an interest in this issue, and it represents an attempt to identify principles that determine how and when knowledge changes in response to new information. Specifically, we argue that two principles—*coherence* and *inertia*—play a central role in determining how people update real-world knowledge. We present two experiments that use a *seeding procedure* (Brown & Siegler, 1993, 1996; Friedman & Brown, 2000), in which people are given location information about a small number of cities, to demonstrate these principles at work. In both experiments, participants first estimated the latitude of a set of cities. Then they learned the actual latitudes of two cities and provided a second set of estimates. The comparison between the first and second estimates provides the basis for inferences about the psychological principles and processes underlying the integration of new information with prior knowledge.

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Perhaps updating knowledge is not better understood because of the considerable difficulties involved in characterizing real-world knowledge and in demonstrating the impact or delimiting the influence of new information that is presented as factual. Although subjective geography—the focus of the present study—is a complex area, our prior research has allowed us to characterize geographical knowledge and to understand the processes used when people make geographical judgments. In addition, we have been able to use changes in estimated latitude and longitude following exposure to new information to quantify the impact of new knowledge and the extent of its influence (Friedman & Brown, 2000).

We proposed a plausible reasoning framework to describe how people reason about geography in particular, as well as to account for how people make judgments in complex, real-world domains in which knowledge is limited and is learned from a variety of sources. The framework also describes how valid conceptual information can yield systematically biased location estimates. We obtained evidence for our main assumptions by examining latitude and longitude estimates (Friedman & Brown, 2000), bearing estimates (Friedman, Brown, & McGaffey, 1999), and temperature estimates (Friedman et al., 1999). We also documented two types of geographical seeding effects (described next): inheritance-based shifts and adjacency-based shifts (Friedman & Brown, 2000, Experiments 2–4).

In the present study, we extend the theory and generalize our previous findings in three ways. First, several possible mechanisms could produce adjacency-based shifts; here, we determine that the physical nature of the adjacency between regions plays a more important role in the postseeding adjustments than do the numerical values of the seeds themselves. Second, we previously speculated that certain regions were "conceptually coordinated" across the Atlantic Ocean, based on beliefs about geographical, conceptual, and other knowledge-based similarities (e.g., climate). Here, we provide direct evidence that seeding one of the regions hypothesized to belong to a conceptually yoked pair influences judgments about the distant, "partner" region, thus verifying that the regions are yoked, and that seeds from one region of the globe affect quite distant, and disjoint, regions.

Third, we introduce the theoretical constructs of coherence and inertia. Coherence implies that people update their knowledge base to keep relations consistent between regions believed to be either adjacent or coordinated. In contrast, inertia is the notion that people only update their knowledge base when it is necessary, for instance, when they learn new information that contradicts prior beliefs (Friedman & Brown, 2000). Experiment 2 provides a means of determining whether coherence or inertia dominates the judgments in a situation in which both are possible.

In the remainder of the introduction, we first review what this line of research has taught us about the organization and representation of world geography. Next, we discuss the plausible reasoning framework and the processes that we assume are used to generate location estimates. We then discuss how geographical knowledge is affected by the seeding procedure in the context of the experiments that motivated the present study (Friedman & Brown, 2000).

The Plausible Reasoning Framework: Representing Global Geography

We assume that not all geographical knowledge is spatial in either its origin or its representation (Hirtle & Jonides, 1985; Hirtle & Mascolo, 1986; McNamara, 1986, 1991; McNamara & Diwadkar, 1997; McNamara, Hardy, & Hirtle, 1989; McNamara, Ratcliff, & McKoon, 1984; Montello, 1994; Stevens & Coupe, 1978) and that people have multiple sources of task-relevant knowledge (e.g., Collins & Michalski, 1989) that is represented abstractly: for example, in propositions or networks. We further assume that conceptual, nonspatial knowledge is often used when people reason about world geography and that it is the primary source of geographical biases. In addition, although knowledge of world geography is undoubtedly complex, idiosyncratic, variable, and culturally biased, it also true that logical and spatial relations that organize important geopolitical units (i.e., cities, countries, continents) are relatively simple. We assume these relations play a central role in location estimation tasks and are what is altered by the seeding procedure (see Friedman & Brown, 2000, for a full discussion).

Our prior research indicates that location estimation tasks engage three levels of geographical knowledge: the region, the subregion, and the city (see also Stevens & Coupe, 1978). In most cases, a region is a continent. Well-known and moderately well known continents are divided into subregions, each of which may encompass a set of countries (e.g., Mediterranean Europe), a single country (e.g., Canada), or a partition within a country (e.g., the northern and southern United States; see Friedman & Brown, 2000, Experiment 1).

Finally, some prior research suggests that people align regions (Tversky, 1981) and subregions (Friedman & Brown, 2000; Friedman et al., 1999) in the Old and New Worlds at the same subjective latitudes (e.g., Canadian and northern U.S. cities with northern and central Europe; southern U.S. cities with Mediterranean Europe; Friedman & Brown, 2000, Experiment 1; Friedman et al., 1999). But the subregions are not aligned on the basis of perceptual factors (Tversky, 1981), because there is little discrimination among the cities within them; indeed, the subregions are discontinuous within continents. Thus, we refer to the general tendency to yoke regions or subregions in different continents as *conceptual coordination,* because it occurs when two (sub)regions occupy similar ordinal positions in continents that are physically disjoint.

Estimating Absolute Locations: Process Assumptions

The plausible reasoning framework is based on the idea that judgments about knowledge-rich domains rely on plausible inferences based on partial knowledge (Brown, 1990; Brown & Siegler, 1993; Collins & Michalski, 1989; Friedman & Brown, 2000). We assume that people have various beliefs about a given domain and that they retrieve some of them to draw inferences; an individual's knowledge has different affordances, allowing some inferences to be drawn but not others. Further, the information activated in a given situation may change as a function of prior knowledge, new knowledge, prior responses, and the task itself.

When people are asked to provide latitudes or longitudes for test cities, their responses are rarely correct, but often quite reasonable (Friedman & Brown, 2000). For example, in addition to the regional or subregional membership of cities, we have shown that people have fairly accurate beliefs about the relative locations of the subregions that compose a region, and of the location of different regions relative to one another. They occasionally have knowledge about the relative locations of cities within a subregion. However, the pattern of performance indicates that participants have little explicit knowledge of map coordinates, which rules out the possibility that they perform these tasks simply by retrieving an answer from memory. Rather, it appears that to generate location estimates, participants rely heavily on knowledge about the regional and subregional membership of the test cities combined with beliefs about the relative location of regions and subregions to reference locations—such as the equator, the oceans, and the poles.

We assume that location estimation tasks require a preparatory stage during which participants first decide, perhaps implicitly, on an overall response range, and next divide this range by assigning values to the upper and lower bounds of relevant regions and subregions in a consistent manner. Thus, if one subregion is known to be north of, but adjacent to, a second, the lower bound of the former would be the same as the upper bound of the latter.

Once the ranges for the regions and subregions are established, response generation is accomplished by identifying the target city's immediate superordinate. Next, information is retrieved about the upper and lower bounds of the superordinate, or of a prototypical value that lies somewhere in between the superordinate's upper and lower bound. Finally, in the absence of fine-grained knowledge of the relative location of cities within a region or subregion, a number close to the central value of the superordinate range is selected as a response. Alternatively, if fine-grained knowledge is available, a numerical response is selected from the appropriate portion of the range.

The process of selecting a response from the superordinate response range involves an *inheritance-based inference* because estimates about the coordinates of the possible location of a target city are inherited from, and directly reflect beliefs about, the location of its superordinate region (Huttenlocher, Hedges, & Duncan, 1991). Note that this account correctly predicts that new information about regional boundaries should shift subsequent estimates for all cities within the seeded region, but not necessarily within other regions, by approximately the same amount. It also provides a simple explanation for why *subjective location profiles* (i.e., graphs plotting mean estimates as a function of the subjectively ordered latitudes of the test cities; Friedman & Brown, 2000; see also Figures 1 and 4) often look like step functions.

Updating Geographical Knowledge Through Seed Facts

Inheritance-based shifts occur when exposure to seed facts from a particular (sub)region causes people to modify their beliefs about the location of that (sub)region. For example, they might modify the upper bound, the lower bound, or the location of a prototypical city. More generally, if something is believed to be true of a region, it is generally believed to be true of all members of the region (e.g., Collins & Michalski, 1989; Stevens & Coupe, 1978). Consequently, the knowledge gained from seed facts should be applied to all members of the (sub)region. For example, if southern Europe is believed to be further south than it actually is, and participants learn the actual location of, say, Lisbon (38° north), they should shift all the southern European cities north by an amount that takes account of the discrepancy between their original belief and the new information. Thus, inheritance-based shifts reflect the fact that new information learned about a particular city is likely to generalize to other cities in that region or subregion.

Adjacency-based shifts occur when exposure to seed facts from one region affects postseeding estimates of cities belonging to an adjacent region. We believe that adjacency information operates primarily to change knowledge at the regional (category) level; updated regional knowledge is then inherited by the instances within the category and is used to make subsequent estimates.

One of our previous experiments provides a clear demonstration of both inheritance- and adjacency-based seeding effects (Friedman & Brown, 2000, Experiments 2). The data also implicate coherence and inertia as principles in knowledge updating and thus provide part of the rationale for the present study.

In Friedman and Brown (2000, Experiment 2), when participants estimated the latitudes of a set of southern European and African cities, they displayed a strong tendency to underestimate the location of both regions. After one group learned the actual location of two north African cities (Tunis and Algiers, both located at 37°), their second estimates of both African and European cities shifted north by approximately the same amount (15°), which was substantially less southwardly biased than the initial estimates. In the present terminology, the postseeding change in the African estimates reflected an inheritance-based shift, and the change in the southern European estimates reflected an adjacency-based shift.

In contrast, a second group learned the actual locations of two southern European cities (Lisbon and Athens, located at 39° and 38°, respectively), which were numerically very similar to the African ones. Nevertheless, the European seeds affected postseeding estimates only for southern European cities. In other words, the European seeds produced an inheritance-based shift for European cities but failed to produce an adjacency-based shift for African cities.

The asymmetry of the seeding effects across the two groups led us to speculate that there are at least two principles governing the impact of the new facts on prior knowledge. First, there appears to be a sort of cognitive inertia that prevents people from modifying domain knowledge unless it is absolutely necessary to preserve coherence. This tendency must have been at work when participants in the European seed group assimilated new information about the location of southern Europe but did not modify their estimates of African cities. Inertia may have been abetted because of the flexibility afforded by knowledge about the location of the Mediterranean Ocean, coupled with a certain vagueness regarding its width. Thus, the European seeds informed observers that their metric was wrong about where to locate southern Europe, and perhaps about how wide the Mediterranean is, but did not entail an adjustment of beliefs about the location of the northern border of Africa.

Second, it appears that people will update their knowledge base to maintain its coherence when they learn new facts that directly or indirectly contradict prior beliefs. Regions that are either physically adjacent or conceptually coordinate to the seeded region are good candidates for such updating. For example, the African seeds indicated to participants that the commonly held belief that most of Africa lay south of the equator was wrong, and that they should discard this old belief and adopt a new one. However, the new belief about the absolute location of the northern border of Africa was inconsistent with the knowledge that Europe is north of Africa, combined with the old belief that some southern European cities are close to the equator. Thus, these participants also had to modify their beliefs about the lower bound of Europe to avoid the obvious contradiction. The adjacency-based shift in the southern European estimates thus accommodates the newly learned information about the northern boundary of Africa, yet maintains a coherent representation in which southern Europe is still north of Africa. Moreover, though participants could have modified their estimates of cities in northern Europe by the same amount as they modified their estimates for cities in Mediterranean Europe, they did not have to in order to maintain the original relations among the three regions (northern Europe, Mediterranean Europe, and northern Africa); in fact, the second estimates for cities in northern Europe shifted less than half as much as the second estimates for Mediterranean Europe. The principle of inertia thus permitted the second estimates to change only as much as was required to accommodate the new information, while at the same time maintaining initial beliefs about the ordinal relations between regions.

To summarize, we assume that new location information, in the form of seed facts, provides feedback regarding the accuracy of the quantitative beliefs (or inferences made) about the location of the seeded region and the cities within it. As a result, we assume that these quantitative beliefs are adjusted in a way that is consistent with the feedback, and that beliefs about the quantitative properties of other regions may also be adjusted, but only as much as necessary to maintain coherence in the categorical relations between regions.

Knowledge-Based Constraints on Latitude Estimates

As just noted, we believe participants revise their initial estimates in part because they strive to maintain coherence and consistency in their representations of geographical knowledge. In principle, adjacency relations should be transitive and symmetric. For instance, if A is above B, A can move up or B can move down with no implication for the relation between them. However, the physical nature of the boundaries between geographical regions can have different implications for updating the knowledge base. That is, though it is equally true that Europe is north of Africa and the U.S. is north of Mexico, because of the existence of the Mediterranean, Europe can be moved north without entailing that Africa be relocated, but if the U.S. is moved north, Mexico must move with it. This is an example of what we mean by *local knowledge-based constraints;* they are typically based on knowledge about physical adjacency. We investigate the mechanism underlying adjustments made on the basis of adjacency in Experiment 1.

There may also be *global knowledge-based constraints,* which should result in updates based on the conceptual coordination between regions. Conceptual coordinates have mutual dependencies and implications and thus may be mutually readjusted on the basis of the new information. That is, changes to the location of a region may propagate to regions that are quite distant but that are believed to be similar along some dimension or dimensions relevant to the judgment. For instance, if people associate certain kinds of climates with certain general locations around the globe, then learning that, for example, the location of a city like Athens, Greece is at 38° north latitude may cause them to rethink where other nonadjacent, but conceptually similar, regions are located (e.g., Phoenix, Arizona, or Miami, Florida). In this example, though the regions are physically distant and disjoint, they are nevertheless conceptually coordinated. Experiment 2 provides evidence for the operation of global knowledge-based constraints on the assimilation of new geographical facts.

Experiment 1

Upon learning the correct numerical values of either African or southern European latitudes (i.e., the seed facts), participants who learned the African seeds shifted their estimates for both Africa and southern Europe, but participants who learned the European seeds shifted their estimates only for cities in southern Europe (Friedman & Brown, 2000, Experiment 2). The focus of this experiment was to determine which of two possible adjacency-based mechanisms was responsible for the asymmetry observed in the seeding effects.

It could be that the African cities did not move northward with the southern European seeds because the southern European seeds had no consequent, numerical implications for the relocation of cities in Africa. That is, learning that Lisbon and Athens were further north than previously believed did not contradict any prior knowledge about the relation that Europe is north of Africa. In contrast, the African seeds overlapped numerically with the previously held location of the border of southern Europe, so to keep the relation between the categories consistent, the southern European cities had to be relocated in addition to the African cities. That is, learning that Tunis and Algiers were further north than previously believed also entailed that southern Europe was further north, because the African seeds themselves were numerically larger (more northerly) than the initial estimates of the location of southern Europe. In these examples, the inconsistencies have their origins in the numerical comparison between the first estimates and the seed facts. Thus, one possibility is that cities are relocated only as a function of inconsistencies between prior knowledge (as made explicit by the first estimates) and the new numerical information conveyed by the seeds.

Alternatively, the asymmetry between the postseeding estimates in our previous study may be knowledge based, in that the Mediterranean allowed some flexibility in where southern Europe was located relative to Africa. The principle of inertia dictates that, in this case, the second estimates for African cities would remain close to the initial estimates because it is simpler, and equally consistent with the European seeds, merely to "widen" the Mediterranean than to update all the African estimates.

We prefer the latter alternative. However, because the southern European seeds did not overlap numerically with observers' beliefs about the location of northern Africa, we could not test whether the asymmetry in the second estimates of African cities as a function of new information about Europe was due to the absence of a numerical inconsistency per se or whether knowledge about the existence of a large body of water separating the two regions—the Mediterranean—also played a role. We tested these alternatives in Experiment 1.

We had people provide estimates of the locations of cities in Canada, the northern U.S., the southern U.S., and Mexico. Then we gave them information about the location of two cities and asked for a second set of estimates. Two seed cities from each region that were relatively northerly (San Diego and Tijuana, 33°) were factorially combined with two cities that were further south (Orlando and Chihuahua, 29°). Combining the cities like this meant that the numerical information in all four groups was identical.

The southern U.S. and Mexico are analogous to southern Europe and Africa, respectively: The latitudes in all four regions were underestimated (Friedman & Brown, 2000, Experiment 1), and there was no overlap between the estimates for either the southern European and African cities or for the southern U.S. and Mexican cities. Further, the Mexican seeds are likely to be further north than the initial estimates for the location of the southern U.S., just as the African seeds were further north than the initial estimates of southern Europe. The first prediction, therefore, is that learning the correct location of any cities in Mexico (MX; i.e., in the MX–MX, MX–U.S., and U.S.–MX groups) should affect adjacency-based updates of the location of the southern U.S. region in a manner similar to the way that learning about cities in Africa affected beliefs about the location of southern Europe: The Mexican region should be moved northward, and that should force an inference that the southern U.S. should be shifted north too. Note that this finding by itself does not distinguish between the numerical versus knowledge-based mechanisms of adjacency-based updating and would be consistent with both of them. The more interesting case, therefore, because it is analogous to the case provided by the southern European seed group, is what happens when participants learn about the location of cities in the southern U.S.

If the African estimates in the previous study did not shift with the European seeds because there was no numerical reason to do so, then in the present experiment, the prediction is that there should be no northward movement of the Mexican cities in the U.S.–U.S. group for the same reason. That is, the first estimates for cities in the southern U.S. would be south of the U.S. seeds, but still north of the Mexican estimates; on the principle of inertia, the Mexican estimates do not have to shift to keep the spatial (and numerical) relation between regions the same in the U.S.–U.S. seed group.

In contrast, if the physical nature of the adjacency plays a role in adjacency-based shifts, then we expect a different outcome when two subregions physically abut than in the case of Europe and Africa, where they are separated by a large body of water. The prediction here is that the land mass connection between the U.S. and Mexico should imply that if the southern U.S. cities are shifted north, Mexican cities should also be shifted north.

The U.S.–U.S. group is crucial in distinguishing between the two alternatives: Like the southern European seed group in our previous research, both seeds come from the same region, and we anticipate no numerical overlap between the southern U.S. seeds and the first estimates for Mexican cities. If shifts in the second estimates are a function of reconciling numerical inconsistencies between the first estimates and the seed facts, then the difference between the first and second estimates of the Mexican cities should be reliable in the MX–MX, U.S.–MX, and MX–U.S. groups but not in the U.S.–U.S. group. In contrast, if shifts in the second estimates are based on knowledge about the physical abutment between regions, then we should see shifts in all four groups. And, within seed groups, the shifts should be approximately the same for cities in Mexico as for cities within the southern U.S. We do not have strong predictions regarding the magnitude of the shifts between seed groups.

Method

Participants and design. One hundred twenty Canadian-born undergraduates from the University of Alberta participated for credit toward their introductory psychology course. They were randomly assigned to one of the four seed groups formed by the factorial combination of whether the northern seed came from the U.S. (San Diego) or Mexico (Tijuana), or whether the southern seed came from the U.S. (Orlando) or Mexico (Chihuahua). Thus, the seeds could come from the southern U.S. subregion (U.S.–U.S.: San Diego and Orlando), or Mexico (MX–MX: Tijuana and Chihuahua), or the northern seed could come from the U.S. and the southern from Mexico (U.S.–MX: San Diego and Chihuahua) or vice versa (MX–U.S.: Orlando and Tijuana). Note that in the two "mixed" seed groups (U.S.–MX and MX–U.S.), the first country listed in the shorthand notation refers to the one with the more northerly seed city.

Twelve cities from Canada, the northern U.S. subregion, the southern U.S. subregion, and Mexico were selected on the basis of estimates obtained in previous research (Friedman & Brown, 2000). The cities were presented in a different random order for each participant and each phase of the experiment and are listed on the abscissa of Figure 1.

Procedure. When a participant arrived, he or she was seated at a computer terminal. In the first phase, to familiarize participants with the cities and with using the numeric keypad on the keyboard to provide their responses, we had them rate their relative knowledge of each city, on a scale from 0 (*no knowledge*) to 9 (*a lot of knowledge*). The instructions emphasized knowledge in general, not just knowledge about locations. We then described the metric used for estimating latitudes; that is, that the equator is at 0°, the North Pole is at 90N°, and the South Pole is at 90S°. We asked the participants to provide us with absolute estimates of all of the cities. To do so, they again used the keypad to enter their numeric responses, followed by either an *N* or an *S* to indicate whether the city was in the northern or southern hemisphere.

The first estimates were followed by the introduction of the seed facts. Participants were told that the information on the screen was the actual latitudes of whichever seed cities were appropriate for their condition. The seed information remained on the bottom of the screen throughout the second estimates, but participants were given no other feedback about their performance.

Results

First estimates for seed cities were excluded from the data to be able to compare means across both sets of estimates. A p value of .05 was used as the significance level for both experiments.

Knowledge ratings. Knowledge ratings were analyzed across seed groups. The ratings differed as a function of region, $F(3, 348) = 642.21$, $MSE = 0.85$, for participants and $F(3, 44) = 37.42$, $MSE = 1.46$, for items. Planned contrasts on the participant means showed that participants felt more knowledgeable about Canadian cities than about cities in the northern U.S. (6.70 vs. 3.56), $F(1, 116) = 840.29$, $MSE = 1.41$; more knowledgeable about cities in the southern U.S. than in the northern U.S. (4.03 vs. 3.56), $F(1, 116) = 53.42$, $MSE = 0.48$; and more knowledgeable about cities in the southern U.S. than cities in Mexico (4.03 vs. 1.53), $F(1, 116) = 332.56$, $MSE = 2.24$. Objectively, the "break" between the northern and southern U.S. regions occurred between Philadelphia/Pittsburgh (each are at 40° north) and Las Vegas (36° north); subjectively, the break occurred between Milwaukee (estimated at 34° north) and Memphis/Atlanta (each estimated at 29° north). The finding that participants felt more knowledgeable about southern U.S. cities than they did about northern U.S. cities is somewhat counterintuitive, but it did not replicate in Experiment 2.

First estimates. The data in Figure 1 are sorted according to the mean subjective latitudes across observers for each city, with the most subjectively northern city at the left and the most subjectively southern estimate at the right. We call this type of graph a *subjective location profile* (Friedman & Brown, 2000). It can be seen that the first estimates decreased reliably as a function of region, $F(3, 357) = 378.55$, $MSE = 151.00$, for participants and $F(3, 44) = 834.60$, $MSE = 6.86$, for items, and that the four subregions we found in our first study (Friedman & Brown, 2000) were clearly replicated. Planned contrasts on the participant means indicated that the Canadian estimates were further north than the northern U.S. subregion, $F(1, 119) = 101.19$, $MSE = 115.00$; the northern U.S. estimates were different than the southern U.S. estimates, $F(1, 119) = 231.10$, $MSE = 48.00$; and the southern U.S. estimates were reliably further north than the Mexican estimates, $F(1, 119) = 178.50$, $MSE = 190.00$.

It is interesting to note that there was virtually no discriminability among the cities in any of the subregions, regardless of clear differences among them in the knowledge ratings, which, presumably, reflect familiarity. This weakens the likelihood that differences in familiarity among the subregions caused the differences in the amount they were shifted after learning the seed facts.

Second estimates and the effects of seeding. The mean second latitude estimates for each city and seed condition are shown in Figure 2, and the means for each of the regions and seed conditions, across participants and cities, are displayed in Figure 3. The group of particular interest with respect to the adjacency predictions was the U.S.–U.S. group. Here, it is clear from the figures that the estimates for the Mexican cities moved the least amount, relative to the other three groups. Nevertheless, they did move reliably northward, $t(29) = 3.57$, $SD = 12$. Indeed, as predicted, the mean shift of the Mexican cities in this condition was the same as that for the southern U.S. cities (7.8° vs. 7.9°). Because the U.S. seeds delineated, indirectly, a northern boundary for Mexico, participants probably inferred that the shift of the Mexican cities

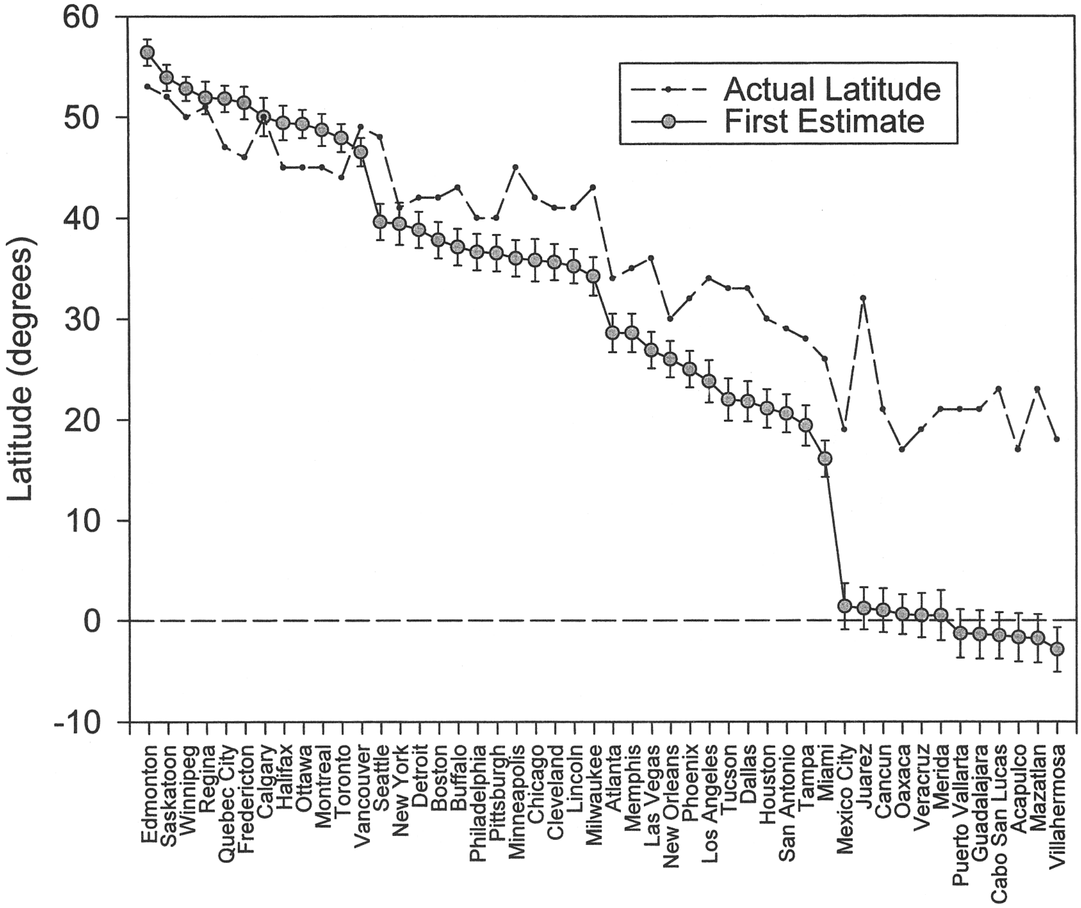

Figure 1. Average first estimates across participants for each of the cities in Experiment 1 (listed on the abscissa). Error bars are standard errors of the mean across participants.

should approximate that of the southern U.S. cities. Consequently, estimates for the U.S.–U.S. group exhibited a type of adjacency judgment that was not seen in our previous study.

The data in Figure 3 were analyzed in an analysis of variance (ANOVA) in which seed condition (U.S.–U.S., MX–MX, U.S.–MX, and MX–U.S.) was between participants, whereas region (Canada, northern U.S., southern U.S., and Mexico) and estimate number (first or second) were within participants. In the item analysis, seed condition and estimate number were within items, and region was between items. The results of both analyses are presented in Table 1. The significant interactions indicate that the seeds had differential effects on the second estimates, depending on the particular region and seed group.

As can be seen in Figure 3, relative to their own baseline, each of the seed groups tended to move the two southern regions (Mexico and the southern U.S.) north by a greater amount than they moved the two northern regions (the northern U.S. and Canada). In addition, a post hoc contrast showed that participants who received the more northerly Mexican seed (MX–MX and MX–U.S.) shifted their estimates by a greater amount than did participants who received the more northerly U.S. seed (U.S.–MX and U.S.–U.S.), $F(1, 116) = 34.01$, $MSE = 123.00$. Mean estimates for participants in the MX–MX and MX–U.S. groups shifted by an average of 9.9°, 13.1°, 17.0°, and 30.4°, respectively, for the Canadian, northern U.S., southern U.S., and Mexican cities, whereas the estimates for participants in the U.S.–MX and U.S.–U.S. groups for the same regions shifted by 0.4°, 6.3°, 7.6°, and 11.7°.

To explore this effect further, we conducted two ANOVAs with region and estimate number as within-participant factors; the between-participant factor was the location of either the northern seed (U.S. or Mexico) or the southern seed (U.S. or Mexico). Importantly, the interaction between region, estimate number, and seed location was reliable for the northern seeds, $F(3, 354) = 3.94$, $MSE = 79.00$, but not for the southern seeds. This difference in the amounts shifted probably occurred because when the U.S. seed was further north than the Mexican seed (U.S.–MX), or when there was no Mexican seed (U.S.–U.S.), the known ordinal relation between the two countries was preserved. Thus, though the known physical relation dictated that if the estimates for the U.S. were moved north, the estimates for Mexico had to be moved, it was not necessarily obvious by how much they had to be moved. Still, the estimates for the southern U.S. and Mexico were moved reliably north, relative to baseline estimates, in all four seed groups.

It is also the case that in all four groups, there was a "domino effect" of sorts, and the northerly movement of the Mexican cities

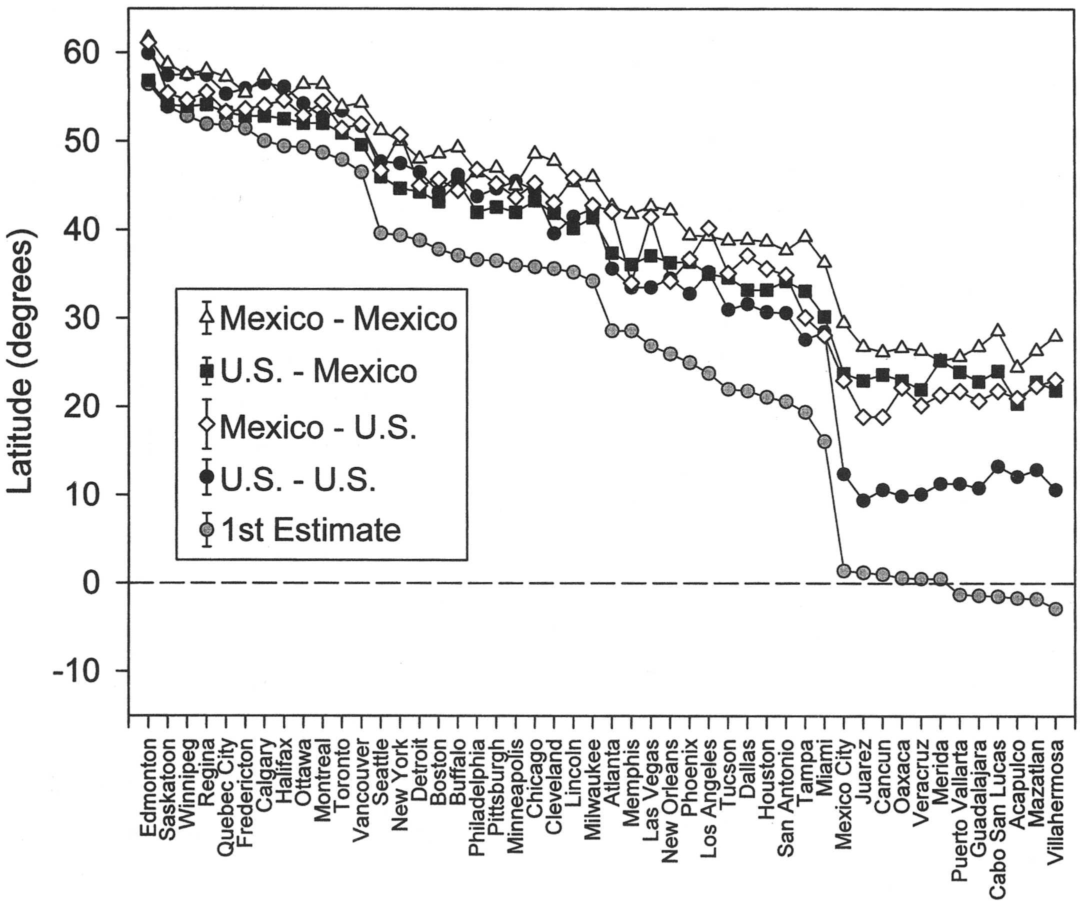

Figure 2. Average first and second estimates across participants for each of the cities in Experiment 1 (listed on the abscissa). All estimates are plotted as a function of the subjective order of the first estimates, averaged across participants and seed condition. The error bars in the legend are the average standard error of the mean for each city, computed across participants for each city, and then averaged across cities.

caused a northward shift in the estimates for the southern U.S., the northern U.S., and sometimes, even the Canadian cities. This is similar to our previous study (Friedman & Brown, 2000, Experiment 2), and with a similar explanation. When the seeds informed the participants that their Mexican estimates were too far south, this meant that, in principal, the southern boundary of the southern U.S. cities must shift northward to keep the ordinal relations between the regions coherent. The other regions then shifted northward to keep the categorical relations between them, as well as the overall range of the estimates, the same. It should be noted, however, that the seeding effect appears to decrease as the distance between the seeds and the test cities increases. We also observed this in our previous study (Friedman & Brown, 2000, Experiment 2). In both cases, the southern regions were so largely underestimated that there was a lot of "room" to shift them northward before shifts in the more northerly regions were necessary.

Discussion

The relation between Mexico and the southern U.S. region examined in the present experiment was similar to the situation between Africa and southern Europe in Friedman and Brown (2000, Experiment 2). Moreover, in both the previous and present work, all of the groups exhibited inheritance-based seeding effects (i.e., cities in the seeded regions shifted). In addition, the seeds from the more southerly regions (Africa and Mexico) caused an adjacency-based shift in the estimates of the more northerly regions (Mediterranean Europe and the southern U.S.). But, whereas European seeds did not influence the second African estimates, U.S. seeds did influence the second Mexican estimates. Because the categorical relations between the regions were the same (southern Europe is north of Africa; the southern U.S. is north of Mexico), it must be that knowledge about the nature of the adjacencies themselves influenced whether the second estimates were shifted: Southern Europe and Africa are separated by a large body of water, and Mexico and the U.S. are not. Thus, whereas inertia influenced the second estimates in our previous study, it did not in the present case.

It is also of interest to note that the amount that the cities in each region were shifted was not a constant in any of the four groups. Rather, the amount of shift decreased with increasing distance from the seeds. This implies that when participants were updating regional knowledge as a function of learning the seed facts, they

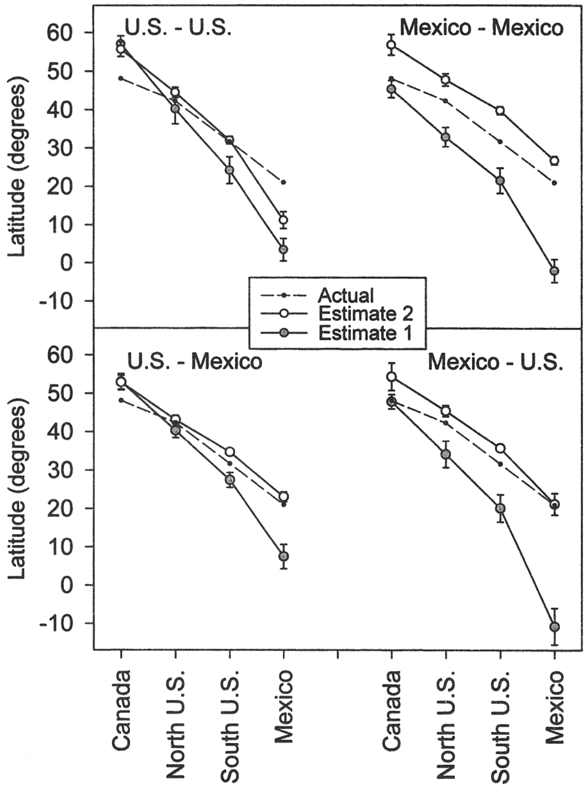

Figure 3. Average first and second estimates in Experiment 1 as a function of seed condition for each subjective region listed on the abscissa. The error bars are standard errors of the mean computed across participants for each region. Dashed lines are the average actual latitudes for cities within each region.

did not merely add to each of their first estimates the difference between the first estimates and the seed facts. Rather, they applied the new information to the regions differentially. The differential application of new information to update the knowledge base may be another example of inertia.

Experiment 2

In Experiment 1, the nature of the adjacency between the U.S. and Mexico had different consequences for updating knowledge than did the adjacency between Africa and Europe. In Experiment 2, we examined the relations between regions across the Atlantic Ocean, and on the basis of the way the new information was integrated into distant regions and subregions, we determined which of them are coordinated. In particular, we compared location estimates made before and after participants received seed cities from either the southern subregion of the U.S. or the southern subregion of Europe. This allowed us to test directly whether transatlantic regions and subregions that appeared to be coordinates in our previous study (Friedman & Brown, 2000, Experiment 1) are, in fact, mutually dependent. The numerical information given in both cases was identical, so any differences between the first and second estimates had to be a function of the implications of the seed cities for the relations between the regions.

There are several interesting possibilities for the observed estimates. The first estimates provide a replication of Friedman and Brown (2000, Experiment 1) and permit us to determine which regions are potentially coordinated across the Atlantic. On the basis of our earlier findings, we believe that Canadian cities are coordinated with cities in northern Europe (e.g., Winnipeg and Oslo), cities in the northern U.S. with cities in central Europe (e.g., Minneapolis and Berlin), and cities in the southern U.S. with cities in Mediterranean Europe (e.g., Atlanta and Rome). It is possible that observers would align Mexico with the Mediterranean Ocean, but it is also possible that they would align Mexico with Africa.

For the second estimates, we expected to observe inheritance-based judgments—southern U.S. seeds should cause a northward shift in estimates for southern U.S. cities, and southern European seeds should cause a similar northward shift for estimates in southern Europe. The interesting cases are the within-hemisphere, adjacency-based shifts and the transatlantic adjustments based on the presumed coordinate relations between regions. That is, we are able to observe whether the effects of learning new seed facts propagate to regions at a global level. In the present view, this sort of propagation should occur whenever the seeds carry implications that require changes to the knowledge base in order to maintain its coherence (i.e., the rough ordinal equivalence between coordinated regions). Because many patterns are possible for the second estimates, we discuss the ones we think are most likely.

In the simplest case, the Atlantic Ocean should have an effect similar to the Mediterranean. That is, southern European seeds did not influence the second estimates of cities in Africa (Friedman &

Table 1
Participant and Item Analyses of Variance (ANOVAs) for the First and Second Estimates in Experiment 1

	Participant ANOVA			Item ANOVA		
Source	*dfs*	*MSE*	*F*	*dfs*	*MSE*	*F*
Seed condition (S)	3, 116	576	1.25	3, 132	4	82.63*
Region (R)	3, 348	140	571.22*	3, 44	37	859.55*
Estimate number (E)	1, 116	247	127.34*	1, 44	4	2970.86*
S × R	9, 349	140	2.74*	9, 132	4	44.12*
S × E	3, 116	247	127.34*	3, 132	3	352.89*
R × E	3, 348	79	39.74*	3, 44	4	295.95*
S × R × E	9, 348	79	2.31**	9, 132	3	22.38*

* $p < .001$. ** $p < .05$.

Brown, 2000, Experiment 2), and on the basis of the results of Experiment 1 in the present study, we surmise that this was because the presence of the Mediterranean allowed some flexibility in the location of Africa. In a similar vein, the separation of the Old and New Worlds by the Atlantic Ocean might permit participants merely to readjust their estimates for the seeded hemisphere. If so, the southern European seed cities should shift cities in southern Europe, but not Africa, whereas the southern U.S. seed cities should shift cities in both the southern U.S. and Mexico. However, the new knowledge about locations in either southern Europe or the U.S. should not propagate across the ocean.

In contrast, the data from bearing estimates (Friedman et al., 1999) as well as from absolute latitude estimates (Friedman & Brown, 2000, Experiments 1 and 2) give some indication that when individuals are asked to estimate locations in both the Old and New Worlds, they take account of subregions in both of them. Moreover, we have data from participants who made longitude estimates of cities in the New World (Friedman & Brown, 2000, Experiments 3–4) that show that, even though North and South America are separated by the Panama Canal (and an intervening, unprobed region: Central America), the postseeding estimates preserved the way the two continents were initially coordinated. Given this precedent, in the present experiment, seeds from the Old World could plausibly affect estimates in the New World, and vice versa.

There are several ways we might observe transatlantic seeding effects. The most obvious rests on the previous observation that the locations of cities in southern Europe and the southern U.S. are underestimated and on the corresponding assumption that the two subregions may be coordinates. Thus, if participants learn the locations of Athens and Lisbon, they should move cities in southern Europe and cities in the southern U.S. northward. The new knowledge still has no implications for the relation that Europe is north of Africa, so African estimates might remain where they were. However, on the basis of the results of Experiment 1, we hypothesized that if southern U.S. cities are moved north for any reason, Mexican cities should move north too. And, if the Mexican cities shift northward, this, in turn, might move the African estimates north if Mexico and Africa are linked.

Using this same logic, we predicted that the group that received the southern U.S. seeds should move the southern U.S. and Mexican cities north. They should also move the southern European cities north to realign them with the southern U.S. cities. Thus, this experiment permits us to examine whether people realign the subregions in both the Old and New Worlds; or in just the U.S. and Mexico (because of the landmass); or in just the southern regions (e.g., southern Europe, southern U.S., and Mexico), because they are the ones that are generally matched for climates.

In summary, if observers are constrained only to preserve local adjacencies, then the southern European seeds should affect only estimates in the Old World, and southern U.S. seeds should affect only estimates in the New World. In contrast, if observers also preserve the coordination between regions across the Ocean, then seeds from the New World should affect location estimates in the Old World, and vice versa.

Method

Participants, stimuli, and design. Including seed cities, there were 30 cities from North America (5 from Canada, 5 from the subjectively northern U.S. region, 12, including seed cities, from the subjectively southern U.S. region, and 8 from Mexico) and 30 cities from the Old World (10 from the subjectively northern region of Europe, 12, including seed cities, from the subjectively southern region of Europe, and 8 from Africa). Sixty Canadian-born paid participants from the University of Alberta estimated the latitudes of all the cities. Thirty participants were randomly assigned to each seed group.

Because most of southern Europe is actually north of cities in the subjectively southern U.S. region, and because we wanted both seed groups to have identical item-level information, we averaged the actual latitudes of Lisbon (39°) and San Diego (33°), and the actual latitudes of Athens (38°) and Tucson (32°), and presented the average values as the "true" latitudes. Thus, after the participants made their first estimates, half of them were told that the latitudes of Lisbon and Athens are 36° and 35°, respectively, and the other half were told that the latitudes of Tucson and San Diego are 36° and 35°, respectively. Keeping the new item-level information identical for each group allowed us to examine effects of the category of the seeds on the second estimates in each subregion.

Procedure. The procedure was identical to that used in Experiment 1.

Results

Knowledge ratings. The knowledge ratings again differed as a function of region in both the Old and New Worlds. The mean ratings for cities from Canada, the northern U.S., the southern U.S., and Mexico were 6.81, 4.52, 4.27, and 2.29, respectively, $F(3, 177) = 179.20$, $MSE = 1.15$, for participants and $F(3, 24) = 17.48$, $MSE = 1.21$, for items. The mean ratings for cities in northern Europe, Mediterranean Europe, and Africa were 2.96, 2.24, and 0.95, respectively, $F(2, 118) = 82.71$, $MSE = 0.75$, for participants and $F(2, 25) = 5.69$, $MSE = 1.63$, for items.

First estimates. Figure 4 shows the subjective location profile for the first estimates of all of the cities, organized by hemisphere. The most striking aspects of these estimates are, first, the clear separation between regions and subregions within both the Old and New Worlds. In the New World, there were again subregions for Canada, the northern U.S., the southern U.S., and Mexico. In the Old World, there were subregions for northern Europe, Mediterranean Europe, and Africa. Second, there was generally limited resolution between cities within subregions, even when they were well-known subregions (e.g., the northern U.S.). Third, the southern U.S., Mexico, Mediterranean Europe, and Africa were all underestimated. Fourth, the range of estimates within continents appears to be based on global reference points. For example, cities in Mexico were believed to be at or near the equator, as was the Mediterranean Ocean, whereas Africa, in turn, was believed to begin at the equator and continue to −20°. These four findings suggest that observers made their estimates by establishing a range for each of the major continents (i.e., North America, Europe, and Africa). The continental ranges were divided into ranges for each of the subregions, and the cities within subregions did not differ very much from one another.

Finally, observers aligned subregions across the Atlantic Ocean: Canadian and northern U.S. cities were aligned with northern European cities, cities in the southern U.S. were aligned with cities in Mediterranean Europe, Mexico was aligned with the Mediterranean Ocean (i.e., the gap between southern Europe and Africa), and Africa occupied the southern hemisphere on its own. There also appeared to be some subregionalization in Africa. The alignment of the major continents may have been the result of retrieval from a representation distorted on the basis of principles of per-

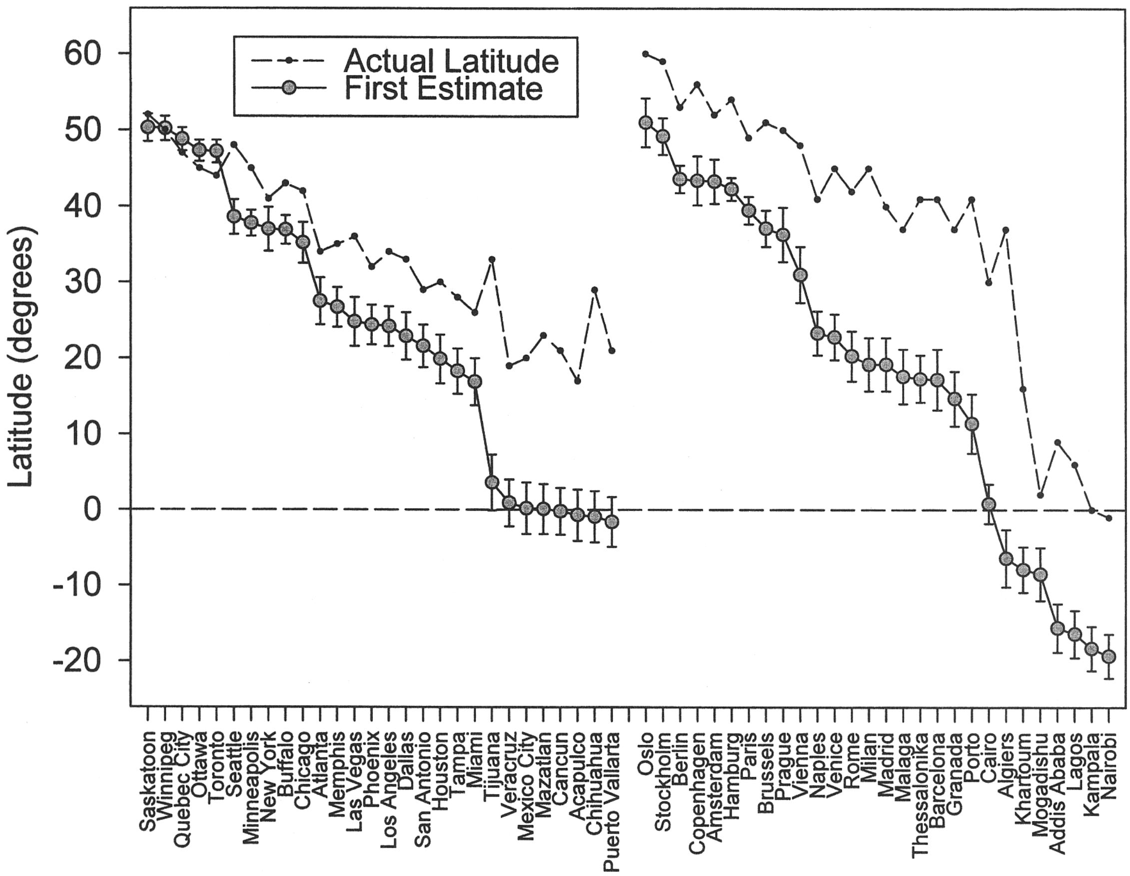

Figure 4. Average first estimates across participants for each of the cities in Experiment 2 (listed on the abscissa). Error bars are standard errors of the mean across participants.

ceptual organization (cf. Tversky, 1981, 1997). However, it seems unlikely that the alignment of the subregions was based on such a representation, particularly given the coordination between subregions and the landmarks (like the equator) used to align the continents and their borders (Friedman & Brown, 2000; see Figure 4).

Second estimates and effects of seeding. Figure 5 shows the mean second estimates for each city as a function of seed group, and Figure 6 shows the mean first and second estimates across observers and cities, separately for each seed group and subregion.

In the participant analyses that follow, seed condition (Mediterranean Europe and the southern U.S.) was between participants, and an average first and second estimate was computed for each observer as a function of region in each hemisphere, so region, hemisphere, and estimate number were within participants. We combined the Canadian and northern U.S. cities into one region to have an equal number of regions in each hemisphere. Note that all of the theoretically important predictions involve the southern regions in each hemisphere (Mediterranean Europe and Africa in the Old World, and the southern U.S. and Mexico in the New World), and ANOVAs on just those regions led to the same conclusions as the complete data set.

In the item analysis, the ANOVA was conducted on the cities displayed on the abscissa in Figure 5; estimate number (first or second) and seed group (southern U.S. or southern Europe) were within city, and region (north, central, or south) and hemisphere (Old or New World) were between cities. The Canadian and northern U.S. cities were also considered together in this analysis, so that the northern regions in both the Old and New Worlds had 10 cities each, the "middle" regions (i.e., the southern U.S. and southern Europe) had 10 cities each, and Mexico and Africa had 8 cities each.

Most of the effects in both analyses were significant; most important, they were mitigated by the four-way interaction (see Table 2). The interaction indicates that the difference between the first and second estimates changed as a function of all three variables. From the pattern of means in Figures 5 and 6, it can be seen that the European seeds increased the second estimates of cities in southern Europe and Africa as well as the estimates of cities in the southern U.S. and Mexico (see Table 3). Similarly, the southern U.S. seeds influenced the new estimates in all of the North American regions but also in northern Europe and southern Europe (only the participant data were reliable for the African estimates in this group). Thus, it is clear that observers were making their second estimates on the basis of the global coordination between regions.

By increasing their estimates for coordinate regions and subregions by roughly the same amounts, observers kept the

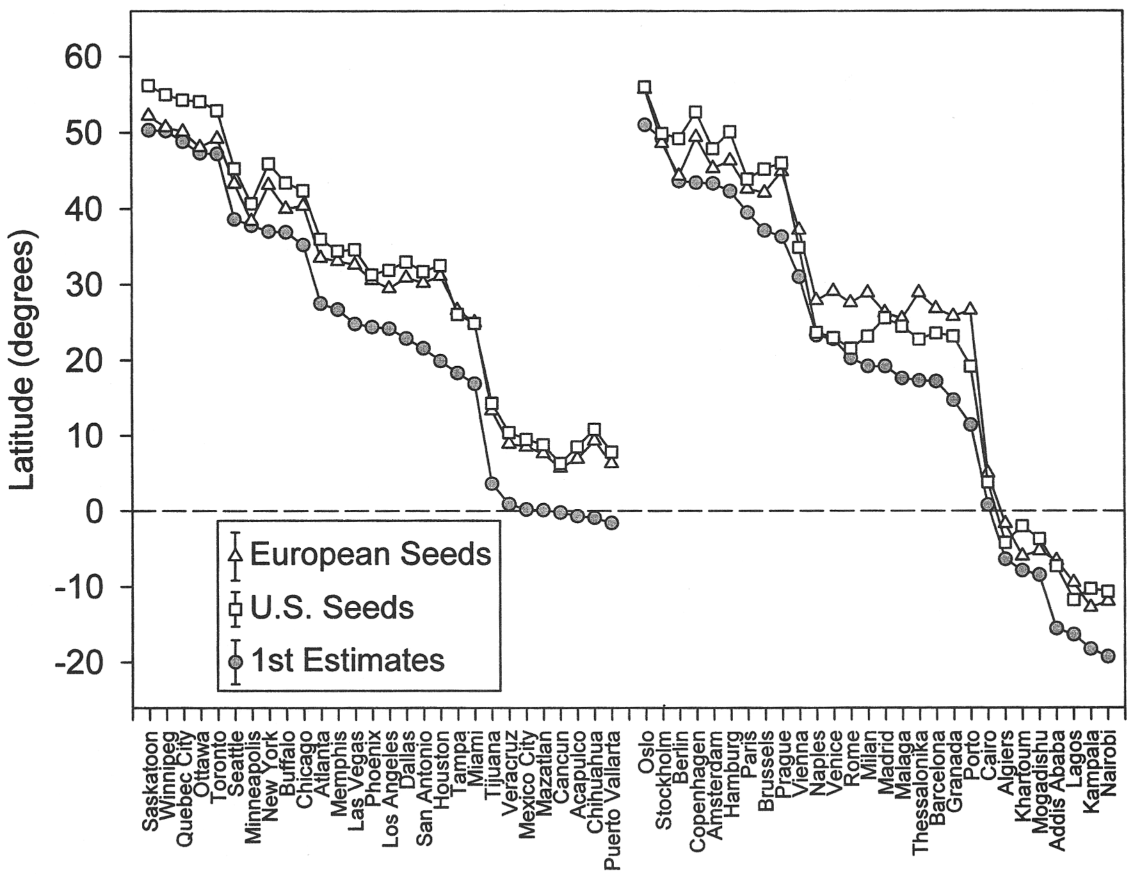

Figure 5. Average first and second estimates across participants for each of the cities in Experiment 2 (listed on the abscissa). All estimates are plotted as a function of the subjective order of the first estimates, averaged across participants and seed condition. The error bars in the legend are the average standard error of the mean for each city, computed across participants for each city, and then averaged across cities.

initial relations between the coordinate regions intact. For example, although neither group placed the Mexican cities at the equator in their second estimates, Mexico maintained its coordinate position to the Mediterranean Ocean (and/or at the northernmost border of Africa; see Figure 5). Similarly, across seed groups, the average initial estimate for cities in southern Europe was 18°, and for the southern U.S. cities it was 23°. Both southern Europe and the southern U.S. cities maintained a rough coordinate relation to each other in the postseeding estimates: The mean second estimate for the southern European cities was 27°, and for southern U.S. cities it was 30°. Thus, across seed groups, the average latitude estimates for cities in the two regions were not reliably different from each other, for either the first or the second estimates.

Discussion

Location estimates for cities in the Old World were influenced by seeds from the New World, and vice versa. Thus, we have evidence for the first time that on learning information regarding the location of cities within a particular region, people propagate the information to distant, disjoint, but ordinally coordinated regions (cf. Brown & Siegler, 1993, in which seeding did not affect population estimates in unseeded regions). Thus, the existence of a body of water between Europe and North America did not prevent observers from adjusting their estimates of one region on the basis of learning new information about the other. The transatlantic seeding of coordinate regions reinforces the idea that the desire to maintain coherence underlies both local adjacency-based judgments and global judgments based on conceptual coordination.

It is possible that shifts in the second estimates were not due to updating the knowledge base per se but rather reflect numerical adjustments people make to avoid inconsistencies in their answers. In this sense, the second estimates shift because of a kind of task demand, in which participants want to appear to be consistent in their second responses and do so by making a simple numerical adjustment to their first estimates. The difference between the two alternatives (knowledge updating vs. numerical adjustments) is subtle but important.

The *task demand* argument is undermined by a previous study as well as by the present data. First, the simplest way for participants merely to make their second estimates consistent with the feedback provided by the seeds is to adjust their first estimates of all the cities by the difference between their first estimate of the seed city

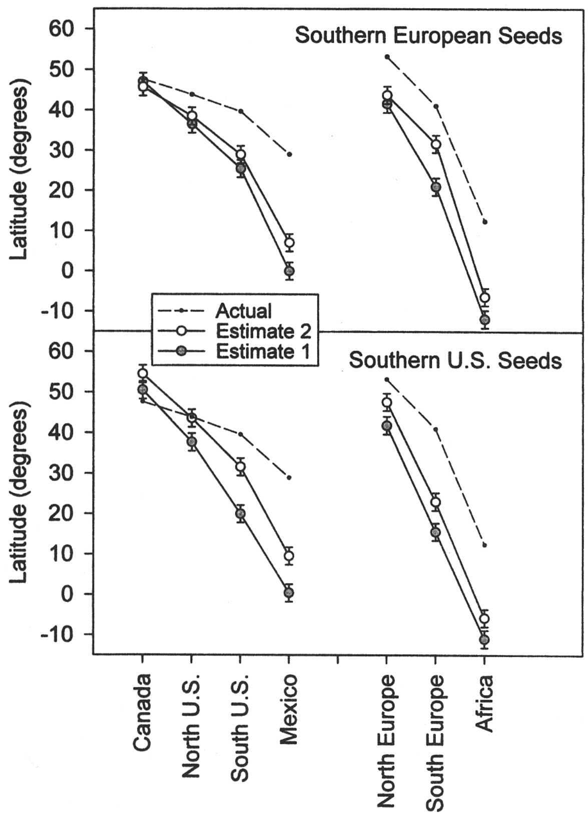

Figure 6. Average first and second estimates in Experiment 2 as a function of seed condition for each subjective region listed on the abscissa. The error bars are standard errors of the mean computed across participants for each region. Dashed lines are the average actual latitudes for cities within each region.

and its actual location. This would predict that all of the cities should shift by the same amount. As noted for the present experiment, as well as for Experiment 1, the effect of the seed facts diminished with distance from the seeded region, so whatever adjustments are being made are not being made by means of a straightforward "delta" shift.

Second, the task demand issue was explicitly addressed by Brown and Siegler (1996), who first introduced the seeding task to the literature in the context of population estimates. In one experiment, participants made their estimates both immediately and approximately 4 months after learning the seed facts. Performance on both posttests was virtually identical, even though there was evidence that after 4 months, participants had forgotten the specific numerical information conveyed by the seed facts. This is direct evidence for long-term modification of the knowledge base as a function of seeding. It is not likely that the task demand explanation of seeding effects carries with it any long-term implications.

General Discussion

In the present study, people estimated latitudes of cities in the Old and New Worlds, before and after learning specific location information about two particular cities. Together with our previous research, the current study allows us to make several new observations about geographical judgments, as well as about the mechanisms underlying plausible reasoning and the assimilation of new information into the knowledge base.

The first important observation is that the initial location estimates confirmed the existence of psychologically distinct subregions in each continent, and that within subregions, estimates of the location of individual cities were hardly discriminable. Further, the subregions appeared to be coordinated, in an ordinal sense, across the Atlantic ocean. The existence of coordinated subregions, together with the strong initial bias to place cities located in the southern U.S., Mexico, and Mediterranean Europe to the south of their actual locations, also confirms the tendency to organize

Table 2
Participant and Item Analyses of Variance (ANOVAs) for the First and Second Estimates in Experiment 2

	Participant ANOVA			Item ANOVA		
Source	*dfs*	*MSE*	*F*	*dfs*	*MSE*	*F*
Seed condition (S)	1, 58	1,398	<1	1, 50	10	<1
Region (R)	2, 116	275	470.56*	2, 50	78	489.72*
Hemisphere (H)	1, 58	493	12.13*	1, 50	78	23.65*
Estimate number (E)	1, 58	305	22.01*	1, 50	5	386.78*
S × R	2, 116	275	3.31**	2, 50	10	28.74*
S × H	1, 58	493	<1	1, 50	10	11.81*
S × E	1, 58	305	<1	1, 50	3	30.88*
R × H	2, 116	184	13.70*	2, 50	78	9.33*
R × E	2, 116	63	6.27*	2, 50	5	24.49*
H × E	1, 58	38	<1	1, 50	5	<1
S × R × H	2, 116	184	<1	2, 50	10	2.67†
S × R × E	2, 116	63	<1	2, 50	3	4.07**
S × H × E	1, 58	38	6.90**	1, 50	3	29.41*
R × H × E	2, 116	31	2.76†	2, 50	5	4.62*
S × R × H × E	2, 116	31	3.77**	2, 50	3	13.83*

* $p < .001$. ** $p < .05$. † $p < .10$ (marginally significant).

Table 3
Mean Difference in Estimated Latitude (Est) as a Function of Seed Group and Region in Experiment 2

Seed group	Region	*N* cities	Est 2 − Est 1	|*t*| Participants[a]	|*t*| Cities[a]
Southern Europe	N. Europe	10	2.2°	*ns*	*ns*
	S. Europe	10	10.6°	4.41 (2.4)*	7.53 (1.5)*
	Africa	8	5.5°	2.56 (2.2)*	4.05 (1.4)*
	Canada + N. U.S.	10	0.3°	*ns*	*ns*
	S. U.S.	10	3.5°	2.21 (1.6)**	4.36 (0.8)*
	Mexico	8	7.1°	3.30 (2.2)*	10.36 (0.7)*
Southern U.S.	N. Europe	10	5.8°	3.15 (1.9)*	8.09 (0.8)*
	S. Europe	10	7.5°	2.44 (3.1)**	6.67 (1.2)*
	Africa	8	5.2°	*ns*	9.16 (0.6)*
	Canada + N. U.S.	10	4.9°	3.35 (1.5)*	7.68 (0.7)*
	S. U.S.	10	11.7°	3.95 (3.0)*	19.62 (0.6)*
	Mexico	8	9.1°	2.59 (3.6)*	21.95 (0.4)*

Note. N. = north; S. = south.
[a] Numbers in parentheses are the standard error of the difference between the means for participants and cities.
* $p < .01$, one-tailed. ** $p < .05$, one-tailed.

geographic knowledge in terms of categories, and it illustrates how regions may be conceptually linked according to nonspatial factors (e.g., climate; Friedman et al., 1999).

A second important observation, revealed by the postseeding estimates, is that participants tended to maintain the relations between adjacent and coordinate regions after learning new information. For example, in Experiment 1, new information about the southern boundary of the U.S. affected estimates of cities in Mexico. Moreover, in Experiment 2, southern U.S. seeds not only caused the Mexican cities to shift northward, they had a similar effect on the southern European estimates (and vice versa). This is a clear case of coordination between distant regions: When one region was adjusted because the seed facts revealed it had been underestimated, cities in other regions, both near and far, were adjusted. Thus, the second estimates validated the claim that discontinuous regions are coordinated in the knowledge base.

Third, the findings of the present study permit us to better understand and to generalize the conclusions we reached about the longitude estimates in our previous research (Friedman & Brown, 2000, Experiments 3 and 4). Briefly, longitude estimates in the New World showed good discrimination among cities in North America and virtually none among cities in South America. When a South American city was given as a seed fact, all the South American cities were moved eastward, reflecting inheritance-based updating. But in addition, cities in North America were moved by an amount that preserved the initial relation between the continents (i.e., either aligned in the middle or at the eastern seaboard). Thus, North and South America were functionally adjacent and coordinated (despite the existence of the Panama Canal and of unprobed Central American cities), and modifications to South America through seeding were thus propagated to North America.

In principle, because the Americas are aligned in the north–south dimension, there is no reason North America had to move to keep the relation between continents intact. So by the principle of inertia, North America should not have shifted with the South American seeds. However, it did shift, and in so doing, it maintained the type of relation between regions that was initially manifested. Thus, we now have evidence that adjacency and coordination between regions affects both latitude and longitude judgments and that the principle of cognitive coherence apparently overrides that of inertia.

Fourth, the adjacency- and coordinate-based shifts we obtained were observed across a variety of regions that varied in their overall familiarity to the participants. Consequently, familiarity is unlikely to play an important role in the amount that cities are shifted as a function of seed facts, or even in whether they are shifted. In our previous work, for example, participants were largely unfamiliar with any of the African cities, yet they moved them about 15° northward when given African seeds and hardly moved them at all when given European seeds (Friedman & Brown, 2000, Experiment 2). In that case, the category of the seeds was more influential than the familiarity of the region per se. In the present case, regions of presumably very different familiarity (e.g., Mexico and the southern U.S. in Experiments 1 and 2; southern Europe and Mexico in Experiment 2) were shifted by roughly similar amounts. Thus, it seems more parsimonious to describe postseeding shifts in the estimates in terms of how the seeds interact with prior beliefs about relative and absolute locations of regions (categories) than in terms of the differences in familiarity of the regions.

In addition to processes used to assimilate new information, the present study adds to the body of evidence demonstrating that people have a strong tendency to think about geography in hierarchical terms (e.g., McNamara et al., 1989; Stevens & Coupe, 1978). Thus, the nature of the representation of geographical knowledge we are proposing is in no sense analogous to a "cognitive map" of global geography in which the regions are part of the same "fabric," as they would be in an actual map. Instead, we assume that some regions and subregions are represented quasi independently so that the "spread" of new knowledge is not uniform throughout the knowledge base. Though the representation of geographical knowledge—for example, in a hierarchy, a heterarchy, a feature list, and so forth (Collins & Michalski, 1989; McNamara et al., 1984, 1989; Stevens & Coupe, 1978)—continues to be a matter of debate; the important point is that people have knowledge about the hierarchical ordering of units and the relations between units at a given level of abstraction, and it is this knowledge that governs their inferences and their assimilation of new information.

Indeed, an important goal of the present study was to determine how and when information propagates through such a knowledge base; we provided evidence for both coherence and inertia as principles underlying the propagation of new information. In particular, in our previous study (Friedman & Brown, 2000), there were two potential reasons that location estimates for African cities did not shift with the southern European seeds: Either the physical discontinuity between Europe and Africa was responsible, or the absence of inconsistencies between the first African estimates and the numerical values of the southern European seeds could have been responsible. Experiment 1 in the present study eliminated the second possibility: The known physical contiguity between the U.S. and Mexico caused adjacency-based shifts in the absence of numerical inconsistencies between the first estimates and the seed facts. Thus, we conclude that the second estimates of African cities in our previous study did not shift with the European seeds because of the known physical discontinuity between Africa and Europe. The theoretical conclusion is that the different physical relations between regions have different affordances with respect to the assimilation of new information, and that when physically and logically possible, the principle of inertia prevents new information from propagating throughout the knowledge base.

However, Experiment 2 demonstrated that physical discontinuity per se is not all that underlies the operation of the inertia principle: Far-ranging realignments occurred between coordinated regions across the Atlantic. We conclude that physical contiguity alone does not predict the influence of seeds on the second estimates, nor does the absolute distance between regions. Rather, the influence of seeds on shifts in the second estimates is governed by the principle of maintaining coherence in the knowledge base when presented with new information that entails updating it.

In our previous research (Friedman & Brown, 2000), when we tested only cities from the Old World, both inertia and coherence allowed the estimated locations of African cities to remain unchanged when participants learned the correct location of Mediterranean Europe. In contrast, when we tested cities from a fuller global context in the second experiment of the present study, participants did shift the estimated locations of African cities northward upon learning the correct location of Mediterranean Europe; as just noted, we attribute the difference between studies to the precedence of coherence over inertia. Importantly, there is another implication of this difference: For conceptual coordination to exert an influence on the knowledge base, it may be that cities from the coordinate regions have to be activated, or at least tested, within the same experimental context. For example, in the current case, the southern European seeds may have influenced the African estimates because the causal chain was something like the following: "If Mediterranean Europe is further north than previously believed, so is the southern U.S. (because they are coordinates); if the southern U.S. is further north, so is Mexico (because they are physically adjacent); if Mexico is further north, the Mediterranean Ocean and/or Africa should also be shifted (because they are coordinated with Mexico)." Thus, knowledge updates might be influenced not only by the particular new information that is given but also as a function of the particular items that have been presented in the experimental or learning context.

It should be noted that we assume that the distance of a region from the start of the causal chain involved in updating the knowledge base does not necessarily predict the amount that the region will be adjusted, nor does its distance from the seeded region. Indeed, for the southern European condition in Experiment 2, the amounts that the regions were shifted in the chain Mediterranean Europe → southern U.S. → Mexico → Africa were 10.6°, 3.5°, 7.1°, and 6°, respectively (see Table 3). Besides the difficulty of knowing what the causal chain actually is in a particular situation (e.g., in the southern U.S. seed condition, a direct link from the southern U.S. to Mexico is as plausible as a link from the southern U.S. to southern Europe, or from the southern U.S. to both Mexico and southern Europe at the same time), it seems reasonable that other factors should play a more important role in the size of the recalibration(s). For example, factors that might better predict how much a given region is adjusted include the amount that an adjacent or coordinate region is adjusted, together with the amount that either or both regions were under- or overestimated to begin with; a priori, it is not clear how these pieces of information should be combined. Similarly, knowledge about the physical constraints of global geography, as well as beliefs about the location of regions relative to global landmarks, should affect how much a given region is adjusted. For example, the amount that Canadian and northern European cities were adjusted may have been limited because participants believed that portions of these regions are close to the North Pole. Attempting to delineate the broader set of principles that predict not only whether a seed fact will affect a given region but also by how much is beyond the scope of this article. However, these issues are important to resolve, not only for a theory of geographical representation and reasoning but also in a more general framework of how knowledge is updated.

In sum, subjective geography forms a complicated knowledge base, and the location estimate task combined with the seeding procedure allows us to explore how new quantitative knowledge is integrated into this rich and highly structured domain of world knowledge. The multiple sources of geographical knowledge and their coordinate and hierarchical relations to one another constrain this process. Together, new knowledge and prior knowledge dictate how the knowledge base must change in order to maintain a coherent knowledge structure.

This finding—that new knowledge and prior knowledge interact—is not in itself new. But the way that they do so in the domain of large-scale geography is, and this may generalize to domains other than geography. That is, prior knowledge about any domain can act in at least two ways when new knowledge is introduced: First, prior knowledge, together with inertia, constrains the particular aspects of the database that will be updated. But also, prior knowledge forms a more or less coherent system that, apparently, people prefer to keep. Inertia dictates that the knowledge base will be altered only as far as is entailed by the logical implications of new information and the a priori linkages among categories; coherence overrides inertia to restore consistency to the knowledge base in light of new information.

In our previous research, we speculated that regions in the Old and New Worlds that were positioned at the same subjective latitudes were coordinated, but we had only a single set of estimates (Friedman & Brown, 2000, Experiment 1). Here, the second estimates in Experiment 2 provide evidence that these regions are conceptually linked. Moreover, because there is no physical contiguity between southern Europe and the southern U.S., the link between them must be relatively abstract. Although the linking of physically adjacent regions and their consequent joint updating is somewhat obvious, the necessarily abstract coordination of distant regions is not. Thus, because many real-world domains in which people must update their knowledge do not have the property of physical contiguity (e.g., economics, demographics, risk evaluation, and event dates), an understanding of how updating geographical knowledge occurs may generalize to these other domains. That is, though there is no analogy to physical adjacency in many knowledge domains, there may be an analogy to conceptual coordination. If so, we should be able to predict when seeding effects will propagate across categories that do not have physical boundaries but that are nevertheless conceptually linked.

In conclusion, we assume that in many domains, the instances to be judged on some dimension are often members of functional categories, and people hold beliefs about the relations that obtain between these categories. The fact that geography is a spatial domain is less important in this context than the fact that the domain is rich and is learned over a long period of time from a variety of sources that include, but are not limited to, maps, newspapers, teachers, and direct navigational experience. Similarly, the fact that the judgments are numerical does not seem to limit the kinds of representational categories, relations, and perhaps even analogical information that can be revealed by them. Thus, to the extent that this general perspective is accurate, we should be able to use the estimation task to explore the structure of many real-world domains, as well as to document similar seeding phenomena across domains. If so, we should also be able to predict how exposure to seed facts will affect peoples' understanding of the world and when the structure and organization of knowledge dictates what kind of new information will produce optimal improvements in understanding.

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