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Cognitive Maps: Analysis of Distance Estimates

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Abstract

Subjects were required to estimate distances between pairs of landmarks in a natural environment based only on their memorial representations of these distances. Analysis of the estimates revealed the use of mental representations of the space that had great fidelity to the space itself. Examination of the latencies to make these estimates suggested the use of a counting process as the basic mediator of distance estimation in this task. The results were discussed in terms of a second-order isomorphism between cognitive maps and their cartographic counterparts.

Suppose a tourist were to approach you and ask, "How far down the street is the art museum?" If you were familiar with the museum's location, you would probably ponder the question for several moments then answer with some estimate of distance like, "Oh, seven blocks or so." The question that we address in the present paper is: What happens during the several moments in which one contemplates an answer to this sort of question?

Previous experiments using distance estimation measures have demonstrated that distances in environmental spaces are actually stored and retrieved in a fairly veridical manner. That is, there appears to be a linear relationship between estimated and actual distance, especially with respect to intraurban distances (Cadwallader, 1976; Canter and Tagg, 1975; Golledge and Zannaras, 1973, but see Golledge, Briggs, and Demko, 1969, for a report of a curvilinear relationship as the intraurban distances become long). This general linear trend has even been obtained under conditions in which subjects' only experience with an environment is via a randomly ordered sequence of slides depicting a particular urban region (Allen, Siegel, and Rosinski, 1978). Recently, Kerst and Howard (1978) have reported that a similar relationship is also obtained with state-to-state distances that are many times longer than those involved in the above-mentioned experiments. In short, the linear function relating distance estimates to actual distances seems to be a robust result.

This is not to imply that variables other than actual distance do not affect distance judgments at all. For example, there have been reports of an asymmetry in estimates that depends upon the direction of the stated distance from city center (see Golledge and Zannaras, 1973, and Briggs, 1973, and 1976; but also see Lee, 1962, 1970). In addition, there have been hints that travel time might play a role in affecting subjects' judgments of distance (Canter and Tagg, 1975). Finally, by way of example, Stea (1969) reports that preferred or familiar trips tend to be judged as shorter than unpreferred or unfamiliar ones. Thus, the determinants of judged distance appear to be multiple in number. Nevertheless, actual distance has uniformly been reported as having an extremely high correlation with estimates (typically above .90), thus suggesting that its influence is dominant.

While these studies and others have helped to establish the empirical regularities of distance estimation, they have only hinted at the kind of cognitive representation and kind of mental process that might underlie such judgments. In addressing these issues, various investigators have followed a long tradition in psychological research (first formally introduced by Tolman, 1948) of proposing that subjects have available to them a cognitive map that serves as the source of information about distances in the reference environment. According to this proposal, subjects are able to retrieve such a stored map and somehow "measure off" from it the requisite distance, in much the same way that they might measure a comparable distance on a cartographic map. Perhaps the most compelling evidence for this proposal comes from subjects' introspections: They typically report engaging in precisely this sort of activity during a distance estimation task.

How could one test this proposal more analytically than merely collecting records of introspections? Careful examination reveals that there are, in fact, two separate assumptions that must be tested. The first is that there is an isomorphism between a mental representation of an environmental space and a cartographic map of that space. Now, as Shepard and Chipman (1970) and Shepard (1975) have made amply clear, to claim that an isomorphism exists between two structures is not necessarily to claim that the two structures are in any obvious sense identical. That is, a "first-order" isomorphism need not exist. Rather, one might lay claim to a "second-order" isomorphism, by which one would mean that relationships among distances on a cartographic map are, in some explicit sense, similar to relationships among distances on a mental map. According to this version of the isomorphism hypothesis, similarities in the actual physical representations of the respective structures are irrelevant; only similarities in the relationships of their parts are of concern. An example of such an isomorphism is provided by Shepard and Chipman (1970). They had subjects judge the similarities in shape between pairs of states either under a condition in which they actually examined drawings of the states or under a condition in which they had to retrieve the shapes of the states from memory. Comparison of multidimensional scaling solutions of the similarity ratings in these two conditions revealed striking similarities. They concluded that the mental representations of the shapes of the states are, in the sense described above, second-order isomorphic to the representations formed under perceptual conditions.

The second assumption inherent in the proposal that mental maps are used as the basis of distance estimation judgments is that the process by which distances are retrieved from these structures is similar to the process by which they would be obtained from a cartographic map. Once again, this amounts to the assumption of an isomorphism, presumably second-order in nature, between two entities; but in this case the entities are processes, not structures. There have recently been many demonstrations of second-order isomorphisms between perceptual and memorial processes, although in most cases the perceptual processes have been implicitly assumed rather than explicitly demonstrated (e.g., Shepard and Metzler, 1971; Kosslyn, 1973; Bundeson and Larsen,1975). In all of these cases similarities in patterns of judgment latency between memorial and presumed perceptual processes have served as the basis of the demonstration of second order isomorphism.

The present study examines both of these assumptions within the context of a single experiment. On the one hand, to examine the assumption of isomorphism between structures, we collected distance estimates and compared relationships among these estimates to relationships among the actual distances involved in the task. On the other hand, we measured the latencies with which subjects provided estimates, and compared patterns in these latencies to patterns in latencies obtained under a similar experiment by Hartley (1977).

A second purpose of the present experiment was to examine potential individual differences in the representations and processes underlying the distance estimation task. Accordingly, we preselected our test sample of subjects after screening a larger sample of subjects with two standardized tests of spatial ability.

METHOD

Subjects

The initial sample of subjects consisted of 101 undergraduates of the University of Michigan who participated in the pre-test in order to partially satisfy a course requirement. From this sample, twenty-three subjects were selected (according to a criterion described below) for inclusion in the experiment proper. These subjects were paid $1.25 plus a performance bonus.

Apparatus

A Scientific Prototype 3-Channel tachistoscope (model 320 GB) was used to display the stimuli. Responses were recorded manually and timed by a digital millisecond clock which as actuated by a pulse from the control unit of the tachistoscope, and which was stopped by a pulse from a voice operated relay connected to a microphone into which the subjects spoke their responses.

Stimulus Materials

Pre-test. All 101 subjects in the original sample completed a questionnaire and two standardized tests of spatial visualization ability.

The questionnaire contained three types of items of relevance to the present experiment. First, it queried subjects about relevant items of personal history such as year in school, years in Ann Arbor, and mode of transportation around campus. Second, it required subjects to rate their familiarity (on a seven-point scale) with 37 campus and Ann Arbor landmarks. Finally, it presented subjects with items from the Bett's questionnaire on vividness of imagery (Sheehan, 1967; see Richardson, 1969, for the original version), and from the Gordon test of visual imagery control (Gordon, 1949; see Richardson, 1969, for the version used here).

The two tests of spatial visualization ability were the Space Relations subtest (Form T) of the 1972 version of the Differential Aptitude Test, and the Spatial Visualization Test of the 1964 version of the Dailey Vocational Test. These two tests require subjects to mentally manipulate complex patterns in various ways in order to solve spatial problems. We reasoned that they might tap some components of the ability to retrieve a complex spatial representation and operate on it in such a way as to estimate various distances.

Experimental stimuli. The 20 landmarks rated as most familiar were selected as stimuli. The locations of these landmarks on campus are illustrated in Figure 1. Each landmark was paired with each other one once (with order counterbalanced) to yield 190 pairs. Ten of these pairs were selected for presentation twice in the session, once in each order. This yielded a total of 200 pairs of landmarks as stimuli. These 200 pairs were divided into five blocks of 40 pairs each such that the mean actual distance represented by the pairs in each block was roughly the same from block to block. The pairs were arranged into experimental

Insert Figure 1 about here

trials such that the last two trials of each block were two of the ten reversed pairs that had been selected. The final constraint on ordering the trials within each block was that no two consecutive trials contained the same landmark name. The blocks were arranged in a Latin Square with at least two subjects in each group assigned to each of the five block orders in the Latin Square design.

Procedure

Pre-test. Subjects were tested in groups of 10 to 20 on the pre-test items. First, subjects were given 15 to 20 minutes to complete the questionnaire. Then, they were given 20 minutes to complete the Dailey Vocational Spatial Visualization Test. Finally, they were administered the Spatial Relations Subtest of the Differential Aptitude Test in a 25-minute period.

Subject selection. Subjects were selected for participation in the experimental session on the basis of combined performance on the standardized tests (which correlated .76), with the additional criterion that commuters to the campus were excluded from selection. Seven subjects who scored extremely poorly on the tests (less than 41 items out of a maximum possible 90 on the two tests combined) were also excluded because we judged such performance to be strikingly unrepresentative of an average college population. We suspect that motivational factors may have played a role in producing some of these low scores.

Using the guidelines just stated, 12 subjects were selected and assigned to the "high spatial" group (combined raw score performance of

83-89 out of a maximum possible score of 93), and 11 were assigned to the "low spatial" group (combined raw score performance of 42-58). The assignment of subjects to groups was accomplished using a double-blind procedure so that neither the experimenters nor the subjects knew which subjects had been assigned to which group until after the experimental session.

Experimental session. To begin the 2-hour experimental session subjects rated the 20 landmarks used in the experiment for familiarity on a 7-point scale. Then they received 10 practice trials and 5 blocks of 40 test trials, with short breaks intervening between blocks.

The sequence of events on each trial was as follows: The experimenter said "ready" after which the subject was to gaze at a fixation point in the center of the field of the tachistoscope. When he was prepared, the subject initiated the trial by depressing a footswitch which caused the name of a landmark (printed in Letraset, 18-point Franklin Gothic Condensed) to replace the fixation point. This first landmark name remained in view for 4 seconds after which it was replaced by a second landmark name. At this point the subject was to estimate the straight-line distance on campus from the point of the first-named landmark closest to the second landmark and speak his response into a microphone located just beneath the viewer of the tachistoscope. The latency of each estimate was timed from presentation of the second landmark name until the subject responded.

Subjects were told to give their estimates in units corresponding to the distance between the center of the main quadrangle and the Graduate Library. They were told that this unit, the GLU (Graduate Library Unit), corresponded to approximately 100 feet. They were further told that estimates were to be given in whole unit or half unit increments. This procedure amounts to having subjects engage in direct magnitude estimation with a 100 foot standard.

The pre-experiment instructions stressed four major points: (a) Subjects were told to estimate straight-line distances between the closest points of the landmarks on each trial; (b) They were exhorted to report their estimates as accurately as possible; this exhortation was backed up with a performance bonus of $.05 for each estimate within one-half GLU of the correct answer; (c) They were asked to respond as quickly as possible within the accuracy constraint; (d) Finally, they were told to make each estimate independently of each other estimate in the session.

RESULTS AND DISCUSSION

There are three aspects of the results that are reported: (a) the relationship between the distance estimates and the corresponding actual distances, (b) the relationship between latencies and estimates, and (c) analysis of group differences on various measures. These topics will be discussed in turn.

Distance estimates

Reliability. By examining the 10 pairs of landmarks that were presented twice to each subject, we can assess the reliability of the estimates themselves. Correlations between first and second presentations of each of these pairs were computed for subjects in the high and in the low spatial groups. The means of these correlations for the two groups are

.68 and .74 respectively (not reliably different, $p > .10$). While these correlations are respectably high, they are not astounding. One potential explanation of an attenuation in this correlation is an effect similar to the relationship between estimates and direction from city-center reported by Briggs (1973, 1976) among others. However, examination of estimates for these 10 pairs as a function of direction from the center of campus revealed no consistent effect.

A second possible reason for the attenuation of these correlations is that subjects were not able to fully comply with the instruction to make their estimates independent of one another. In fact, verbal reports from subjects support this contention: Many subjects commented that they sometimes used information from a previous trial to arrive at an estimate for the present trial.

A final possiblity for the attenuation of the test-retest correlation is that practice effects may have caused each subject to get better at the estimation process as the session progressed. In fact, analysis of the relationship between estimates and actual distances for the first versus the fifth block demonstrated precisely such a trend (analysis of this effect is presented below).

Estimates versus distances. Figures 2 and 3 present scatterplots (of each landmark pair averaged over subjects) of distance estimates versus actual distances for the high and low spatial groups respectively.

Insert Figures 2 and 3 about here

It is quite clear from these scatterplots that for both groups there is a strong linear relationship between estimates and distances. This is confirmed by calculation of the correlations between the estimate and distance variables for each group: These correlations are .95 for the high spatial group and .94 for the low spatial group (the mean individual subject correlations are .81 for the high spatial group, and .77 for the low spatial group). The difference between the two groups by r to Z transformation is not statistically reliable ($z = .87$; $p > .10$).

Both groups showed an improvement in the consistency of their estimates during the course of the session. For the high and low spatial groups on the first block of trials, the mean correlation between estimates and distances were .79 and .70 respectively. For the last block of trials, the comparable figures are .85 and .81. This improvement is statistically significant for the low spatial group ($t = 3.31$; $df = 10$; $p < .01$), and marginally significant for the high spatial group ($t = 2.02$; $df = 11$; $p < .07$).

In general, it certainly appears that both groups of subjects demonstrate remarkable consistency in estimating distances within the range used. This is all the more impressive given that we placed our subjects under a stress for speed as well as accuracy.

Intervening landmarks. Kaplan (1973) has conjectured that the representation of distances in a space may be influenced by the amount of clutter in the space. In particular, he raises the hypothesis that greater clutter (in terms of number of landmarks) may psychologically expand a space. In the present context, this possibility is relevant because one might argue that the relationship between estimates and distances is actually mediated by a spurious correlation between distance and the number of intervening landmarks. On this account, one would claim that subjects actually count intervening landmarks between the relevant pair of landmarks on each trial, then they somehow convert this into an estimate of distance in GLU's. Because our experiment tested for distance representations of a natural environment, we had no control over the number of landmarks intervening on campus between each pair of stimulus landmarks that we used in the experiment. Thus, our analysis of a potential effect of clutter on distance estimates is of necessity post hoc. Nevertheless, it is suggestive.

For each pair of landmarks used in the experiment, we laid out a 50 foot wide corridor on a map of the campus and counted the number of buildings between members of the pair. Pairs of landmarks on the same street were assigned an intervening building count of 0 even if they were separated by one or more other buildings (the rationale for this exception is that introspection suggests that in such cases the direct pathway connection between the landmarks renders the distance between them to be unobstructed, at least for purposes of travel).

Because the correlation between actual distance and the number of intervening buildings was, naturally, quite high (.74) we calculated partial correlations of estimates and intervening buildings with distance partialled out. For high and low spatial groups these correlations are .30 and .29 respectively (both statistically significant, $p < .01$).

Pilot research in our laboratory had suggested that the effect of intervening buildings might be entirely accounted for by the difference between no intervening buildings and one, with additional buildings having no substantial impact on estimates. We checked this possibility in the present data and found it to be true for the low spatial group ($r = .22$, $p < .05$ for 0 versus 1 building; $r = .06$, $p > .10$ for 2 or more) but not for the high spatial group ($r = .30$ for both correlations, $p < .01$). One could interpret this difference to mean that subjects in the high spatial groups have a more complete mental representation of the space in question and are thus influenced by a greater range of the intervening landmark variable. In any case, the overall result of this analysis is a confirmation of an effect, albeit small, of clutter on distance estimates.

Multidimensional scaling. One method of uncovering a spatial representation for a set of distance estimates is through the use of multidimensional scaling (Canter and Tagg, 1975; Golledge, Rivizzigno, and Spector, 1976). This technique provides a method of constructing an n-dimensional spatial structure that minimizes mean square error from a matrix of distance estimates.

Suppose one were to actually measure inter-landmark distances on a cartographic map (with points as landmarks) and submit these measures to multidimensional scaling. The obtained solution would require 2 dimensions (as long as the points did not lie along a straight line on the map), and, since a cartographic map represents a geographic space, the appropriate metric for the solution would be Euclidean (i.e., the shortest distance between two points would be a straight line).

With distance estimates, however, a multidimensional scaling solution may be more complicated. First of all, there is no reason why the optimal solution must be represented in 2 dimensions. Perhaps subjects code a third dimension (e.g., building height) and use it in arriving at their estimates. Second of all, the shortest psychological distance between two landmarks may not be a straight line (even if subjects are instructed to estimate straight-line distances). Instead, for example, estimates may somehow follow the pathway structure of the environment, and thus a City-Block metric may be more appropriate. These potential problems suggest that in examining scaling solutions of distance estimation data, one should generate several empirical solutions and compare them for the best fit (contrary to Canter and Tagg, 1975, and Golledge et al., 1976, who report only 2-dimensional Euclidean solutions).

Accordingly, we submitted distance estimates for each subject in both groups to nonmetric scaling using the program MINISSA-I (Roskam and Lingoes, 1970, Lingoes, 1973). Although Tobler (1976) has argued that metric scaling of distance estimates is a defensible procedure, we chose the more conservative nonmetric technique. For each subject a solution was obtained in 1, 2, and 3 dimensions with a Euclidean metric and in 2 dimensions with a City-Block metric.

Figure 4 indicates the goodness of fit for each of the solutions. This figure presents stress values for each of the Euclidean scaling

Insert Figure 4 about here

solutions in 1,2, and 3 dimensions. We have dispensed with a presentation of stress values for the City-Block solutions since the data of each subject in both groups was better fit by a Euclidean than by a City-Block metric. This result is not very surprising since the experimental instructions, in fact, ask for Euclidean distances; apparently subjects complied with these instructions. The function labeled "actual distances" in Figure 4 represents the scaling solution when the actual distances between each of the landmark pairs were entered as data. Note that there is a dramatic drop in stress for this function between 1 and 2 dimensions. Adding a third dimension hardly improves the stress value at all. This is as it should be since these distance values are taken from a true 2-dimensional cartographic map. (The stress does not drop to 0 for a 2-dimensional solution because the distances entered as data were those between the closest points of each landmark pair. If the landmarks themselves had no extent, a 2-dimensional solution would have been perfect.)

The scaling solutions of the high and low spatial groups share a striking similarity to that of the actual distances. There is a large drop in stress for 2 compared with 1 dimension, and a much smaller drop between 2 and 3 dimensions. This observation can be verified by examining Coefficients of Alienation (Lingoes, 1965). These values show a 23-25% drop in unaccounted variance from 1 to 2 dimensions, but only a 4-5% drop from 2 to 3 dimensions. Apparently, then, a 2-dimensional Euclidean solution provides a parsimonious description of the data.

It is also apparent from Figure 4 that for the 2-dimensional case the high spatial group had scaling solutions with lower stress values than those for the solutions of the low spatial group. This is confirmed by t-test ($t = 2.82$, $df = 21$, $p < .01$). The implication of this effect is that the high spatial group is somewhat more consistent at providing its estimates, but not necessarily more accurate in representing the space.

In a sense we already know that both groups represent the distances in the space comparably well. This is indicated by the high correlations between estimated and actual distance. But an examination of the scaling solutions should reveal precisely how much both groups distort the campus space in their distance estimates. Unfortunately, a simple examination of the solutions is awkward since, in order to be really meaningful, they must be compared to a map of the space. An alternative method of providing a comparison between distance estimate scaling solutions and the actual space has been provided by Tobler (personal communication). He has developed a Bi-Dimensional Empirical Transformation Program that can be used to construct a 2-dimensional grid that represents distortion of an empirical scaling solution from the actual space by deviations of the grid from rectangularity. This technique demonstrates that the empirically obtained scaling solutions range from quite veridical to quite poor. Panels a and b of Figure 5 give examples of good and poor solutions respectively. On the whole, however, there is very good agreement between the empirical solutions and actual maps. The average percent variance (across groups) in the empirical solutions accounted for

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Insert Figure 5 about here

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by the actual maps was 88%. There was a reliable difference between groups in this percentage of variance, ($t = 3.74$; $df = 21$; $p < .01$). Although this difference is small (91% versus 85% for high and low spatial groups respectively), it is of interest to examine the average solutions of the two groups to see how they compare. Accordingly, we produced average solutions for each group using Procrustean Individual Difference Scaling (Lingoes and Borg, 1976), a program that determines a configuration that simultaneously best fits a collection of individual configurations. These solutions were then submitted to the Bi-Dimensional Empirical Transformation Program that we previously used on individual solutions. The results are shown in panels a and b of Figure 6. It is quite clear that the two configurations in these panels are very similar. This is further emphasized in panel c which superimposes the grids in panels a and b. Overall, the grids are quite rectangular in shape except at the lower left (southwest) corner. Although we have no obvious explanation of the consistent distortion of this part of the space, the entire effect may actually hinge on a small misestimation of the location of just one or two of the landmarks. In any case, apart from this distortion, the maps are strikingly veridical, and quite similar for the two groups.

Insert Figure 6 about here

In summary, then, the analyses presented in this section reveal that subjects are extremely good at providing estimates of distance for a space the size of the University of Michigan central campus. Our analysis of re-presented pairs indicated that these estimates were fairly reliable, although apparently influenced by such factors as practice and dependence on previous estimates. Nevertheless, both the individual subject correlations and the group correlations of estimates with actual distances showed a very strong linear relationship. This effect was confirmed by multidimensional scaling which uncovered impressively veridical representations of the campus space. Analysis of the scaling solutions also confirmed that subjects' estimates are best represented as a 2-dimensional Euclidean space. All of these results support the contention that distance estimates are mediated by a representation that is second-order isomorphic to an actual cartographic map. Furthermore, although there were some reliable differences between the two subject groups in the quality of this representation, these differences pale in comparison to the similarities between the groups.

We turn now to an examination of the latencies for the distance estimates in order to characterize the process that operates upon the "mental map" representation to yield the estimates themselves.

Latencies

In order to analyze the latencies, we have used individual landmark pairs as the unit of data and we have averaged response times across subjects within groups for each pair. The rationale for this procedures is based on the analysis of the reliability of the estimates themselves (presented above): Practice and order effects seemed to have played a role in subject's performance. The order effects are particularly troublesome because on the one hand, they are not directly subject to analysis since we randomly assigned trial orders to subjects, yet on the other hand, they seem to have played at least some role in influencing distance judgments since subjects reported not being able to completely isolate each estimate from others previous to it. To illustrate the impact of such a trial to trial dependence, consider just one possible empirical consequence of it: If a pair on one trial shares some portion of the space between members of the pair with a pair on a previous trial, a subject might simply recall his previous estimate and modify it somewhat to arrive at an estimate for the present trial. The latency for this current trial, then, would not necessarily reflect the underlying process used to arrive at distances in an uncontaminated situation. However, on the reasonable assumption that such effects will contaminate the latencies of different landmark pairs for different subjects, averaging over subjects for each pair should produce a response time for each pair that is more representative of the underlying estimation process. We have followed such a procedure.

Panels a and b of Figure 7 are scatterplots of latencies versus estimates for each pair of landmarks averaged over subjects in the high and low spatial groups respectively. The correlations between latency and estimate for each group are .60 and .53 respectively. Regression

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Insert Figure 7 about here

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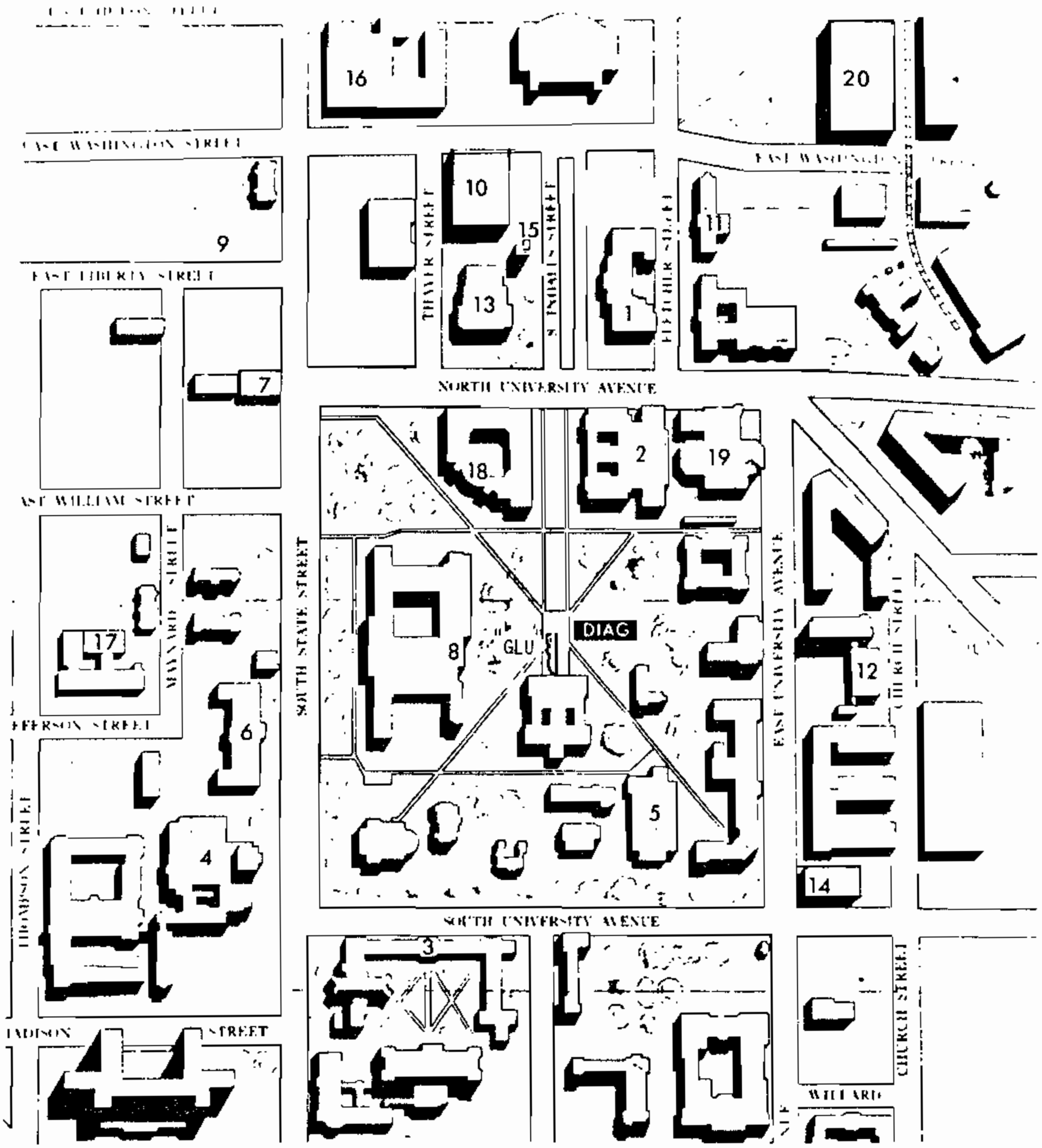
with best fit (negatively accelerated) quadratic functions improves these figures to .69 and .58. Inspection of the scatterplots suggests that these quadratic functions are largely due to lower than linearly predicted latencies for large estimates. To check on this observation, we re-scattered the data of both groups eliminating the top 20% of the estimates. Correlations for linear fits using this reanalysis were .69 and .59 for the high and low spatial groups respectively, while quadratic fits accounted for only 2% more variance than linear functions alone. This additional effect of quadratic fits is obviously quite small.

One plausible interpretation of the lower than predicted latencies for large estimates hinges on an examination of the absolute magnitude of the latencies involved. The average latency for an estimate of 10 GLU's in the high spatial group is 8.2 sec; in the low spatial group it is 9.2 sec. We think it reasonable to presume that subjects might feel somewhat embarrassed to sit quietly for 8 seconds or more while determining their estimate on a particular trial involving a long distance. Perhaps to avoid this discomfort they simply terminate their normal estimation process somewhat prematurely, and take a guess at the increment in distance to add to the value they have derived by the normal process in order to arrive at an answer. The probability of this occurring undoubtedly rises as does the estimate itself. Apparently, then, although the speeded instructions of the present experiment left the <u>estimates</u> relatively unperturbed, they might have perturbed the process by which these estimates are produced.

This artifact aside, the latencies for both groups show a substantial linear relation to the estimates. Correlations for both groups, .60 and .53, are significantly greater than 0. Furthermore, by a z-test based on a Fisher r to z transform, they are not reliably different from one another (z = 1.03, p > .05). We shall speculate on processes that might produce such a linear relationship after briefly considering other comparisons of the two subject groups.

Other comparisons of the groups

On the whole, stratification of subjects on the basis of combined performance on the two standardized tests did not reveal any major differences in distance estimation. There are two possible reasons for this lack of an effect. The first and most obvious possibility is that although our criterion tests clearly measure some aspect of spatial cognitive ability, they may not tap the particular aspect of this ability required in the distance estimation task. Although we cannot comment definitively on this possibility, we have attempted to stratify the 23 subjects on criteria other than standardized test performance to obtain some other possible differences. In particular, we divided subjects on median splits of their scores on: (a) the Bett's imagery vividness protocol, (b) the Gordon test of visual imagery control, (c) their rating responses to the question, "How good is your sense of direction?" (see Kozlowski and Bryant, 1977, for correlations between responses to this question and various measures of cognitive map quality), (d) Verbal SAT scores, and (e) Quantitative SAT scores. In all cases there was no consistent difference in either the quality of the estimates or the relationship of latency to estimate for the groups stratified according to these variables. Of course, it remains an open possibility that some other criterion measure would fare better than any of the ones cited above. Further research would be required to assess this possibility.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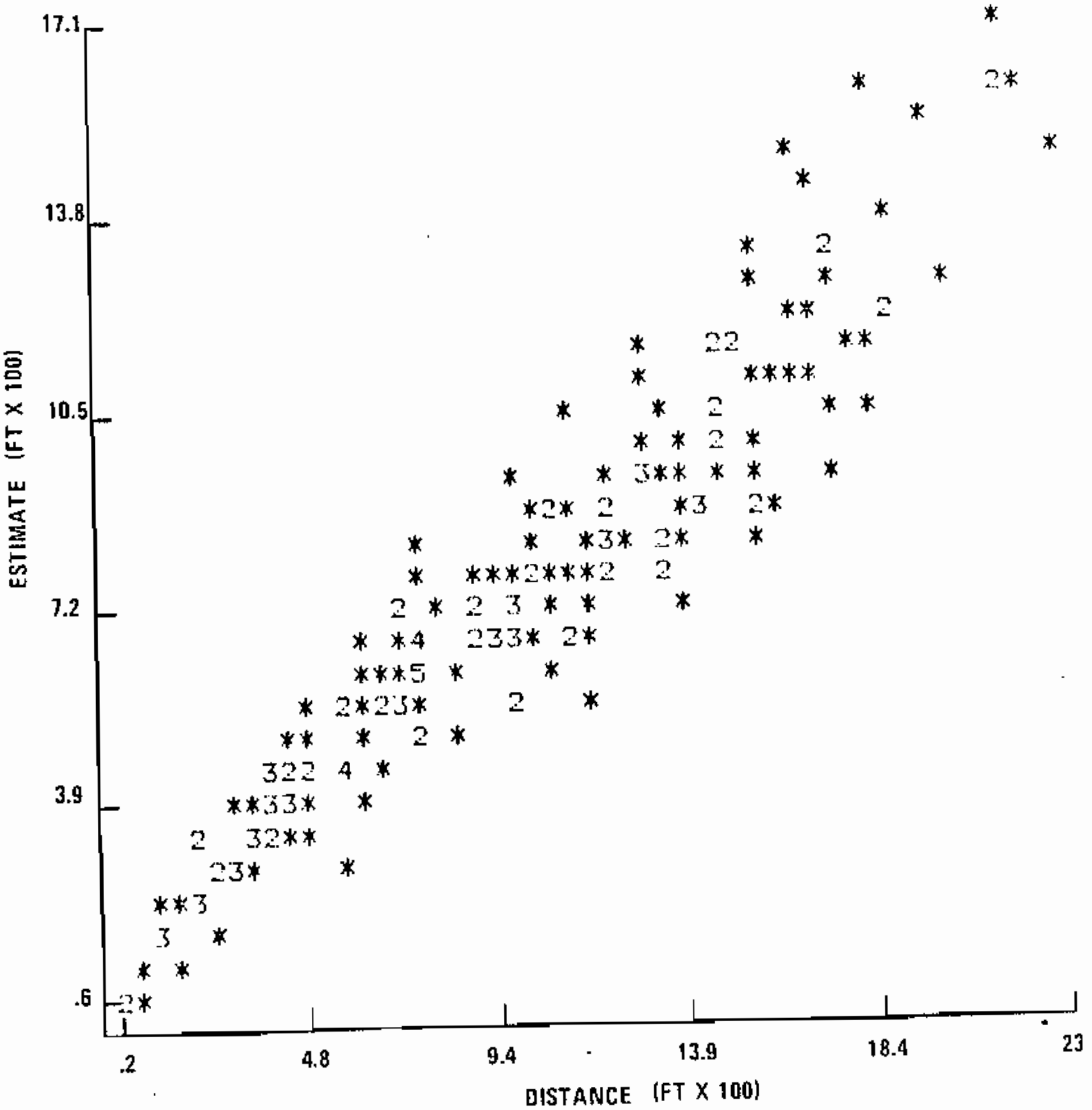
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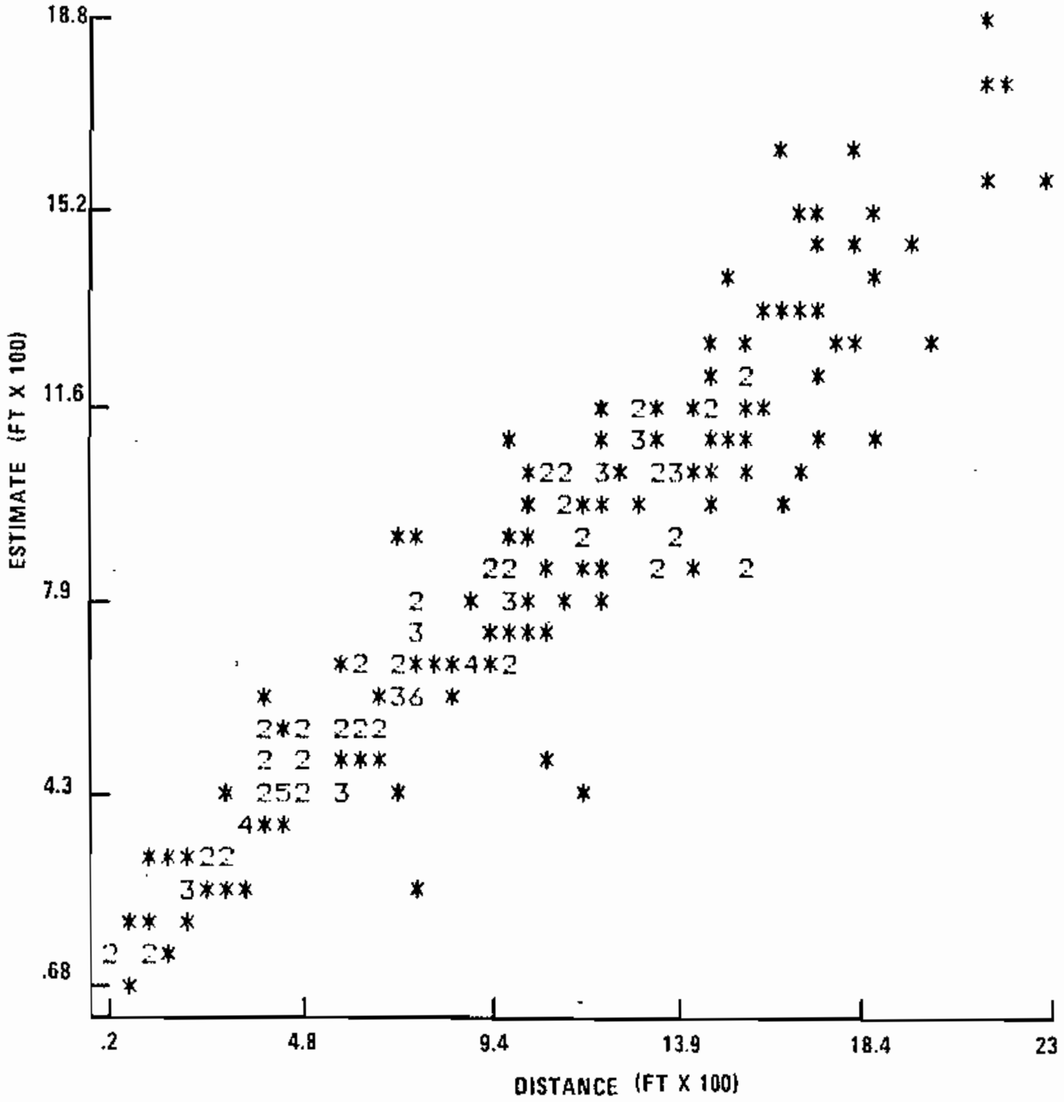
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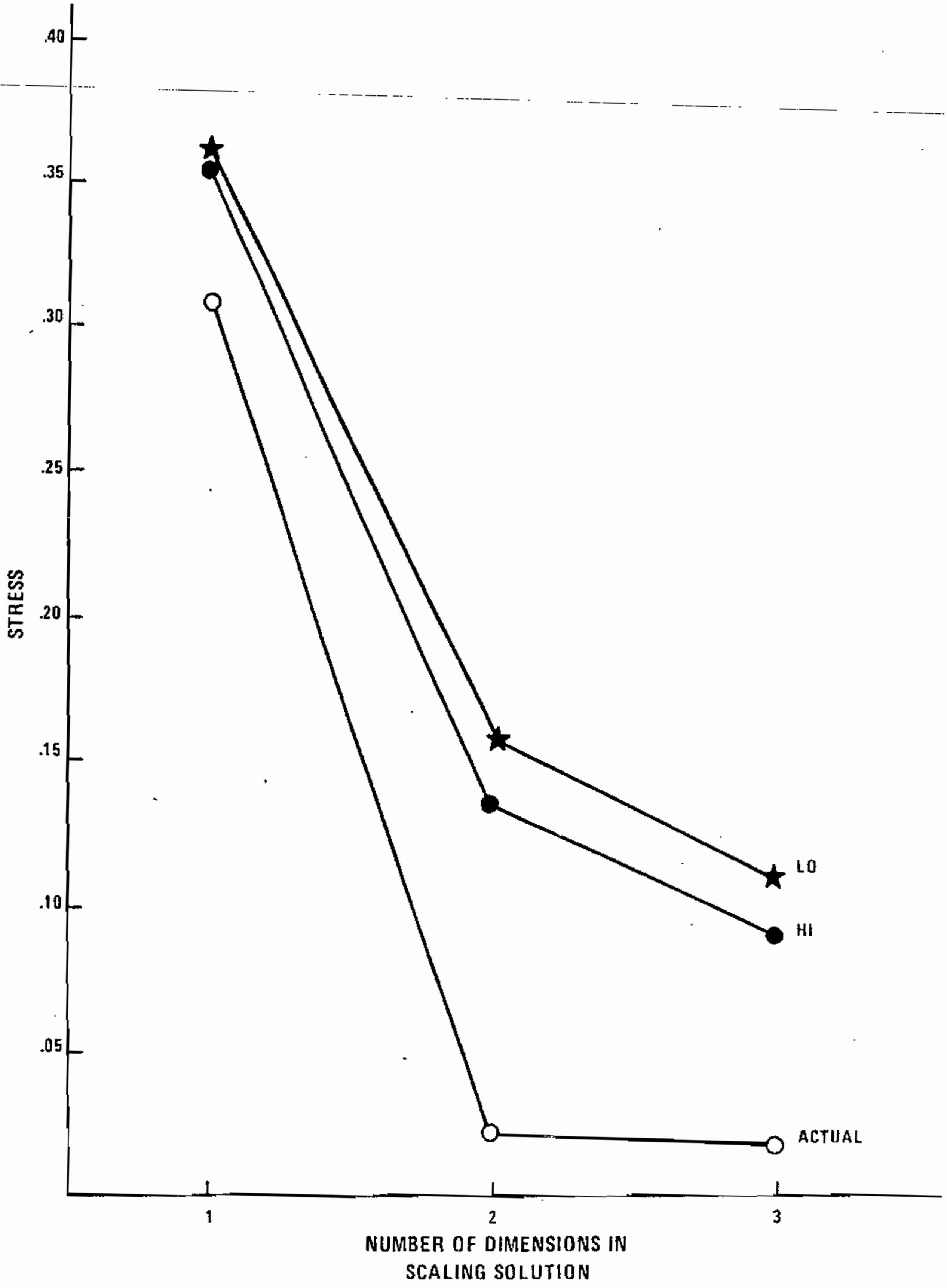

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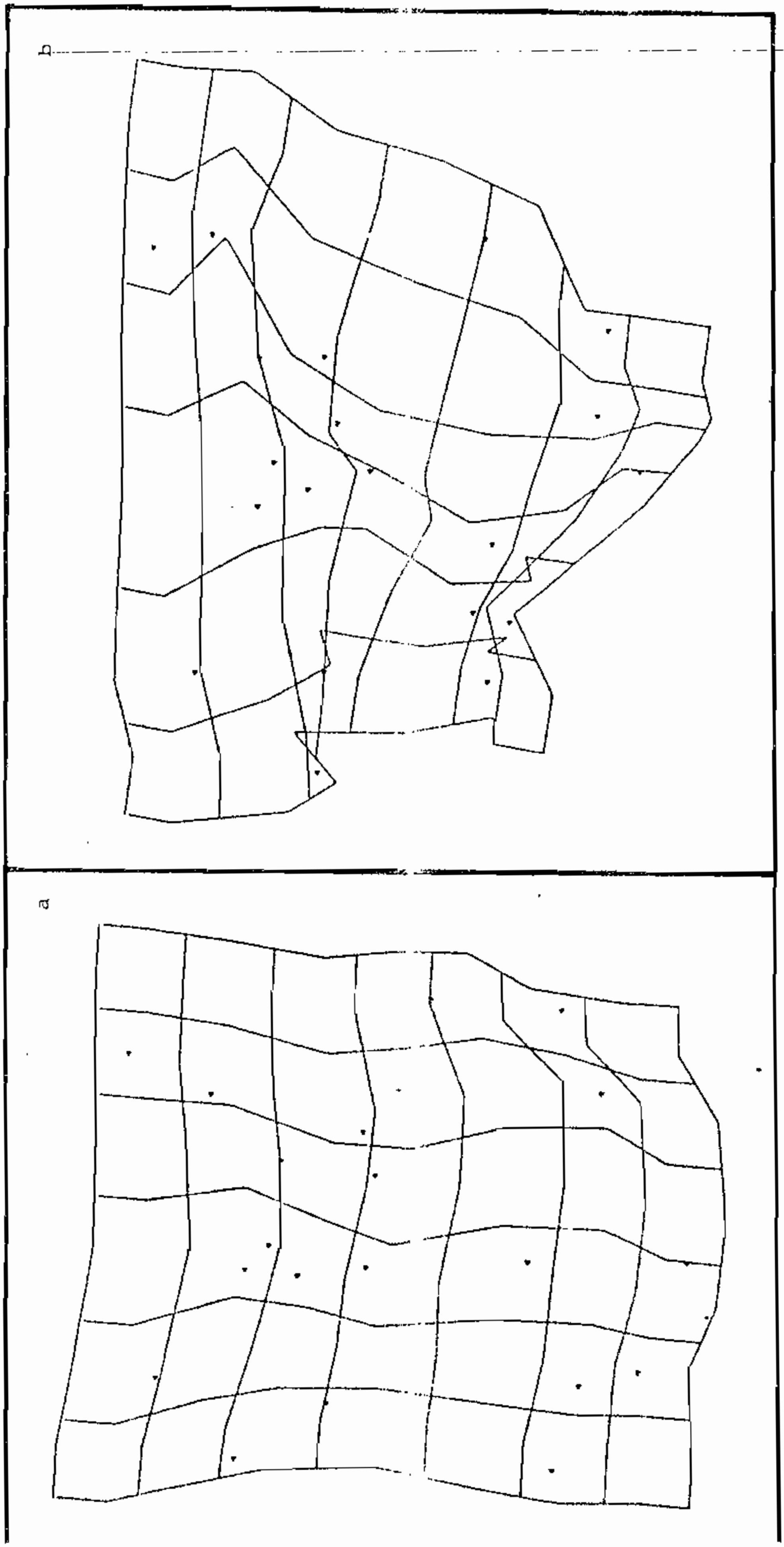
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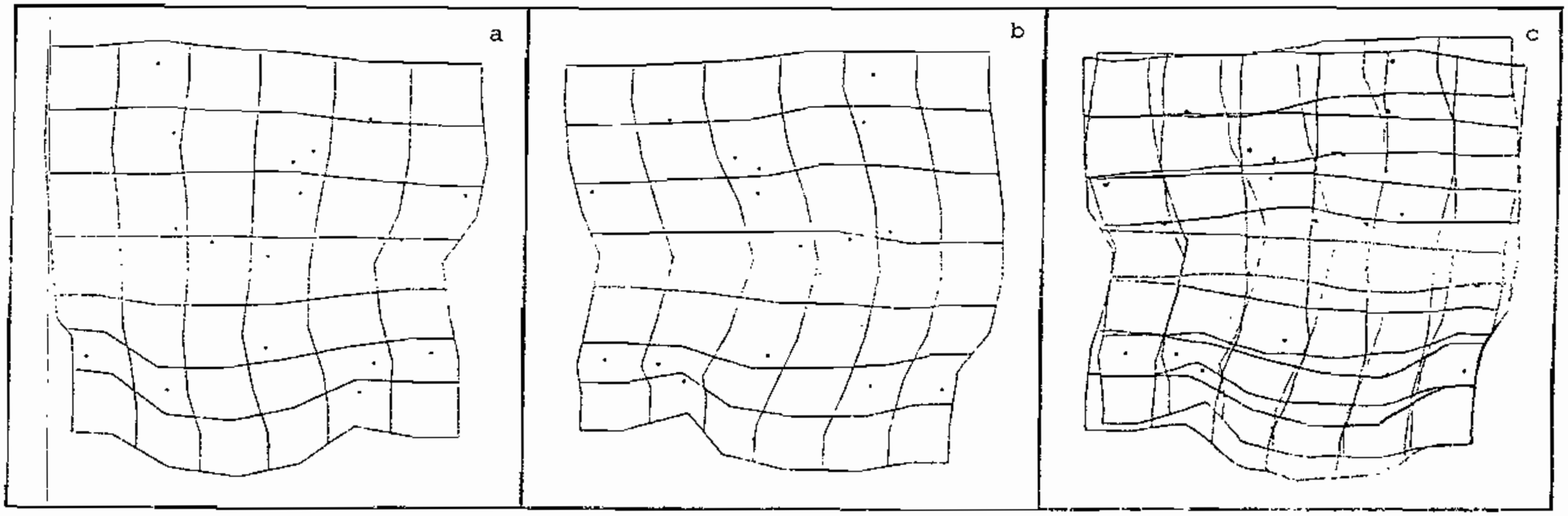
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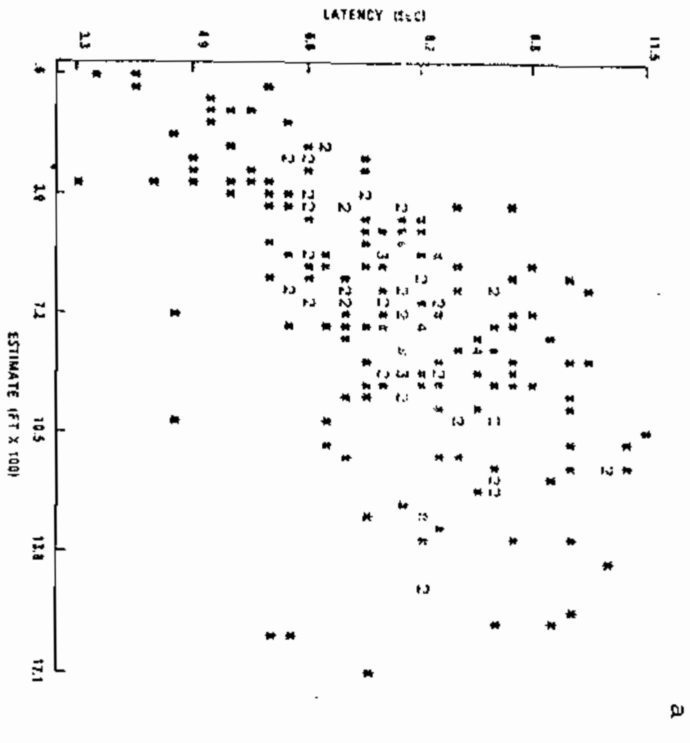
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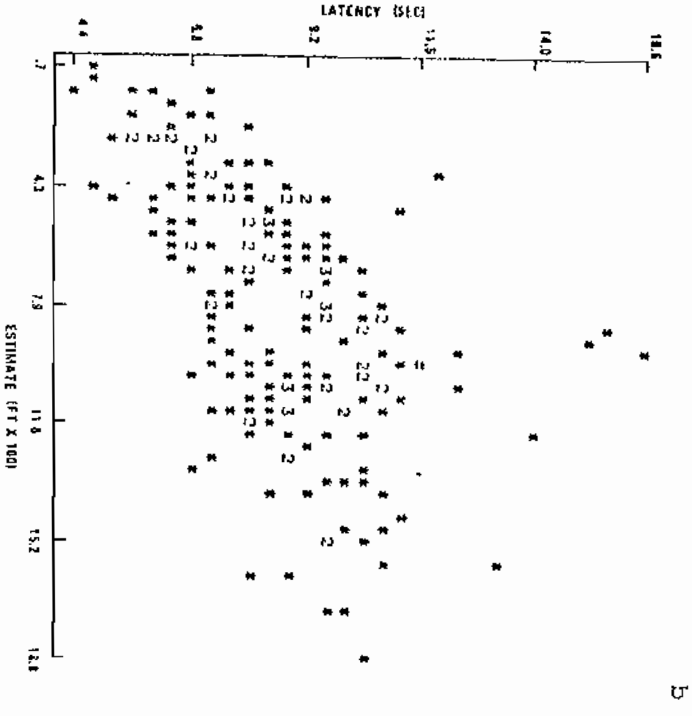
LATENCY (SEC)
4.4
6.8
9.2
11.6
14.0
16.4
ESTIMATE (FT X 100)
.7
4.3
7.9
11.6
15.2
18.8
b

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The second potential reason for not finding consistent differences between groups is that none, in fact, exist. That is, it seems quite plausible that the level of familiarity these subjects had with the campus was sufficiently high so that all subjects had developed well-specified representations of the test space. Perhaps any individual differences that exist in the quality of spatial representations can be overcome by extended experience with the environment. Interestingly enough, the small effects of spatial ability that we have found may actually be explicable in terms of overall experience with the environment. By chance, subjects in the high spatial ability group lived in Ann Arbor an average of 26.0 months at the time of test, while the low spatial group lived in Ann Arbor for 14.7 months. Even this difference, however, correlated as it is with spatial ability, seems to cause only a small difference in the quality of spatial representations for the two groups of subjects.

GENERAL DISCUSSION

Individual differences aside, our results have provided support for the notion that a second order isomorphism exists between a mental map and its cartographic counterpart. The evidence that leads us to this conclusion refers both to the representation itself and to the process that yields distance estimates from this representation. With respect to the mental representation itself, we, and others before us as well, have demonstrated that there is a great deal of correspondence between environmental distances and memory for those distances. Construction and examination of multidimensionally scaled maps from the distances further emphasizes this correspondence.

The evidence that bears on distance estimation processes is the linear (or nearly linear) relationship of latencies to estimates. In much the same way that Shepard and Cooper and their colleagues (e.g., Shepard and Metzler, 1971; Cooper and Shepard, 1973) have developed a case for an analog mental rotation process, we can use the latency effect of the present experiment to argue for a kind of "mental traversing" process to estimate distances. While our data do not reveal the details of this process, they suggest a counting process which increments distances with time.

What is this counting process like? Well, it may amount to something like iteratively laying out a mental ruler end to end between the memorial representations of the landmarks in question. This could explain the progressively greater underestimation of longer distances if one assumes that subjects overestimate the length of the mental ruler. An alternative candidate for a counting process is a mental traverse between the landmarks on a trial after which the traversing time is translated into the estimation units appropriate to the experiment (in our case, GLU's). While it is not immediately clear what it might mean to traverse a mental map, Kosslyn (1973) and Kosslyn, Ball and Reiser (1978) have provided evidence for a scanning mechanism which may be quite similar.

Whatever this process is like, however, it appears to have a counterpart in the perceptual domain, and therein lies the second order isomorphism. Hartley (1977) has recently reported that when subjects are asked to make magnitude estimates of perceptually present line lengths, they do so via a counting process. He draws this conclusion on the basis of a correlation between magnitude estimation latency and line length of .52, roughly the same magnitude as the correlations we have obtained. To the extent that our results parallel his, we have provided evidence for a second order isomorphism between perceptual and memorial estimations of length. Of course, such an hypothesized second-order isomorphism now requires further verification. This could be accomplished by studying the effects of such variables as the number of intervening landmarks or the size of the magnitude estimation standard on both perceptual and memorial tasks. Such investigations should reveal the extent of the isomorphism, and should provide boundary conditions on the analogy between processes operating in perception and memory.

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FOOTNOTES

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Figure Captions

Figure 1. Map of University of Michigan Central Campus area. (Key: 1. Michigan League; 2. Chemistry; 3. Law Quad; 4. Michigan Union; 5. Undergraduate Library; 6. Literature, Science, and Arts; 7. Follett's; 8. The Fishbowl; 9. Michigan Theater; 10. Modern Languages Building; 11. Health Service; 12. Physics and Astronomy; 13. Hill Auditorium; 14. Ulrich's; 15. Bell Tower; 16. Frieze Building; 17. Student Activities Building; 18. Natural Sciences; 19. Barbour-Waterman Gym; 20. Power Center).

Figure 2. Scatterplot of the relation between average estimates and distances for the High spatial ability group.

Figure 3. Scatterplot of the relation between average estimates and distances for the Low spatial ability group.

Figure 4. Stress in multidimensional scaling solutions for 1, 2, 3, dimensions.

Figure 5. Grid distortions of scaling solutions for two subjects. Panel a: Good solution; Panel b: Poor solution.

Figure 6. Grid distortions of group average scaling solutions. Panel a: High spatial ability; Panel b: Low spatial ability; Panel c: The two grids superimposed. (Note: The different perspectives shown in panel a and b, the two are reversed with b veridical, are an artifact of the Empirical Transformation Program).

Figure 7: Scatterplots of the relation between average latencies and estimates. Panel a: High spatial ability. Panel b: Low spatial ability.