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THE MEASUREMENT OF COGNITIVE DISTANCE: METHODS AND CONSTRUCT VALIDITY

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Abstract

Cognitive distances are mental representations of large-scale environmental distances that cannot be perceived from a single vantage point but require movement through the environment for their apprehension. A comprehensive review of techniques for measuring cognitive distance is organized around five classes of methods: ratio scaling, interval/ordinal scaling, mapping, reproduction, and route choice. Advantages and disadvantages of each class are discussed, with particular reference to assessing estimation accuracy, and to their usefulness in various research contexts. Several general issues related to construct validity are also discussed.

Introduction

Debates about measurement and the meanings of measured constructs are common in scientific literature, especially so perhaps in the social and behavioral sciences. The study of cognitive distance is no exception (Golledge, 1987). ‘An individual's distance estimate is not independent of the methodology used to obtain that estimate’ (Cadwallader, 1979, p. 563). This statement about cognitive distance reflects an axiom of the scientific method: evaluation of empirical evidence requires consideration of how numeric values are assigned to variables in the process of measurement. Below I summarize and critically review five classes of methods used to measure cognitive distance and cite published examples of their uses. In addition, I discuss several issues related to what researchers do when they collect and analyse distance data, issues that have implications for their interpretation. I conclude with recommendations about the appropriate use of various methods and about interpretation of the data they generate. Although a complete understanding of measurement issues would require understanding the underlying informational and processing mechanisms involved in cognitive distance, I do not broadly address these mechanisms in the present review. Such a consideration would take us far afield and considerably expand the manuscript's size. A comprehensive review and synthesis of informational and processing issues is currently in preparation, however.

The term *cognitive distance* refers to people's beliefs about distances between places in large-scale spaces, places which are far apart and obscured so as not to be visible from each other (Ittelson, 1973; Canter & Tagg, 1975; Cadwallader, 1976). Such large-scale distances typically require movement through an environment and some kind of integration of information over time for their direct apprehension. In contrast, *perceptual distance* refers to people's beliefs about distances between places which are

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visible from each other and are typically in sight during the estimation procedure (Künnapas, 1960; Baird, 1970; Dainoff *et al.*, 1974; Wiest & Bell, 1985). Although they are not the focus of the present review, many of the measurement methods used to study perceptual distance, in particular psychophysical ratio-scaling, are also used to study cognitive distance; the methods have similar difficulties in both cases.

An exhaustive set of five classes of measurement methods is discussed in this review. This set is partially derived, with some elaboration, from a comprehensive list of methods for collecting environmental cognition data provided by Golledge (1976). Golledge (1987) also contains an illuminating discussion of some of these issues. The five classes include:

(1) Psychophysical ratio scaling
(2) Psychophysical interval and ordinal scaling
(3) Mapping
(4) Reproduction
(5) Route choice

In a sense, all five classes of methods are psychophysical methods in so far as they involve measurement of a psychological quantity (cognitive distance) that corresponds to a directly measurable physical quantity (physical distance). However, only the first two classes consist of traditional psychophysical scaling techniques designed to measure any psychological quantity at the ratio, interval or ordinal level of measurement. The last three methods are more specialized for distance estimation. Mapping requires simultaneously representing the relative locations of several places in an environment but at a smaller scale of size than the estimated environment. Reproduction involves directly reproducing traversed distances without a change in scale of size from the estimated distances. The final class, route choice, consists of measures of psychological distance based on recording the routes people choose to travel.

The methods differ from each other in several general ways (Table 1) including, of course, the frequency with which they have been used by researchers. One important difference is the level or scale of measurement of the resulting distance estimates. *Ordinal* measurement leads to information about the rank orders of distances, indicating which distances are shorter or longer than other distances without directly indicating how much shorter or longer. It represents the minimum level of quantitative information possible. *Interval* measurement produces estimates in which quantitative intervals between distances are meaningfully expressed; it indicates not only that one distance is longer than another, but that it is longer by a defined amount. However, no absolute zero-point (value of the scale that represents no amount of distance) is defined on an interval scale. As a consequence, one cannot describe an interval distance as being a certain ratio or proportion of another distance (e.g. one cannot speak of interval distance A as being twice as long as interval distance B). This last property belongs to *ratio* measurement; absolute zero and consequently meaningful distance ratios are defined.

Besides level of measurement, the methods differ as to whether they require arbitrarily-sized scale translations and calculations of ratios between test and standard distances. Also, the methods suffer differentially from weak or strong forms of non-independence between pairs or larger subsets of distance estimates. *Strong non-independence* occurs when the magnitude of one among several distance estimates

TABLE 1

Methods of cognitive distance measurement

Methods	Ratio scaling	Interval, ordinal scaling	Mapping	Reproduction	Route choice
(1) Level of measurement	Ratio	Interval, ordinal	Ratio	Ratio	Ordinal
(2) Scale translation and ratio calculation	Yes	No	Yes	No	No
(3) Degree of non-independence of estimates	Weak	Weak, strong with MDS and ranking	Strong	Weak, strong with same-size mapping	Weak
(4) Utility for estimating multiple and single distances	Useful for both	Useful for multiple only	Useful for multiple only	Useful for both, inefficient for many	Useful for multiple only
(5) Utility for very large-scale distances	Yes	Yes	Yes	No	Yes
(6) Specific techniques	Ratio and magnitude estimation, familiar units, etc.	Paired comparison, ranking, rating scales, partition scales	Maps, grids, models	Pairwise reproduction, same-size maps, triangulation	Route choice

necessarily depends in part on the magnitudes of some or all of the remaining estimated distances (e.g. as in ranks or maps). *Weak non-independence* occurs when the magnitude of one among several distance estimates *may* be influenced by the magnitudes of some of the remaining estimates, often because of order or context effects that can be ameliorated (e.g. time-order 'errors'). The methods also differ in their efficiency for collecting large numbers of estimates and in their utility for collecting single distance estimates. Finally, their usefulness for spaces of various sizes varies somewhat. The ways in which the classes of methods differ are discussed in detail below.

Psychophysical ratio-scaling

Psychophysical ratio-scaling methods have been among the most commonly used methods in the study of cognitive distance, presumably because of the ease and efficiency with which they can be used with small and very large distances. These methods generate ratio scales for cognitive distance just as they do for any psychological quantity measurable at the ratio level. They have commonly been classified into four techniques, described here in the context of distance estimation (for general discussions of scaling, including ratio scaling, see Stevens, 1964; Engen, 1971; Laming, 1973; Gescheider, 1985):

(a) *Magnitude production:* the observer adjusts a test distance so its length matches a number provided by the experimenter. A standard distance and its modulus number may be provided by the experimenter or implicitly generated by the observer.

(b) *Magnitude estimation:* the observer assigns a number to a test distance that reflects its apparent length relative to a standard distance assigned some modulus number. The standard distance and modulus may be provided by the experimenter or implicitly generated by the observer.

(c) *Ratio production:* the observer adjusts the length of a test distance until it appears to stand in a prescribed ratio to a given standard distance.

(d) *Ratio estimation:* the observer directly estimates the ratio of the lengths of two distances or adjusts one of a pair of lines so as to make the ratio of the two match the apparent ratio of a test distance to a standard distance.

While the production of ratios or magnitudes can be used to determine scaling functions and to calibrate respondents for other scaling tasks, it is less useful for collecting direct estimates of test distances. But both magnitude estimation (Allen *et al.*, 1978; Cohen *et al.*, 1978; Cadwallader, 1979; Sherman *et al.*, 1979) and ratio estimation (Lowrey, 1970, 1973; Briggs, 1973*a*, 1976; Byrne, 1979; Sadalla *et al.*, 1979; MacEachren, 1980; Sadalla & Magel, 1980; Sadalla & Staplin, 1980*a*; Foos, 1982) have been used in many studies of cognitive distance.

One type of magnitude estimation deserves special note: estimation of distance in terms of *familiar units* such as meters or miles (Lee, 1970; Canter & Tagg, 1975; Briggs, 1973*a*, 1976; Cadwallader, 1973, 1976; Böök & Gärling, 1981; Säisa *et al.*, 1986). In this case, the modulus and standard distance are associated in the respondent's mind via previous experiences (e.g. 'one meter is about the length of this stick'). It is a convenient method that allows people to express distance in units which they are much more familiar with than the units of traditional ratio scaling. Also, like magnitude estimation, but unlike ratio estimation, respondents can calculate the ratio between the numerical value of the standard distance and the numerical value of the distance estimate by a straightforward, precise multiplication. Unless respondents have counted steps, the same calculation must be spatially estimated in the case of ratio estimation. But because units such as miles or kilometers are so familiar as a means of communicating distances, estimates in these units may be more likely to reflect influences such as maps, road signs, city blocks, and other socially shared conceptions of distance. Also, people are likely to have somewhat variable ideas about the extent of a mile or a kilometer, just as conceptions of standard distances, in general, may vary in unknown ways when they are not based on controlled exposure by the researcher (and perhaps even when they are).

One of the most commonly used ratio-scaling techniques has been some version of ratio estimation involving a pair of lines used to estimate the ratio of two environmental distances. Subjects are given a standard line drawn on paper that represents a standard distance in the environment with which they are familiar (Figure 1). Their task is to draw or mark another line so that its ratio with respect to the standard line matches the ratio of the test distance to the standard distance. For example, Lowrey (1973) presented respondents with a standard line of 10 cm that represented 'how far it is from your home to the park' (the standard distance). On a separate line that was somewhat longer, respondents were to 'mark how far it would be from your home to the post office' (the test distance).

In much of the geographical research, the standard line represents a standard distance in the environment that subjects are familiar with before they participate in the study, typically a distance of several hundred meters or more. In such studies, the psychological magnitudes of the test and standard distances are functions of various types and amounts of exposure to the environment for some unknown amount of time prior to the collection of data. Some of the studies (e.g. Lowrey, 1970, 1973; Briggs, 1973*a*, 1976) have used more than one familiar route as standard distances, so that the final distance estimates are based on a variety of standard distances of different lengths for different subjects. As will be evident from my discussion below, some of the difficulties with interpreting ratio-scaled data are especially serious when using different standards with different subjects and uncontrolled exposure to those standards.

As is true with research on perceptual distance, much of the research on cognitive distance has utilized ratio scaling in order to characterize the power function that best

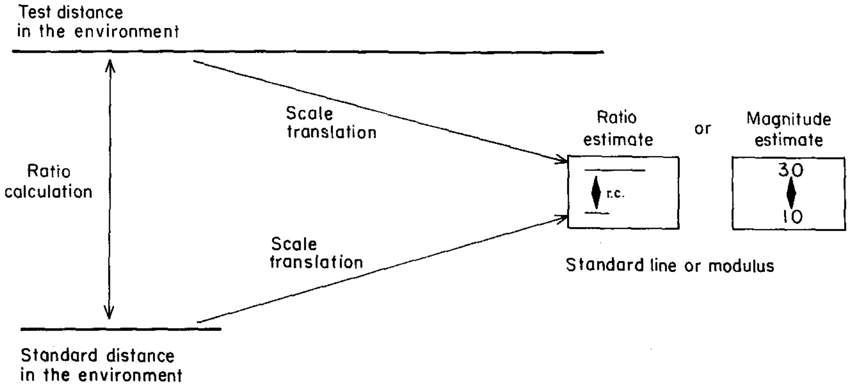

FIGURE 1. Scale translation and ratio calculation in two ratio-scaling techniques. Subjects calculate the ratio of the test distance to the standard distance and draw an estimate line proportionate to an experimenter-supplied standard line (ratio estimation); alternatively, they give a numerical estimate proportionate to an implicit or experimenter-supplied modulus (magnitude estimation).

fits the distance data. A power function states that cognitive distance is equal to physical distance raised to the power of some exponent and corrected by multiplication with a scaling constant. Interest has generally been in the size of the exponent, in particular whether it is equal to 1·0, or greater or less than 1·0. This parameter indicates how fast and in what direction estimated distance changes as physical distance changes. For example, does estimated distance change more rapidly than physical distance? An exponent with an absolute value greater than 1·0 indicates that it does; in fact, researchers have sometimes, but not always, found exponents greater than 1·0 (e.g. Briggs, 1973*a*; Cadwallader, 1976; MacEachren, 1980). Furthermore, does estimated distance increase with increasing physical distance? A positive exponent indicates that it does; in fact, only positive exponents have ever been found, at least in published data.

The exponent of the power function does not tell us about the absolute accuracy of distance estimates, only about relative accuracy. It is true that 'veridical or accurate judgments results in an exponent of 1·0' but not necessarily true that 'distorted judgments produce either smaller or greater exponents' (Kerst *et al.*, 1987, p. 185). Given the appropriate scaling constant, estimated distance may be larger or smaller than the corresponding physical distance, regardless of the value of the exponent. A similar point is true of the scaling constant—by itself it does not inform us about the absolute accuracy of the correspondence between any given physical and cognitive distances (e.g. Briggs, 1973*a*). One should speak about 'overestimation' and 'underestimation' only if both the exponent and the scaling constant are taken into account (and as suggested below, not necessarily then either).

One of the most common criticisms of psychophysical ratio scaling has been the problem of various forms of non-independence reflected in different order or context effects (Poulton, 1968; Ross & DiLollo, 1971; Laming, 1973; Duda, 1975; Walmsley, 1978). This problem is discussed in detail in several of these sources and will not be described here in detail; an example is the dependence of estimates on the range of the presented stimuli. In general, ratio estimation and production are 'particularly sensitive to stimulus context effects' (Gescheider, 1985, p. 174). It is important to note, however, that problems arising through order and context effects are minimized in some respects when a single test distance is estimated with a single standard distance. In any case, appropriate randomization or systematic presentation of stimulus orders can largely alleviate these difficulties. They are therefore referred to as *weak* forms of non-independence in this review.

There are other difficulties with ratio and magnitude estimation. One is the *ratio calculation* subjects must make between the length of the standard distance and the length of the test distance. For example, in Figure 1, accurate estimation requires subjects to calculate that the standard distance is one third the length of the test distance (or the test distance is three times the length of the standard). The same calculation must be made from the standard line to the estimate line (from the modulus number to the estimate number in magnitude estimation). Depending on the direction in which the calculation is arbitrarily phrased, it can be thought of as multiplying shorter distances into longer distances or dividing longer distances into shorter distances.

Magnitudes of distance estimates apparently depend considerably on the size of the ratio that must be calculated between the standard distance and the test distance (cf. Poulton, 1968; Baird, 1970; Phipps, 1979). Other factors equal, distance estimates will tend to be most accurate when the ratio of the standard distance to the test distance is close to 1·0 and very little calculation is required (see Baird, 1970, for a discussion of this point in the context of perceptual distance, and Phipps, 1979, for a general discussion not limited to distance estimation). For instance, Montello (unpublished data[1]) had subjects ratio-estimate a test distance of 16·5 m with a standard distance of 2·1 m. Their mean estimate was 13·1 m in length (after retranslation by the experimenter), a 21% underestimation. However, in a separate task, the same subjects completed a map of the test path given the initial 7·1 m segment of the path (essentially a ratio estimation in which a standard of 7·1 m was used to estimate the remaining 9·4 m). Their mean estimate of the remaining 9·4 m was 9·4 m (after retranslation), neither an under- nor overestimation. In this example, the use of a standard distance of nearly the same length as the test distance resulted in very accurate distance estimates.

A relative decrease in the magnitude of ratio-scaled distance estimates, as the length of the test distance increases, would result in a negatively accelerating power function (exponent $< 1·0$), which is sometimes found (e.g. Briggs, 1973*a*). This psychophysical function may in fact reflect the artifactual influence of the particular standard distances used in measurement, as discussed above, rather than some fundamental relationship between psychological and physical distance (e.g. Byrne, 1979). Also, it is possible that increased estimates found with 'segmented' pathways (Allen, 1981) might result from this scaling artifact; segmentation breaks the test distance into smaller pieces, which would be estimated as relatively longer. Briggs (1973*b*), Sadalla and Magel (1980) and Baird *et al.* (1982) have suggested that a negatively accelerating psychophysical function could explain the effect of segmentation on estimated distance, though none of these authors present this explanation in terms of measurement artifact.

A second difficulty with ratio scaling is the *scale translation* between the standard distance and the standard line, or modulus. For example, in Figure 1, a standard distance in the environment of several meters or more is symbolically represented to subjects in terms of either an arbitrary number or a standard line that is arbitrarily small (lines and numbers are symbolic expressions of environmental distances in the sense that they stand for or take the place of them). The same scale translation characterizes the relationship of the environmental test distance to the 'correct' estimation line or number. Unlike the ratio calculation between the standard and test distances discussed above, of which it is quite independent, subjects are not actually required to calculate the translation ratio between the standard line or modulus, and the standard distance. But the relative or absolute scale of the symbols subjects must use to express distance might also be expected to influence the magnitudes of distance estimates (e.g. Zwislocki & Goodman, 1980).

Another important issue in interpreting ratio-scaled data is the extent of bias in the cognitive representation of the standard distance. Giving subjects a standard distance of a particular length does not ensure that all of them will internally represent it as being of equivalent length. As Engen (1971) states with respect to ratio scaling in general, 'the actual subjective unit used by each observer is not and cannot be known' (p. 73). But an assumption of unbiased standard distances, or knowledge of the type and severity of bias, is necessary to interpret distance data in terms of 'accuracy' with respect to an external physical standard. Presumably, mental representations of standard distances would be subject to the same influences as are representations of test distances (e.g. the presence of turns, slope, clutter, etc.—see Lee, 1970; Cohen *et al.*, 1978; Sadalla & Staplin, 1980*b*; Herman *et al.*, 1983). Due to such biases, a given estimate that is apparently accurate might actually be quite inaccurate, or vice versa. For example, consider the implications of a standard distance of 5 m being internally represented by a given subject as being longer than 5 m. In this case, an apparent underestimation of the test distance might actually reflect an accurate subjective representation of that test distance, or even one that is too long.[2]

Although some influences on subjective distance might be intra-individually consistent, and thus affect test and standard distances similarly, others might depend on particular characteristics of routes or on variables such as familiarity. If subjects are randomly assigned to experimental conditions, and the nature and amount of exposure to the standard distance is equivalent across conditions, biases in the representation of the standard distance will be equal across conditions on the average. However, the researcher would not in principle know the extent of any distortion in the representation of the standard distance. When researchers use several long, naturally occurring standard distances in a single study, and the nature and amount of exposure to them is uncontrolled (as cited above, common in very large-scale distance research), the bias in the standard distance would not necessarily be equal across conditions and would probably be quite substantial. Especially when different subjects use different standards, researchers would have little or no basis for establishing the extent of this bias. Given this opaqueness to the researcher of the true subjective magnitudes of standard distances, using ratio-scaling to determine a person's true absolute cognized distance for a particular physical distance is difficult or impossible to do validly. In essence, the researcher will obtain ratio-level data but will not know the exact size of these ratios. Psychophysicists have discussed this to some degree in a general context not restricted to cognitive distance (Engen, 1971; Zwislocki & Goodman, 1980; Gescheider, 1985). But very little or no discussion of this important problem exists in the literature on cognitive distance.

One final, relatively minor difficulty with ratio estimation is that the orientations of the standard line and estimate line will influence the magnitudes of distance estimates (Hartley, 1977). Vertical lines appear longer than horizontal lines, an effect known as the *vertical illusion*. Although this has implications for the validity of ratio estimates as measures of the absolute accuracy of represented distance, it does not threaten the validity of comparisons of relative distance across experimental conditions (unless the standard and estimate lines are not drawn in the same orientation in all conditions).

Several researchers have based conclusions about absolute accuracy on data generated with psychophysical ratio scaling. This is easy to do: 'knowing the real distance involved in the standard line made it a relatively simple matter to transform the estimates obtained into meter equivalents' (Coshall & Potter, 1987, p. 614). Day (1976), for instance, reviewed urban distance studies and concluded that 'where respondents are familiar with a location their average distance estimate will be fairly correct while unfamiliarity leads to overestimation' (p. 199). MacEachren (1980) stated that estimated distances are generally found to be greater than objective distances for the range of distances within an urban area. Coshall (1985) concludes that 'generally, overestimation of distance is the rule... familiarity with places tends to reduce distance overestimates rather than produce underestimates' (p. 111). Antes *et al.* (1988) concluded from their ratio-estimated data that subjects generally 'overestimated' distances within a city, and that females estimated distances more 'accurately' after a new street had been constructed. Péruch *et al.* (1989) summarized their data collected by estimation in familiar units (km): the shortest distances were overestimated, the medium distances underestimated, and the longest distances quite accurately estimated' (p. 237).

Conclusions such as these cannot be considered empirically substantiated, given the difficulties involved in making conclusions about absolute accuracy discussed in the last several pages. Nor are statements about the accuracy of estimates generated with these methods without problems in laboratory contexts. Kahl *et al.* (1984) and Herman and Klein (1985), for example, concluded that walked distances are consistently underestimated. They based this conclusion in part on data from Sadalla and Staplin (1980*a*) that were generated by ratio estimation.

Psychophysical interval and ordinal scaling

There are several psychophysical scaling methods that can be used to generate distance estimates at the interval or ordinal level:

(a) *Paired comparisons:* distances are presented in pairs, usually all possible pairs. The observer picks which member of the pair is longer or shorter. For the method of constant stimuli, all distances are paired with a fixed standard. The method of *triads* requires observers to pick which of three locations is furthest from the other two. This amounts to an initial judgement about which two locations are furthest apart from each other, followed by a paired-comparison of the distances between each of these two locations and the remaining location.

(b) *Ranking:* the observer arranges a series of distances in rank order along the dimension of length.

(c) *Rating scales:* the observer assigns each distance to one of a set of predetermined classes that represent relative length.

(d) *Partition scales:* the observer assigns distances to classes with the explicit instruction to construct equal-appearing intervals of length.

All of these techniques have been used by cognitive distance researchers (Golledge *et al.*, 1969; Kosslyn *et al.*, 1974; Allen *et al.*, 1978; Baird *et al.*, 1979; Cadwallader, 1979; Allen, 1981; Magaña *et al.*, 1981; Biel, 1982; Newcombe & Liben, 1982).

Except for partition scaling, which directly leads to interval scales, these techniques generate ordinal data. However, by employing certain assumptions (e.g. underlying normality) and certain data transformations (e.g. proportions to z-scores), all of the techniques are routinely used to generate metric data, particularly through nonmetric multidimensional scaling (MDS) (Golledge *et al.*, 1969; Kosslyn *et al.*, 1974; Allen *et al.*, 1978; Baird *et al.*, 1979; Magaña *et al.*, 1981; see also Sherman *et al.*, 1979, for MDS with metric input data). Several different algorithms for performing MDS are available (see Magña *et al.*, 1981). In general, they take a matrix of proximity or distance data (similarity or dissimilarity data) collected on a pairwise basis (complete or incomplete set of pairs) and reproduce it in a space of one or more dimensions of variability, or *semantic distance.* The algorithm minimizes the difference, or *stress*, between the patterns of proximities in the matrix and in the space. The space is usually confined to a Euclidean metric but need not be. The researcher picks a dimensionality for the solution but typically tries to minimize stress with a minimal number of dimensions. For purposes of comparing the resulting space with other MDS spaces, with maps or with the environment itself, the dimensions of the resulting space are typically stretched, rotated and translated to maximize congruency (as in the computer program CONGRU).

It is important to interpret nonmetric MDS output only in terms of relative accuracy, not in terms of absolute accuracy.

> MDS can provide a measure of accuracy between the representation generated using each collection technique and the actual distances between the items in the geographic environment (Magaña *et al.*, 1981, p 296).

Such a statement applies only to relative accuracy. That is, one could use MDS to compare the relative estimated distances between two pairs of locations but could say nothing about the absolute accuracy of a given estimate as compared with the actual physical distance it estimates (e.g. see Hourihan & Jones, 1979). Given the dimensional shifting and stretching involved in MDS congruency procedures, they tell us nothing about uniform scale distortions in the representations (distances might be perfectly accurate in a relative sense but absolutely inaccurate because all distances are equivalently over- or underestimated).

Furthermore, non-uniform scale distortions can lead to erroneous conclusions about absolute *or* relative accuracy when they are widespread enough to drive the congruency transformations carried out before the comparisons. If a large part of the MDS map is relatively accurate with respect to the cartographic map, for instance, the rest of the MDS map will be scaled to that part. It is possible, however, that the relatively accurate part is actually uniformly distorted to a greater extent than is the rest of the MDS map. The best fitting solution does not depend on any correspondence with an external standard—a large, internally consistent area in the representation can determine the final solution though it is actually distorted in an absolute sense relative to the environment it represents. Thus one must be cautious in using MDS to talk about differential size distortion (differential relative accuracy) in different areas of the representation.

The difficulty with interpreting differential accuracy within an MDS representation reflects a form of non-independence in ranking and MDS data that limits their usefulness in answering questions about pairs or other subsets of distances. The relative locations (relative distances) derived from these procedures are just that—relative to the other objects or places included in the estimation set. The resulting data are informative about the overall configurational accuracy of the set of locations (the single pattern of relative distances expressed by the configuration as a whole). But they are not unambiguously informative about the differential accuracy of one part of the configuration relative to some other part (e.g. a claim that distances near the periphery of the configuration are underestimated, while those in the center are accurately estimated). Pairwise distance estimates derived from these procedures should not be parametrically analysed as independent scores (e.g. the parametric averaging of ranks by Newcombe & Liben, 1982). Because it is intractable, a necessary characteristic of such data, I describe this form of non-independence as *strong*.

Many of the difficulties associated with ratio-scaled data also apply to interval- and ordinal-scaled data (e.g. context effects), but there are additional difficulties with ranking and paired-comparison procedures. Ties are either not allowed, or they require certain transformations to analyse. Inconsistent distance estimates are sometimes made. An example would be a subject estimating the distance between two points as being different depending on the direction in which it is estimated. There are various analytical approaches to such metric violations (Killeen, unpublished[3]), but there is no consensus about what they actually mean. Finally, interval and ordinal scaling are not of much use for collecting estimates of single test distances, as would be desirable in some experimental situations.

Mapping

Mapping techniques require subjects to simultaneously represent the relative locations of three or more objects or places in an environment at a smaller scale of size than that of the environment itself. Researchers have, for example, asked subjects to draw or construct maps of environments with or without a specified list of places to be located on the map (Howard *et al.*, 1973; Allen *et al.*, 1978; Magaña *et al.*, 1981). Other researchers have asked subjects to construct models (Howard *et al.*, 1973; Sherman *et al.*, 1979) or locate places on a grid or a matrix (Baird *et al.*, 1979). In any case, a distance standard may or may not be provided, and some initial detail or framework may be included. Subjects are often allowed to rearrange the places on their maps or models as they construct them. Although not derived from classical psychophysics, mapping is actually a modified ratio estimation. If no explicit standard line is supplied, the researcher could not readily infer subjects' implicit standards, although they exist. My discussion of ratio scaling above suggests that even when a distance standard is supplied, reliable conclusions about absolute distance accuracy probably can't be made.

The primary difference between mapping and ratio scaling is that when constructing a map or model, subjects must represent all of the distances between objects or places in a single, simultaneously consistent 2- or 3-dimensional format. This makes it problematic to use individual pairwise distances as independent scores in statistical analyses (strong non-independence). And these methods force a Euclidean metric on the sets of pairwise estimates (e.g. distance from A to B equals the distance from B to A) that might be considered artifactual (Montello, unpublished[4]). In addition, some mapping techniques have been criticized for reflecting drawing ability (e.g. Magaña *et al.*, 1981).

Unlike psychophysical scaling, mapping directly elicits directional information as well as distance information (see MacKay, 1976). That is, constructing maps and similar representations requires the specification of both distances and directions between locations. Expression of directional information and the increased context provided by the simultaneous presence of more than two objects or locations may increase the relative accuracy of estimated distances. Conversely, accuracy may suffer because of distortions in directional information, such as right-angle and parallel biases, that have been documented (e.g. Tversky, 1981; Sadalla & Montello, 1989).

Reproduction

I use the term *reproduction* to refer to non-symbolic estimation of environmental distances at the same scale of size as the environment. Typically subjects rewalk a straight-line distance they think is the same length as the test distance, or they simply place objects in a configuration of the same size in which they previously encountered the objects. Reproduction methods do not suffer, as do ratio scaling and mapping, from the interpretational problems engendered by scale translation and ratio calculation.

Several researchers have used reproduction with walked distances, both with adults (Sherman *et al.*, 1979; Cohen & Weatherford, 1980; Sadalla & Magel, 1980; Newcombe & Liben, 1982) and with children (Cohen & Weatherford, 1980; Herman *et al.*, 1983; Herman *et al.*, 1984; Kahl *et al.*, 1984; Herman & Klein, 1985; Herman *et al.*, 1986). Cohen and Weatherford (1981) had subjects reproduce a two-dimensional configuration of objects, basically a mapping procedure that does not involve a scale translation. Such a reproduction mapping procedure obviously leads to the same strong form of non-independence as mapping, MDS, and other methods that generate simultaneous configurations. Generally, though, reproduction is done pairwise (one pair of locations at a time) and thus does not incur strong non-independence.

The method of *resection* can be considered a form of reproduction. This method requires subjects to point to a target place or object that is out of sight. By pointing to the target from two or more different stationpoints, its location (hence, its distance from other targets) is directly reproduced by the intersection of the pointed directions, without a size translation. Although sufficient to unambiguously establish estimated distance in two-dimensional space, the use of only two pointing directions does not allow conclusions about locational precision. A version of resection known as *triangulation* (Hardwick *et al.*, 1976) results in an estimation 'triangle' formed by the intersection of three pointing directions (Figure 2). The size of this estimation triangle reflects the precision of locational knowledge as expressed from different places in an environment. A related approach is taken by Gordon *et al.* (1989). They discuss an iterative program for constructing a configurational representation from multiple pairwise directional estimates.

Reproduction can be efficiently performed for a small number of estimates. It is easier for subjects to understand than psychophysical scaling, which probably accounts for its popularity among developmental researchers. Because of the direct behavioral nature of reproduction, subjects may base distance estimates partially or completely on time or effort. This may or may not be desirable. Its primary difficulty is its inefficiency for large numbers of estimates and for long distances. The latter makes reproduction almost useless for research at urban or larger scales. Also, reproduction

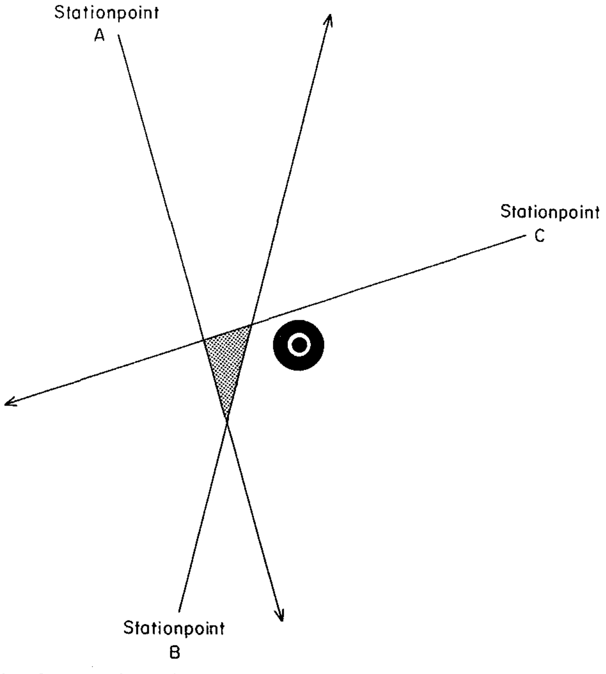

FIGURE 2. triangulation from stationpoints A, B and C to target object. The center of the shaded triangle is the estimated location; the area is the imprecision of estimation.

does require a space in which to make estimates. Just as certain structural characteristics of an environment may influence the subjective magnitudes of test and standard distances, they may also influence the subjective magnitude of the reproduction space used for estimation. It is not obvious what should be defined as a neutral estimation space.

Route choice

A final approach to measuring cognitive distance is very different from the latter approaches, in that it does not require *explicit* memory of the test distances. As effort minimizers, humans usually choose to travel along routes which they believe require the least effort—usually the shortest route (Lee, 1970; Downs & Stea, 1973; Cadwallader, 1976). If this assumption is true, a pattern of route choices would constitute an ordinal measure of people's distance knowledge.

Because this assumption is in fact dubious, as I discuss below, route choice does not constitute a viable class of distance measurement techniques. However, it is included in this review because it has been used several times in published and cited research as a method of establishing subjects' beliefs about environmental distances; as such, it is important that its weaknesses be understood. For example, Lee (1962) found that residents more frequently chose to shop at stores located in the direction of the city center than at closer stores located away from the direction of the city center. Although this may have been due to a variety of factors, Lee concluded that routes in the direction of the city center seemed shorter to residents for some reason. Nasar (1983) used route choice as a direct measure of cognitive distance. He recorded which of two equally distant parking garages faculty members at a large university chose to park in and concluded that the more commonly chosen garage was subjectively closer for most faculty members.

The ordinal distance data generated in this way does not lend itself to sensitive parametric analysis. In addition, there exist at least two serious difficulties with the method. First, the idea of minimization suggests that route choice reflects *cost* or *effort*, not just *distance* (Gärling & Gärling, 1988; Huriot *et al.*, 1989). Often they are nearly equivalent. But sometimes economic costs or the presence of hills, traffic, left turns or other impediments make a shorter route more costly, though it may be known by the traveller to be shorter in distance. A second difficulty is with the assumption that people choose routes only on the basis of some kind of minimization. It is probably safe to assume that route choice reflects route preference (Briggs, 1973*a*), but the basis for this preference need not be cost minimization. Factors like safety, familiarity, or aesthetics could be important. Certainly when alternative routes are nearly equidistant, other factors become more important. Unfortunately, this is just the case when modest discrepancies between physical and psychological distance might noticeably impact route choices.

Research Comparing Measurement Methods

Several studies have attempted to evaluate measurement methods by directly comparing them. At the scale of inter-urban distances, Cadwallader (1973, 1976) compared ratio and magnitude estimation to familiar-unit estimation in miles, and magnitude estimation to partition scaling (1979). His concern has primarily been with correlations between estimates derived from the various methods, and with correlations between estimates and the corresponding physical distances. Most of his correlations were 0·90 or higher; those between magnitude estimation and partition scaling in particular were a bit lower. Cadwallader concludes that 'a methodological difference in data collection can influence the rate at which cognitive and real distances co-vary' (1976, p. 320), although his correlations suggest a very modest influence.

At the intra-urban scale, Howard *et al.* (1973) compared magnitude estimation, ratio estimation, map-drawing and model-building tasks. They found that estimates from the four methods were highly intercorrelated and highly correlated with physical distance. Sherman *et al.* (1979) compared magnitude estimation with model building. Correlations between physical distances on a college campus and geometric means of the estimates from the two methods were greater than 0·90. The exponent of the power function relating estimated distance to physical distance was 1·05 for magnitude estimation and 0·89 for model building. The authors incorrectly concluded from the size of the exponents alone that magnitude estimation produced overestimation and model building produced underestimation. They preferred magnitude estimation to model building because of the independence of the magnitude estimates.

MacKay (1976) compared sketch-maps with non-metric MDS maps of U.S. cities. When compared with actual cartographic maps, both subjective ratings and objective ratings based on a comparison algorithm indicated the configurational superiority of the sketch-maps to the MDS maps. MacKay also pointed out that MDS will not work equally well with all configurations: Those with high interpoint distance variability and low interpoint angular variability will work best.

Similarly, Baird *et al.* (1979) compared MDS maps derived from rating-scale data with maps produced by placement of building names on a matrix. Both methods resulted in highly accurate relative placements of buildings. One week later, subjects tended to choose their own direct placement maps as being more accurate than either the MDS maps or actual cartographic maps. Curiously, a group of subjects who had not generated maps also chose the direct placement maps as the most accurate.

Magaña *et al.* (1981) used MDS to compare the relative configurational accuracy of estimated campus layouts, generated by four methods: sketch-mapping with and without a supplied list of 13 buildings, ratio-scaling by familiar units ('absolute-judgements task'), and a triads paired-comparisons task. All of the data were subjected to non-metric MDS, and compared with the actual campus layout via CONGRU. All but the fourth method generated configurations that were quite similar to one another and to the actual layout. The triads task produced a fairly accurate but somewhat poorer configuration than the other methods, perhaps because of the incomplete set of triadic comparisons used or the somewhat confusing and difficult nature of this task.

Newcombe and Liben (1982) collected distance estimates from first-graders and from college students. In the context of a study of barrier effects, half of the subjects from each age group ranked the distances between ten toy landmarks, and the other half reproduced the distances in a pairwise manner. An age by barrier-condition interaction showed up in the ranking data but not in the reproduction data. However, younger subjects seemed to 'chain' their responses when ranking distances by placing the toys in the order in which they had walked them. A sex by barrier-condition interaction was found for the college students, but only with the reproduction data. The authors explained their somewhat puzzling findings by citing other research that had found inconsistent barrier effects. They concluded that 'any dependent measure draws on skills that are extraneous to the spatial representation *per se* (p. 57).

The studies reviewed above have directly compared some of the distance estimation techniques, but they have focused on correlational indices that reflect relative and not absolute correspondence. Ratio scaling and mapping techniques generate distance estimates that generally correlate highly with each other and with physical distance (the range of distances studied would influence the magnitudes of correlations; in particular, the use of a restricted range of distances would attenuate correlations). These methods should be more or less equivalent for comparing patterns of relative distance as functions of variables such as familiarity, environmental structure, and so on (issues of strong non-independence and the need for estimates of single or configurational distances will influence a choice between the two classes of methods). Interval and ordinal scaling produce data that correspond well with ratio scaling and mapping data, though these techniques are not sensitive enough to pick up all metric information that people know in many cases. They are simple for respondents to use, however, and do not require assumptions about the metric geometry of a set of estimates. Their use would be adequate for many purposes. Also, some research suggests that actual mapping or modelling might be better ways to assess configurational knowledge than are MDS representations. With the exception of Newcombe and Liben (1982), however, the research described above does not inform us of the performance of the estimation techniques in different experimental contexts, when only one or a small number of test distances are compared. How do these methods compare with each other, both within and between experimental conditions, in their abilities to capture relatively subtle influences on cognitive distance? Especially useful for answering this question would be direct comparisons of ratio scaling and reproduction.

The four classes of methods capable of generating metric distance estimates (all but route choice) would not be expected to yield identical distance estimates in part because of differences in the informational cues provided by the various procedures (e.g. Golledge, 1987). Ratio, interval and ordinal scaling generally involve straight recall of distances in a removed setting that does not entail actual locomotion; they do not provide sensory cues of any kind to prompt memory (visual structure, relevant proprioception, etc.). Such a description also applies to mapping techniques, although the angular information called forth by such direct configurational methods probably influences what is recalled. On the other hand, the informational context provided by visual and motoric stimulation during reproduction makes this technique less abstract than the straight recall of the other three classes.

Further Issues of Measurement and Construct Validity

There are several general issues relevant to the interpretation of cognitive distance data in addition to the issues specific to particular measurement methods discussed above. One is whether subjects understand the distance estimation task in the way the researcher assumes they do. Given instructions to estimate the distance between two places, for example, do subjects estimate route distance or straight-line distance? Suppose that a researcher hypothesizes that straight-line estimates of distances between places joined by angular routes will be longer than straight-line estimates between places joined by straight routes (e.g. Kosslyn *et al.*, 1974; Sherman *et al.*, 1979). Unless the researcher carefully specifies straightline estimation (and perhaps even then), subjects might estimate route distances. Any such tendency on the part of the subjects would tend to support the researcher's hypothesis in this case, and depending on the particular hypothesis in question, the converse could happen (e.g. Sadall & Magel, 1980).

Cognitive distance studies in fact differ as to whether subjects are instructed to estimate route distance (e.g. Briggs, 1973*a*) or straight-line distance (e.g. Canter & Tagg, 1975); presumably some studies do not specify which should be estimated. Thorndyke and Hayes-Roth (1982) and Péruch *et al.* (1989) explicitly asked subjects to estimate both types so that they could compare different hypotheses about distance estimation. Rieser *et al.* (1980) also asked for both types. They compared the results from the two to results collected under non-specific instructions. Interestingly, estimates collected under nonspecific instructions were very similar to estimates collected under route instructions and unlike estimates collected under straight-line instructions.

Another way subjects might misunderstand the distance estimation task is to confuse temporal separation between places with spatial separation. People commonly express distance or separation in temporal terms (e.g. 'Portage is four hours away'). Although they realize that time and distance are not always equivalent, subjects might estimate according to travel time when the experimenter wants them to estimate travel distance, without regard for time. Such a confusion would most likely occur in research at urban or inter-urban scales. It would produce data supporting the hypothesis that travel time determines cognitive distance (e.g. MacEachren, 1980).

Another issue concerns the distinction between estimates of physical distance and estimates of 'apparent' distance. Some researchers ask subjects to judge how far it is from place A to place B; others ask subjects to judge how far it 'seems' to be. Teghtsoonian (1965) compared magnitude estimates of circle area with line length under *actual* and *apparent* instructions. Subjects were asked to rate stimuli as to either 'how large they are' or 'how large they look to you'. The exponent of the power function for circle area, but not for line length, differed under the two instructional sets. Da Silva and Dos Santos (1984) similarly found no differential effect between these two types of instructional sets on the exponent of a power function fit to their perceptual distance data. No evidence exists as to whether this instructional variation would affect cognitive distance estimates. It is plausible that an apparent instructional set would elicit subjects' preconceptions about influences on cognitive distance. But the intent of most distance research is to elucidate actual influences on psychological distance, not preconceptions about influences. One could probably get at these preconceptions in a more direct manner.

A final issue deals with the proper unit of analysis for cognitive distance studies. Ewing (1981) points out that aggregating estimates across individuals at each test distance or test time can seriously misrepresent the intra-individual relationship between cognitive distance and predictor variables such as actual distance or travel time. In other words, correlations based on distance or travel time as the unit of analysis may not accurately reflect correlations based on the individual subject as the unit of analysis, an example of a cross-level inference known as the *ecological fallacy* (Pedhazur, 1982). Ewing (1981) suggests that averaged correlations based on disaggregated analyses, could separately for each subject across distances or travel times, are behaviorally valid indices of the effects of these variables on cognitive distance. An equivalent analysis would be to enter individual subjects into the analysis (repeated measures) rather than simply averaging over between-subject variance, as was done in the criticized research.

Ewing's (1981) critique is valid in the cases he considers. However, this problem is reduced when all subjects estimate the same distances. Furthermore, it is not always the case that individual correlations are preferred over aggregated correlations (Pedhazur, 1982). If one wants to speak about average estimated distance for a given physical distance, and subjects estimate all distances in the sample, aggregation across subjects is correct. Of course, the issue is irrelevant when subjects make only a single estimate.

The Measurement of Psychological Distance: Conclusions

The five classes of methods for measuring cognitive distance considered in this review were found to differ in several general ways (Table 1). Ratio-scaling techniques are very efficient, and they are useful for collecting distance estimates at any scale, including intra-urban and inter-urban scales. Several problems discussed above, however, suggest that one should not interpret data generated by them in terms of absolute accuracy relative to actual physical distances. Conclusions about overestimation and underestimation of physical distances should thus be avoided, unless speaking relatively. And it is ill-advised to analyse such data as errors from 'correct' estimates, especially when different test distances are compared and a variety of standard distances are used. Although they can validly be used to test hypotheses about factors that increase or decrease cognitive distance, ratio-scaled data should not be used to draw conclusions about the magnitudes of differences between estimates in various conditions except in terms of standardized differences between means (or something equivalent). In addition, the difficulties discussed above will typically increase error variance in the distance estimates and can distort even conclusions about relative accuracy in some situations (e.g. when different standards are used in different conditions).

Likewise, most psychophysical interval and ordinal scaling techniques cannot be used to make conclusions about estimation accuracy, except the overall relative accuracy of a configuration of locations. Although these techniques are also very efficient for collecting large numbers of estimates and estimates at any scale, they are not useful for collecting single estimates (strong non-independence in ranking and MDS).

Mapping techniques are also very efficient for collecting large numbers of estimates and estimates at any scale but are not useful for collecting single estimates (strong non-independence). However, mapping is very useful for assessing relative configurational accuracy. Like ratio scaling, mapping should not be used to assess absolute accuracy relative to physical distances because it requires subjects to express distance in symbolic terms (drawings or models) that require an arbitrarily large scale translation.

Reproduction techniques do not necessitate ratio calculations with a standard, nor do they involve symbolic expression at some arbitrary scale. Reproduction does not suffer from the strong form of non-independence incurred by MDS and mapping techniques (except in the case of same-size maps). The techniques are easy for subjects to understand, making them attractive to developmental researchers. Furthermore, reproduction may be directly relevant to predicting and explaining locomotion; such methods are actually just quantified locomotion, unlike mapping and psychophysical scaling methods. Reproduction techniques are only moderately efficient for collecting large numbers of estimates, but they can readily be used for collecting single estimates. The most significant difficulty with reproduction is that it is of little use for collecting estimates of distances at urban and larger scales.

Route choice is not efficient for collecting large numbers of estimates, nor is it useful for collecting single estimates. Although admirably behavioral and unobtrusive, the method generates rather insensitive data. But most seriously, it is problematic in so far as effort and cognitive distance do not always strongly co-vary, and in so far as the assumption of effort-minimization does not always hold. Route choice is thus not very useful as a method of measuring cognitive distance; it is probably more interesting as an outcome variable dependent on cognitive distance and other factors.

Ratio scaling and mapping have been shown to generate distance estimates that correlate highly with each other and with physical distance; interval and ordinal scaling correlate somewhat less highly. These methods are therefore generally equivalent for comparing patterns of relative distance as functions of independent variables of interest. Existing research comparing methods, however, tells us nothing about absolute estimation accuracy. Nor does it tell us much about the performance of the estimation techniques in different experimental contexts when only one or a small number of test distances are compared.

The potential for invalid interpretations of distance data, in particular data generated by psychophysical scaling, is greatest in nonexperimental field studies or when using multiple standard distances. However, ratio scaling must be considered the method of choice when independent pairwise estimates are required in very large-scale spaces such as cities and countries. Ordinal scaling and mapping, including MDS, are useful for assessing relative configurational accuracy of several estimated locations but not very useful for assessing relative pairwise accuracy. In many research contexts involving smaller distances that can be reasonably traversed within the time frame of the data collection, reproduction has much to recommend it as the method of choice. It is useful for pairwise estimation with one or a small number of test distances (same-size mapping is useful for assessing configurational accuracy). Of all the classes of methods, only reproduction (sometimes route-choice) directly involves actual locomotor behavior, and it does not require scale translations.

Of course, as in any scientific field, convergence between the results from multiple methods provides the strongest empirical evidence for theory testing. 'What seems to be needed is the use of converging methods that both help understand environmental cognition processes and help overcome some of the limitations inherent in each separate methodology' (Golledge, 1987, p. 160). Lack of convergence between results from different methods is often thought to derive from the differential 'bias' or 'distortion' of a common underlying representation by the output processes of a given measurement method. This is possible, but need not be the case. Another explanation for method divergence is that different methods involve different psychological contexts, thereby activating different representations of cognitive distance in different situations. This notion of context-dependent cognitive distance suggests that the same environmental space is multiply represented; estimated values of a given distance with different methods may be based on different representations depending on what the goal or purpose of the travel is (e.g. going to a restaurant, a funeral, a job interview, a lover's house, etc.). In any event, all of the measurement techniques described in this review (save route choice) are fairly context-free and rather detached from any realistic navigational purpose. It is especially critical to understanding the role of cognitive distance in actual navigational behavior that the relationship of context-free laboratory measurement to purposive real-world behavior is addressed.

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Notes

(1) Montello, D. R. (1986). Imagery and environmental orientation. Unpublished MA thesis, Arizona State University, Tempe, Arizona.

(2) Some readers may find talk about an internal, subjective distance being equal to or different from the external standard distance it represents to be nonsensical. It is important to remember, however, that precisely this logic is involved whenever one talks about distortions or inaccuracies in internally represented test distances, whether absolute or relative.

(3) Killeen, P. R. (1979). Geometric models of proximity data. Unpublished manuscript, Arizona State University, Tempe, Arizona.

(4) Montello, D. R. (1989). The geometry of environmental memory. Unpublished manuscript, University of Minnesota, Minneapolis.

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