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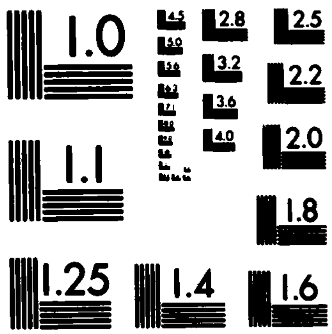

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A COMPARISON OF MAP-LEARNING METHODS: MAP-STUDY, SIMULATED TRAVEL AND MIXED

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Two main methods of studying spatial networks were compared: "travel" in the network, using a computer simulation, and study of a map of the network. Subjects were tested on their ability to demonstrate efficient routes between points on the network, using the same computer simulation. Study times, efficiency of the routes and time characteristics of the performance were recorded. Findings include: latency before beginning a simulated travel increases with the origin-goal distance in map condition, but not in travel

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condition. In travel, latencies are shorter, but study times longer than with the map method. Variants of the basic methods were also studied. It was concluded that variations in the study methods affect study time and performance characteristics. Innovative study methods may produce significant improvement in the performance, especially if care is taken to match study method, spatial task required, and individual characteristics.

PREFACE

In preparing the experiments and analyzing their results, I have greatly benefitted from discussions with Moshe Naveh, Joseph Tzelgov and Avishai Henik. The experiments were run with the assistance of Joachim Meyer, and of Orna Tal-Goldberg, Malka Levy-Hajaj, Dahlia Mizrahi, Miryam Sidi, and Idit Afgin.

PREFACE

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TABLE OF CONTENTS

A. INTRODUCTION

This report summarizes the results of the first phase of a research programme devoted to the experimental comparison of map study methods. Two interrelated factors need to be considered in the design of such experiments: the mode of presentation of the information to the subject and the characteristics of the method used to assess subjects' knowledge.

Among the several study methods investigated, two may be considered as basic: simulated travel, and plain map study. The first presents the information in a way comparable to that accessible to a person who travels freely in a novel environment: At every moment, only a very small part of the environment is visible, but by moving from place to place, the traveller can see all its parts, and learn the links between neighbouring places. The cognitive challenge to be faced is the integration of these local bits of knowledge into a coherent representation, indispensable for the successful performance of spatial tasks such as pointing at unseen locations or planning a route linking two distant ones. In our "simulated travel" method of map study, the subjects also never got to see the whole environment. Instead, they were shown parts of a map, on a CRT screen. The subject could choose himself which neighbouring location to see next, by instructing a computer of the direction of "travel" chosen by means of a small control box. The computer then displayed the intersection wanted. The other method, called simply map study, consisted of providing the subject with a map of the network and allowing him to study it in whatever way he fancied.

At first sight, it would appear that the travel method has drawbacks only. It witholds from the subject potentially useful configurational information, and limits his choice of study strategy, by requiring that locations studied successively be spatially contiguous. Map study, by contrast, is wholly unconstrained. However, a series of studies by Thorndyke and his associates[1] at RAND suggests that map study may not be the ideal method for getting acquainted with a spatial environment, when the ultimate purpose is efficient performance in certain important types of spatial tasks.

Thorndyke and Hayes-Roth[2] compared the spatial knowledge of subjects who came to know a spatial network (the hallways of a large building) either from travel experience (working in the building for some months) or from map study exclusively. These subjects were then administered a range of specific spatial tasks. Their general conclusion was that neither method is superior across the board. Each

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[1] Thorndyke, P.W. Performance Models for Spatial and Locational Cognition. Report R-2676-ONR, The RAND Corporation, Santa Monica, CA, 1980.

[2] Thorndyke, P.W. and Hayes-Roth, B. Differences in Spatial Knowledge Acquired from Maps and Navigation, Note N-1595-ONR, The RAND Corporation, 1980.

method led to good performance on some tasks, and comparatively poor ones on others. The authors convincingly account for the pattern of results obtained by invoking the format of the mental representation induced by the two methods. Studying a map leads to good configurational knowledge. Subjects who learned the network this way are good at estimating straight-line distances, and at drawing on paper the relative positions of distant locations. On the other hand, subjects who became acquainted with it via "navigation" are better at estimating distance along the hallways. They can estimate Euclidian distances, but in a roundabout way: they have to reconstitute each leg of the route and compute from it the straight-line distance, because their knowledge is organized in terms of routes linking the various locations.

One may expect simulated travel to yield mental representations with much the same properties as those which follow actual travel inasmuch as main features of the latter are preserved with the simulation. Other features, however, are not. In our simulated travel, the North always remains at the top, regardless of the subject's turns. In actual travel, the relation between the subject's front and the objective North changes whenever the subject turns. This has no doubt some effect on the resulting mental representation.[3] Moreover, the amount of perceptual detail in simulated travel is nowhere near that available in actual travel, being precisely equal to that afforded by a map. At any rate, there is reason to expect that the mode of presentation of the spatial knowledge affects performance significantly. This relationship should be explored, and could be exploited in practical situations so as to select, in every case, a study method attuned to the intended use of the spatial knowledge to be acquired.

Among the many spatial skills people are called to exerce, one stands out as central: the ability to travel efficiently between distant locations. This ability is often the main purpose of map study, and is the standard used here for comparing methods of map study. It might be noted that this method of assessment has practically not been used before. Many methods for getting at the "cognitive map" of subjects have been devised (Siegel, 1981)[4] but virtually all require the subject to manifest his knowledge from a fixed position. This is unfortunate, since it seems plausible that route knowledge relies on the feedback available in travel, whether real or even simulated (Leiser, 1982).[5]

In the experiments reported here, in which a simulated environment is used, subjects demonstrate their knowledge by travelling as rapidly and efficiently as possible between pairs of locations. This method of

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[3] Evans, G.W. and Pezdek, K. Cognitive mapping: knowledge of real world distance and location information. Journal of Experimental Psychology: Human Learning and Memory, 1980, 6, 13-24.

[4] Siegal, A.W. The externalization of cognitive maps by children and adults. In L.S. Liben, A.H. Patterson and N. Newcombe (Eds.) Spatial Representation and Behavior across the Lifespan. New York: Academic Press, 1981.

[5] Leiser, D. Learning and structuring of spatial networks. Technical Report DL-82/2, Dept. of Behavioral Sciences, Ben Gurion University, August 1982.

testing is not only relevant to a primary goal of map study. It is also very illuminating: if the time course of the performance is accurately timed, it sheds light on the organization of the mental representation induced by each of the study methods, and on the processes which exploit them to perform the tasks.

The remainder of this report is organized as follows: First, two experiments involving the basic study methods (Travel and Map), are reported and discussed. These are followed by two more experiments where the change in performance is examined, when the maps to be studied have special properties (identical looking nodes, and one-way links). The next section is devoted to two methods which combine features of the two basic methods, in an effort to find a hybrid which would share the desirable properties of both. The last experimental section reports experiments with two variants of the Travel method. The one affords the possibility of self-test prior to taking the actual test; the other evaluates the merits of "passive" travel, a method similar to travel, but in which the travel itinerary is not controlled by the subject. The report ends on a set of conclusions and tentative recommendations.

B. MAP vs. TRAVEL

I. EXPERIMENT 1

METHOD

Subjects; Twenty eight students from Ben Gurion University, who participated in fulfillment of a course requirement in introductory psychology.
Apparatus: The experiment was run on an Apple II microcomputer, using its high-resolution graphics mode, a Mountain Hardware programmable clock and an especially constructed input box. Two modes of viewing the network were programmed. In Map mode, the map of the entire network is displayed on the screen (see Fig. 1). In Travel mode, the subject simulates travel among nodes, without ever seeing it in its entirety. At every point in

Figure 1

time, he or she is considered to be at one of the intersections, and shown only the roads leading to that intersection, and the intersection label. That intersection is always centered in the middle of the screen (see Fig. 2a). To change the display, the subject is provided with an input box with four unlabelled press-button switches, disposed in the four cardinal directions. Pressing one of these keys instructs the computer to simulate travel to the adjacent intersection in the corresponding direction. For example, if the subject is at F and presses the East key, he or she will "travel" to I. Pressing the West key at this point restores display F to the screen (see Fig. 2).

More specifically, the transition is effected as follows. The subject presses the key in the direction desired. The computer produces

Figures 2-5

a short tone, acknowledging that the key-press was registered. Nothing happens if the direction indicated does not correspond to a route in the network (such as pressing West at F). If there is a route, then a tiny dot moves just above the road in the direction indicated, starting from the intersection, until the end of the branch. The whole picture disappears, and is replaced by the neighbouring intersection and its label. The dot reappears and continues its travel in the same direction as before, from the extremity of the branch towards the center of the intersection. Finally, a bell tinkles and control is returned to the subject. The whole transition takes about 4 secs. during mapstudy, and is speeded to 2.2 secs. during tests, to reduce floor effects.

Materials: Figure 1 shows the shape of one of the three maps used in the experiments. The maps used all share the following characteristics:

- there are twelve intersections, all labelled

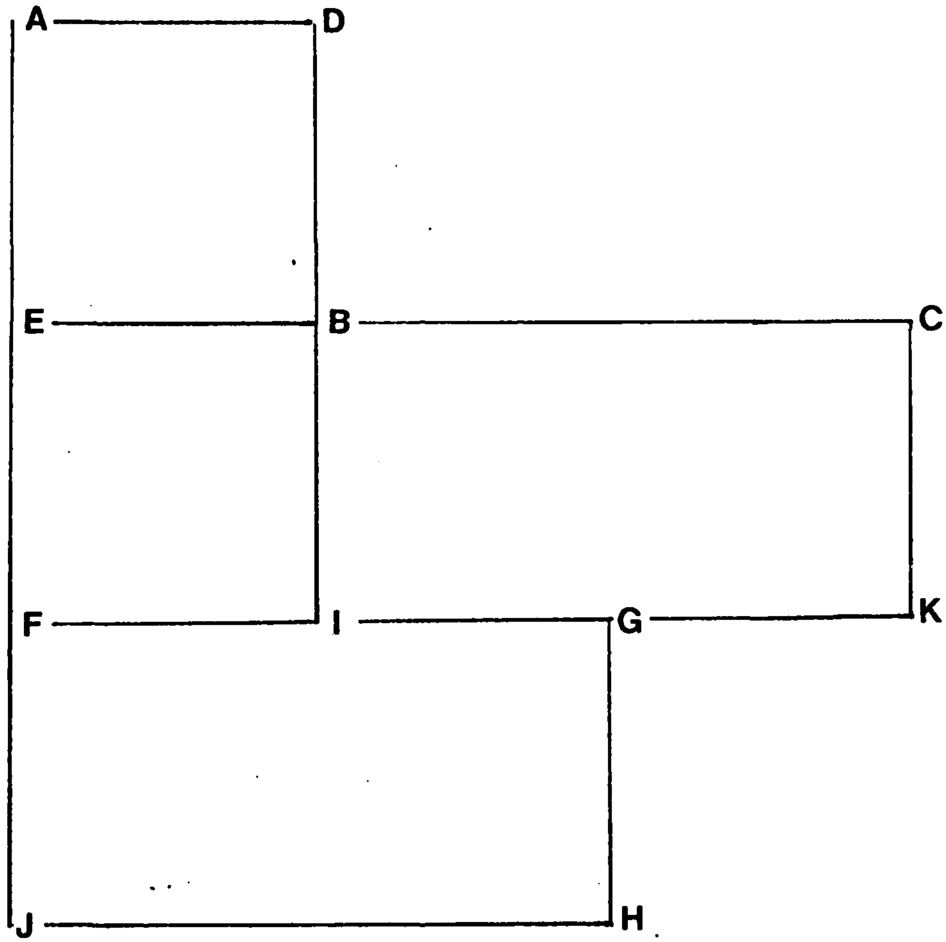


FIGURE 1

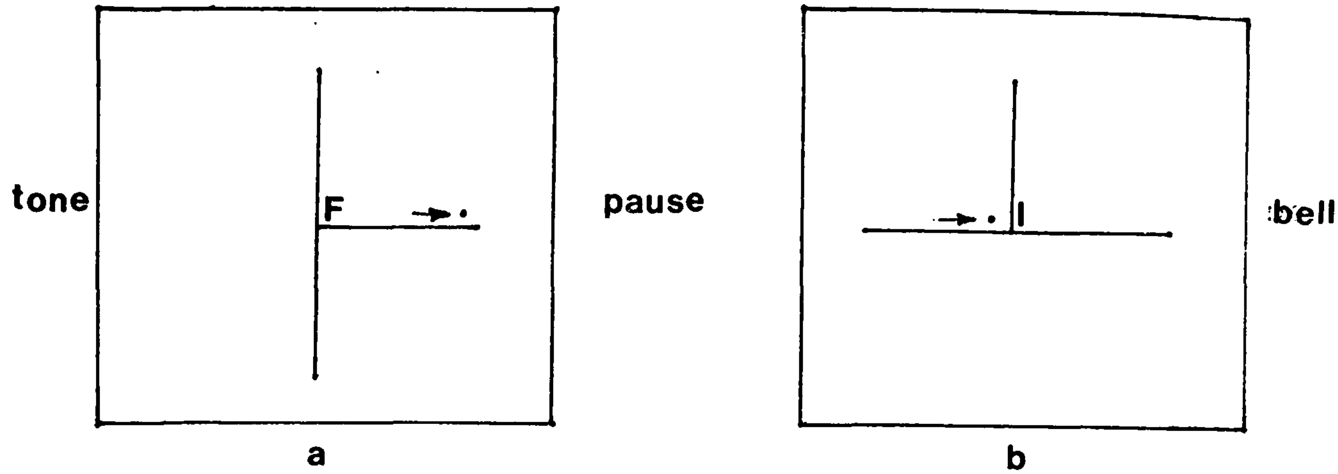


FIGURE 2 : Experiment 1

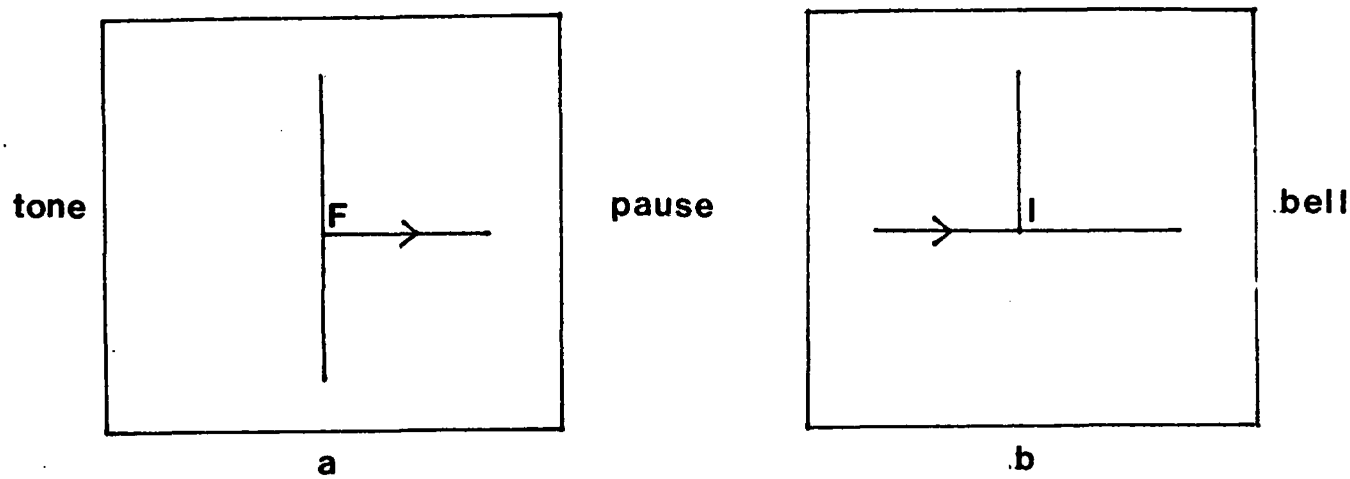


FIGURE 4 : Experiment 2

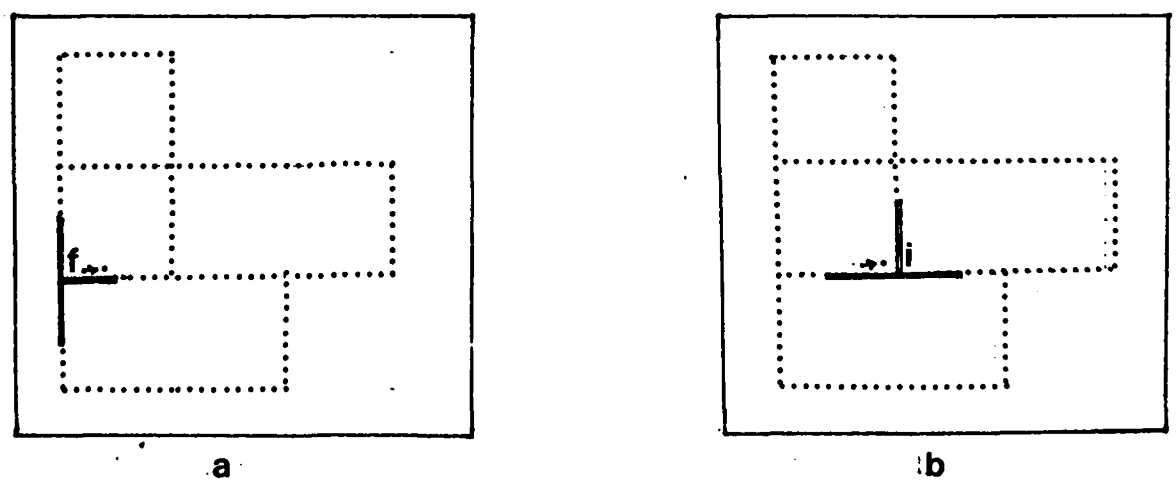


FIGURE 5 : Absolute Travel

- the labels consist of common Israeli girl names, written in Hebrew. All the names are bi-syllabic and three or four letters long

- the roads cross at right angles

- distances between neighbouring intersections are either one or two units (e.g., the B--C and J--H legs in Fig. 1). In Travel mode, when the distance is two units, subjects have to press the same key twice. After the first key press, the display is a long line, without label; after the second, an intersection is reached.

- the maps are "convex" in the sense that, whenever two intersections are located on the same row or column, the line connecting them is part of the network. This feature means that subjects never find themselves in a situation where they have reached an intersection close to the goal, but are separated from it by an unbridgeable chasm -- as constantly happens in labyrinths. "Convexity" in this sense is surely an important variable in route planning, and was controlled here, but not investigated.

Procedure: Subjects were run individually and came for three sessions. Each session consisted of four parts: study of a practice map; test on the practice map; study of the main map; and test on that map. When subjects approached the study of the main map, they knew therefore clearly what was expected of them. More specifically, the practice part went as follows. First, a simple practice map (seven intersection)is displayed on the screen, and the Travel mode is demonstrated. An additional key, away from the directions keys, is marked "Map." Pressing it causes the map of the network to be displayed. Pressing it again returns the subject to Travel mode, to the intersection he or she was at. While studying the practice map, the subject can therefore alternate freely between the two study modes. The subjects are told that there is no time limit. They should study the network well, in order to later pass a test on their ability to travel between locations on the network. The test questions are presented as follows. First, a warning tone is heard for 2 secs. Immediately thereafter, the starting intersection appears in the middle of the screen, in Travel mode (i.e., an intersection and its label), and the Map key is de-activated. At the same time, the label of the goal appears in larger characters at the top left corner of the screen (note that Hebrew is read from right to left). The shape of the goal intersection is not shown. Using the four direction keys, the subject has to reach the goal as quickly as possible. When it is reached, a bell tinkles several times. If the subject is lost and appears to wander aimlessly in the network, then the experimenter moves to the next question, after about ten key-presses. In the analysis, however, all non-optimal routes are counted as errors. The entire practice test consists of ten such questions.

The practice map was studied at the beginning of each session. To avoid interference, the labels in the practice map were single capital Latin letters, while those in the main maps were girls' names written in Hebrew. The specific name assigned to each location was randomly selected out of a pool of fifteen names, and randomly attributed to the intersection for each subject. All subjects received the same questions, but the order was randomly varied. The first question which was the same for all subjects, served as a warm-up question and was not included in the analyses.

Design: Each subject came for three sessions, usually a week and never less than four days apart. One session was devoted to each method: Map, Travel, and a third method, Mixed, which allowed the subjects to mix the other two conditions freely. (Performance following "Mixed" method study will be analyzed below.) The order of succession of the study methods were counterbalanced, as were the assignments of maps to the study methods. The tests consisted of seventeen question: Four questions for each of the inter-pair distances (one to four legs), preceded by the warm-up question. In summary, two variables were manipulated within subjects: Method (Map vs. Travel vs. Mixed) and Distance (1 to 4), in a complete factorial design.

Measures: The following information was collected for each question: Reaction Time (RT): interval between the presentation of the question until the first key press by the subject. Total Time (TT): from the moment the question appeared to the moment the goal was reached. Legs: the number of keys pressed by the subject in reaching the goal.

Using these data, three indices were computed, first for each question separately, and then averaged for each origin-goal distance. Only correct, i.e., optimally short answers were included. These measures are:

- Reaction Time (RT) -- which reflects the time needed to access the information and perform what initial planning is required.

- Average Leg Time (ALT) -- the average time for each key press beyond the first:

$$ALT = \frac{TT - RT}{Legs - 1}$$

This measure is sensitive to factors affecting the unfolding of the plan.

- Error rate (E) -- the percentage of questions on which the subject failed to use the shortest possible route or failed to find the goal. In addition, the Study Times (ST) were recorded.

RESULTS

RT: The results with regard to RT are displayed in Figure 3. The Anova establishes a significant main effect of Method ($F(1, 27) = 6.26$, $p < .025$), a significant main effect of Distance ($F(3, 81) = 2.79$, $p < .05$) and the Method X Distance interaction is significant too ($F(3, 81) = 2.77$, $p < .05$). That interaction is caused by an increase in RT for increasing origin-goal distances in Map, in the absence of such an effect for Travel.

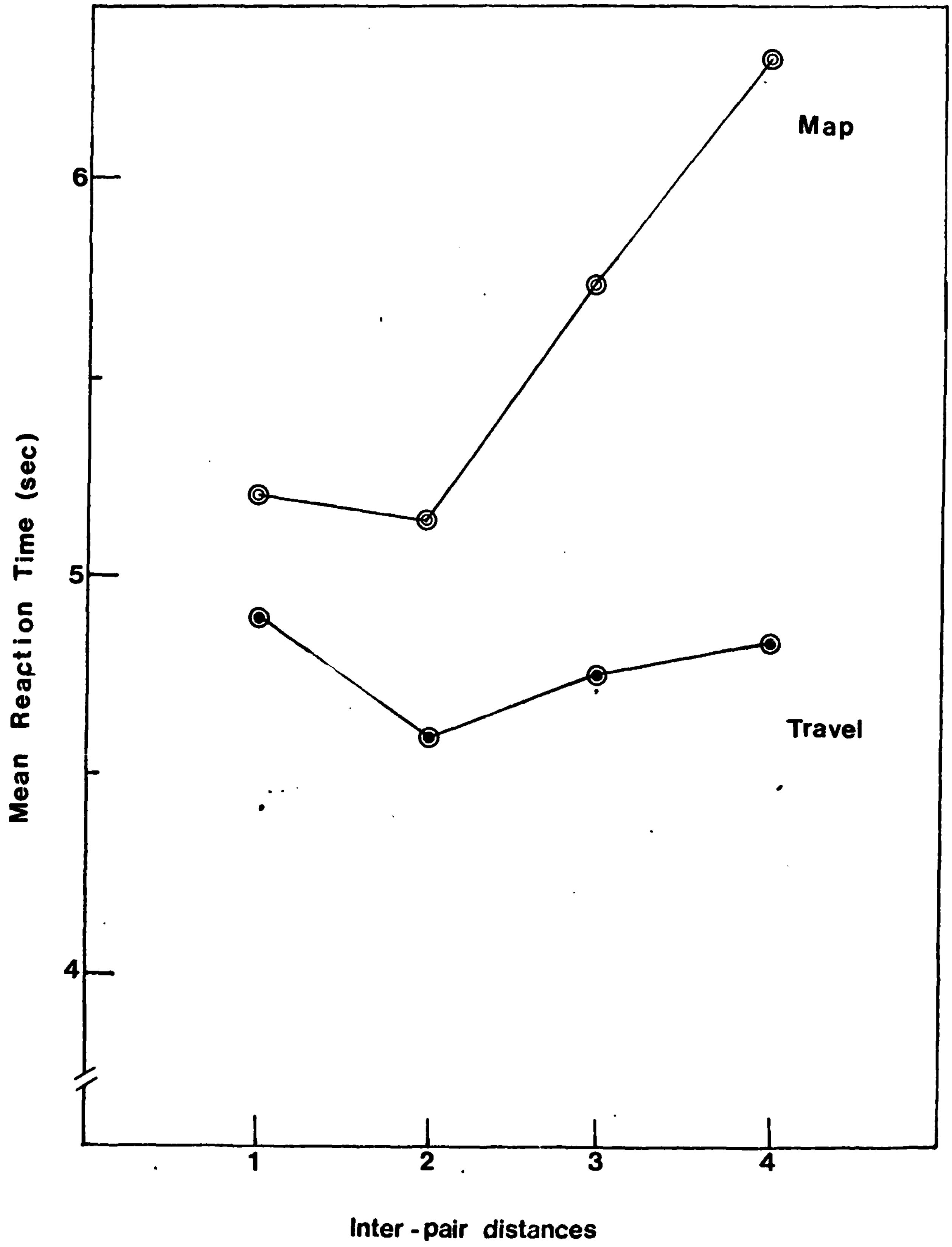

Map
Travel
6
5
4
Mean Reaction Time (sec)
1
2
3
4
Inter-pair distances

FIGURE 3

ALT: Analysis of the Average Leg Time failed to disclose any effect, whether of Method, of Distance, or of interaction. The mean values are given in Table 1.

Table 1

	2	3	4	Mean
Travel	3.03	3.10	2.97	3.04
Map	3.57	3.30	3.30	3.38
(Mixed	2.76	2.96	3.13	2.95)

Average Leg Time (secs)

ST: Most of the study times of Experiment 1 were lost, due to a technical mistake. (Specifically, we lost all of the ST for the Map study condition, and all but 11 of those for the Travel and Mixed mode). The harm is not too great since we do have the ST from several comparable conditions. All attest to the same relation: Map ST are shorter than Travel ST. For Map, we will use the results of a pilot study. The average ST there was 8.11 mins. The ST for Travel, averaged over the 11 available measurements, was 10.7 mins. The difference is significant ($t(22) = 2.20$, $p < .05$) and as will be seen, the difference is usually larger in the other experiments, where within-subjects comparisons are possible.

We found no satisfactory way of equalizing the ST. Subjects in the map condition usually declared themselves ready for the test after several minutes. Forcing them to continue resulted in impatient subjects staring vacantly at the screen. While it is possible to keep the subjects to the task by having them alternately study and draw the map (Thorndyke and Hayes-Roth, ibid.), we did not want to use this technique, since drawing the map is an activity likely to modify the mental representation (Hart, 1981).[6] On the other hand, giving the Travel subjects the test after 8 minutes leads to unacceptably high error rates, and a dearth of data points for computing the time characteristics of successful performance.

Errors: The percentage of errors is fairly close for Map and Travel. What difference there is, is to the disadvantage of the Travel condition, but the difference is not statistically significant. (see Table 2.)

Table 2

	1	2	3	4	Mean
Travel	25	25	29	25	26
Map	18	18	21	31	22
(Mixed	24	26	31	34	29)

Error rates (percent)

[6] Hart, R.A. Children's spatial representation of the landscape. In L.S. Lieben, A.H. Patterson and N. Newcombe (Eds.) Spatial Representation and Behavior across the Lifespan. New York: Academic Press, 1981.

The Distance main effect is significant ($F(3, 63) = 3.15$, $p = .025$). The Distance x Method interaction is not significant ($F = 1$).

DISCUSSION

These results are already suggestive, however, their discussion is best postponed until after the presentation of the results of Experiment 2, in which the same two basic methods were compared in additional ways.

II. EXPERIMENT 2

This experiment was designed to complement the data yielded by Experiment 1, by further comparing the Map and Travel study methods. The extensions were as follows:

- We recorded the Study Time of every subject in every study condition. (Remember that most of the ST had been lost in Experiment 1.)

- We recorded the time interval between every pair of key-presses by the subject during the test. In Experiment 1, we only had an average value for these latencies, ALT, based on the Total Time and the number of legs in the trip. In an attempt to shed some light on the mental representation and processing of our subjects, we recorded the latencies individually.

- We introduced a new test condition, called Blind, and compared it with the usual way of answering travel questions in Travel mode. In Blind mode, the subject receives no visual feedback about the successive intersections by way of which he travels.

- Finally, we replaced the Mixed study method, which had proved disappointing, by a new method, called Absolute Travel. Like the Mixed method, it is a combination of Travel and Map. Both Mixed and Absolute Travel will be discussed separately below. In addition, several methodological improvements were introduced in Experiment 1, as described in the Procedure section. Chronologically, Experiment 2 was the last of the series reported here and these improvements do not apply to Experiments 3 - 5. The results are presented at this point for expository reasons.

METHOD

Subjects: 24 students at the Ben Gurion University, who participated in fulfillment of a course requirement in introductory psychology, and who had not participated in the other experiments in this series.
Procedure: The procedure was fundamentally similar to that followed in Experiment 1. Two minor changes were made after inspection of the ALT there had revealed a floor effect, which might have been responsible for the lack of effect of our experimental variables (Method and Distance). We therefore shortened the minimum time taken by the transition between intersection: (a) we speeded up the timing routines (by rewiring the input box so as to enable us to use the Applesoft WAIT command), (b) we programmed a faster transition by replacing the dot-animation symbolism. The new sequence is as follows: The subject presses a key, say the East key. The computer immediately responds with an acknowledgement tone. A right pointing arrow then appears on the right branch of the intersection (see Fig. 4). After a short pause, the screen is erased. The intersection to the East of the starting point is shown with a right-pointing arrow on its left branch. (This reminds the subject of how he reached the new

intersection.) Finally, a bell tinkles, and control is returned to the subject. If there is no intersection East of the starting point, then control is returned to the subject immediately after the acknowledgement tone.

Experiment 2 included a new way of testing called the Blind Travel mode. This was compared with Feedback Travel, i.e., the normal Travel mode already used in Experiment 1. In Feedback Travel, the subject presses one of the direction keys, is shown the neighbouring intersection after a symbolic transition, selects again a direction key to press, and progresses in this manner until the goal is reached. In Blind Travel, the subject also presses direction keys successively, and the computer keeps track of where he is at every moment. But now, the subject receives no feedback about where his displacements are taking him. Pressing the first key erases the starting point and, from then on, the screen remains blank until the next test question is displayed. The subject only receives a minimal auditory feedback. After every key-press, the acknowledgement tone is always heard. If there is an intersection in the direction indicated by the key, then the bell also tinkles shortly thereafter, when the intersection is -- invisibly -- reached. Otherwise, control is returned to the subject immediately, and the silence of the bell signals to the subject that he attempted an impossible move.

The composition of the tests was also slightly modified, for fear that too many questions answered in Travel mode should affect the mental representation. Since we asked questions in Feedback and in Blind mode, we decided to drop some of the questions. Experiment 1 had indicated that the clearest differences between the methods are found with the longest origin-goal distance. We restricted ourselves accordingly to the distances 3 and 4.

Every subject came for three sessions, four to seven days apart. Each was devoted to a different study method (Map, Travel and Absolute Travel). The order of the methods was counterbalanced, and a different map was studied each time. The assignmene of maps to methods was also counterbalanced.

At the end of each session came the test. This consisted of two blocks of eight questions. The two blocks contained the same questions, in different random orders. One was answered using Feedback Travel, the other using Blind Travel, the order of these two modes was counterbalanced across subjects, and alternated in the three sessions of every subject. Each block contained four questions with origin-goal distance of 4, and four with a distance of 3. The test questions were preceded by a warm-up question, which was always the same for each map, and ignored in the analysis.

<u>Measures</u>

We recorded the Study Time in minutes for every session, and computed the average ST for the three methods across subjects.

There were, all told, twelve classes of questions: three study methods (T, M, AT), two distances (3 and 4), and two test answering modes (Blind and Feedback). For every test question, we recorded the <u>latencies</u> for every key press: from the display of the question to the first key press, and between one key press and the next. We also recorded the number of key presses used by the subject in reaching the goal. Using this data, we computed the following measures for every class of question, before averaging them across subjects.

The Error rate, E. Every route longer than the minimum number of steps was counted as an error, and, of course so where trip which failed to reach the goal.

The Reaction Time, Rt. This is the latency from the moment the question appears on the screen until the first key press, averaged over the correct answers only.

The Leg Time, Lt. This is the time lag between two successive key presses, averaged over correct answers only. For questions with origin-goal distance of 3, there were two Lt; for those with distance 4, there were 3 of them.

DISTANCE - 3 Display $\xrightarrow{Rt_3}$ Key 1 $\xrightarrow{Lt_3(2)}$ Key 2 $\xrightarrow{Lt_3(2)}$ Key 3 $\rightarrow$ Goal Reached

DISTANCE - 4 Display $\xrightarrow{Rt_4}$ Key 1 $\xrightarrow{Lt_4(2)}$ Key 2 $\xrightarrow{Lt_4(3)}$ Key 3 $\xrightarrow{Lt_4(4)}$ Key 4 $\rightarrow$ Goal Reached

---

RESULTS

Study Time: The mean study times for Map and Travel are 6.20 mins. and 17.4 mins., respectively. That difference is significant at the .05 level (using Duncan's multiple range test).

Reaction Time: Of the three variables: Method, Distance and Answering Mode, only the latter had a significant main effect: Feedback = 9.8 secs., Blind = 15.4 secs. ($F(1, 87) = 12.48$, $p < .001$). None of the interactions were significant. There was no significant correlation in the Rt of the same subjects following Map and Travel study. The values themselves are presented in Table 3.

TABLE 3

	Blind		Feedback	
	3	4	3	4
Map	13.59	15.05	9.23	9.91
Travel	13.54	15	9.86	9.90
(Absolute T	19.7	17.1	10.4	10.34)

Reaction Times, N=22

Leg Times: We will begin with the Lt values for the Feedback answering mode. We found no effect of Method, and the average values for each distance are very close (see Table 4), as was the case in Experiment 1.

TABLE 4

	Lt_3			Lt_4			
	2	3	Average	2	3	4	Average
Travel	3.13	2.8	2.96	3.22	3.27	2.68	3.07
Map	3.54	2.81	3.16	3.45	3.08	3.09	2.84
Absol.T.	3.13	2.54	2.84	3.18	2.68	2.68	3.22
Average	3.26	2.71	2.99	3.28	3.03	2.83	3.04

Leg Times, Feedback, N=22

However, there was a significant effect of "position-in-the-route" both in Lt_3 and in Lt_4. The subjects had to press several keys to reach the goal, and the last key(s) were pressed faster than the first ones (even excluding the very first Rt which is of course much longer). This effect is significant both for distance-3 questions ($F(1, 21) = 11.21$, $p < .005$) and for distance-4 questions ($F(2, 42) = 3.29$, $p < .05$).

We did not compute the mean Lt for questions answered in Blind mode, because the distribution of values renders the means useless. Many of the questions yielded one very long value, evidently caused by the subject needing to think carefully about where he is and what his next steps must be.

To give an idea of the range of values involved, the shortest and longest $Lt_4(2)$ for a successful answer were, respectively, 1.41 and 127.2 secs. Comparison of Lt means of Blind and Feedback questions with the "outliers" included would therefore be meaningless (the values for Feedback would of course be much shorter). A comparison after removal of the outliers would depend on the criteria chosen for removing them, and this would always be somewhat arbitrary. On the other hand, we thought it interesting to study the distribution of the outliers, and for this, the specific cutoff criteria matter less. After inspection of the data, we decided to consider as an outlier any value more than 3 times the average of the lower values in its category. For example, a value of 14.51 secs. would be considered as an outlier in Blind $Lt_4(2)$ if the other values were 3.75, 2.98 and 18.34 secs. With this criterium, we obtained the distribution seen in Table 5.

TABLE 5

	Lt_3		Lt_4			Total	Subjects Involved
	2	3	2	3	4		
Travel	4	1	3	2	6	16	12
Map	5	5	2	3	6	21	12
(Absolute T.	2	2	6	6	1	17	10)
Total	11	8	11	11	13	54	

Distribution of outliers(very long Lt)

There are no main effects of Method, Distance or Place-in-a-route, and there seems to be no meaningful pattern in the distribution.
Errors: The error rates for the various methods and types of questions are presented in Table 6.

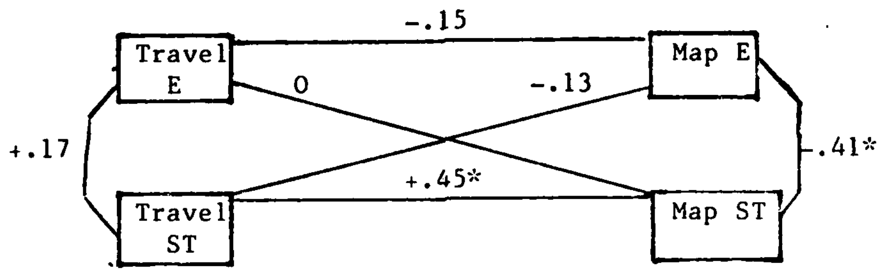
TABLE 6

	Blind		Feedback	
	3	4	3	4
Travel	15	26	12	20
Map	17	29	8	18
Absol.T.	15	19	10	15
Average	15.7	24.7	10	17.7

Errors (N=22)

The main effect of Distance is significant: (there are more errors when the origin-to-goal distance is 4, than when it is 3 ($F(1, 21) = 13.52$, $p < .005$). The number of errors also increases in Blind answering mode when compared to the Feedback mode, and this difference is also significant ($F(1, 21) = 6.43$, $p < .025$). The differences in Method, however, are not significant ($F < 1$). None of the interactions approaches significance, the strongest effect

being the Method * Blindness interaction (with F(1,42) = 1.71, p = .2 only.)
Correlations: Since subjects were free to study as long as they pleased, we thought it interesting to check the correlation between the ST and E of the two methods, Travel and Map. The Pearson correlation coefficients are given below. (Starred values are significant at the .05 level.)



Subjects who require a long time to study the network in Travel mode tend also to study the Map at length. Further, while subjects who study the Map a long time tend to make fewer mistakes afterwards, the same does not hold true for study by Travel: ST and E are not significantly correlated for Travel. It can be shown that the two significant correlations are unrelated, by comparison with the partial correlation coefficient. The partial coefficient of correlation between Map ST and Map E, when the correlation between Map ST and Travel ST is removed, is still -3.98 (vs. -.41 for the original coefficient). In summary, there are two unrelated significant correlations: positive between Map ST and Travel ST, and negative between Map ST and Map E.

III. DISCUSSION OF EXPERIMENTS 1 & 2

Our approach to the comparison of map study methods is based on the hypothesis that the mental representation of a spatial network reflects the way the subject learned it. The results of Experiments 1 and 2 support this hypothesis. This data will be interpreted with reference to models of the representation induced by Map and Travel study, which are derived form an analysis of the study methods and based on some suggestions found in the literature (McCalla, Reid & Schneider[7]; Thorndyke[8]). In presenting them here, we will refrain from a detailed specification which would go too far beyond the available data, and do no more than sketching two broad classes of mental models. The one is based on familiarity with the geometrical shape of the network; the other on knowledge of routes.

The product of Map study is a mental representation akin to a visually accessible cartographic map (cf. Kosslyn[9]). In this representation, specific routes are not separately represented. When travel tasks of the form "Go from X to Y" are set during the test, the following steps are required: (1) Locate X on the mental map. (2) Locate Y on it. (3) Plan a route linking the two locations in the fewest steps possible. (4) Execute the plan step by step. The planning step is sensitive to the complexity of the route linking X and Y, and this is reflected in the RT: the longer the distance between origin and goal, the longer the RT.

The mental representation constructed in the course of Travel study is very different. During his experience with the network, the subject learns how to travel between many pairs of locations. His knowledge consists essentially in a system of routes. The system is integrated, since the subject begins by knowing some routes, and later uses this knowledge as a basis for devising and learning new ones. (An extensively worked out model of this is described in Leiser, ibid.) There need be no awareness of the geometric shape of the network; the knowledge can be restricted to the system of connections. Performing tasks of the form "Go from X to Y" involves two steps only: (1) Retrieve the relevant route directions. (2) Execute them step by step. Since the retrieval time is independent of the length of the route to be retrieved, there is no effect of origin-goal distance on RT.

After the planning or retrieval of the route is over, there should be no difference between the methods, and indeed, our data does not point to any. The implementation phase consists merely in following well-defined instructions. Doing this requires but little effort, and the Lt are always

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[7] McCalla, G.I., Reid, L. & Schneider, D.F. Plan creation, plan execution and knowledge acquisition in a dynamic microworld. International Journal of Man-Machine Studies, 1982, 16, 89-112.

[8] Thorndyke, P.W. Spatial cognition and reasoning. In J. Harvey (Ed.) Cognition, social behavior and the environment. New Jersey: Lawrence Erlbaum, 1981.
Thorndyke, P.W. Performance models for spatial and locational cognition. The Rand Corporation, R-2627-ONR, December 1980.

[9] Kosslyn, S.M. Image and Mind. Cambridge, Mass.: Harvard U. Press, 1980.

much shorter than the Rt. The ALT are not influenced by the origin-goal distance in either method, as predicted from the models.

Note that the instructions are normally implemented with some reliance on feedback from the environment. When subjects are forced to travel in Blind condition, they often need long "thinking pauses," during which they try to get their bearings; the error rate increases. The subjects themselves are evidently aware of the handicap, when feedback is removed, and before starting on their way, try to prepare their plan in such a way that feedback will not be required. This additional preparation is reflected in the longer Rt before the start of a Blind trip, at a moment when the subject is in possession of exactly the same information as in the Feedback answering mode (i.e., the shape and label of the starting point, and the label of the goal).

We have no clear explanation for the shorter LT before the last key press ($LT_3(3)$ and $LT_4(4)$). It could be some artifact of the size of our maps, although we do not have any specific mechanism in mind in mentioning this possibility. If the effect is genuine, several possible factors might be invoked. Links involving neighbours might be overlearned and more rapidly accessed. Alternatively, it could be that the route instructions kept in short-term memory are rehearsed. This would increases the latencies before every leg except the last.

The different Study Times reflect the difficulty of learning the network under each condition: studying the Map consists in remembering a complex geometrical shape, and the labels associated with each intersection. Learning from Travel requires memorizing a complex system of routes, which must be integrated in a coherent representation. This is much more difficult and takes longer. The association of longer ST with more difficult tasks rather than, say, with the uncertainties of self-assessment is demonstrated by the positive correlation of ST and E across methods. For nine of the study conditions presented in this report (AT being excluded because of the different test used) Spearman rho = .93($p < .01$). This relationship also means, incidentally, that the different patterns in RT (for Travel and Map) cannot be accounted for by the longer ST in Travel, which could be taken to result in a better knowledge of the network. On the contrary, the longer mean ST testifies to the increased difficulty of the study task, while the mean error rate for Travel is actually higher than that for Map (although the latter difference is not statistically significant in this case).

The correlational data about inter-subject differences in ST and E, for the two study conditions, yields some interesting conclusions regarding individual differences. There is an individual characteristic of duration of learning. The ST for Travel and Map are positively correlated (Pearson $r = .45$.) It was also found that ST and E are negatively correlated for the Map condition, and uncorrelated for the Travel condition. The two correlations are unrelated, as evidenced from the partial correlation coefficient when Travel ST is partialled out. These results are consistent with those reported by Goldin and Thorndyke[10] (1981), who compared good

[10] Goldin, S.E. & Thorndyke, P.W. An analysis of cognitive mapping skill. The Rand Corporation, N-1664-ARMY, March 1981.
Thorndyke, P.W. & Goldin, S.E. Ability differences and cognitive mapping skills. The Rand Corporation, N-1667-ARMY, March 1981.

and poor mappers on various tasks, after having classified them as such on the basis of the accuracy of their spatial judgment, with regard to an environment they had learned from actual travel experience. Good mappers were found to have shorter ST and lower E for spatial judgments, after study in either (actual) Travel or Map condition. On the other hand, they were no better at travelling in an environment after memorizing its map. Similarly, we found that people who learned rapidly how to travel accurately in a simulated environment on the basis of a memorized map are not particularly good at learning it from travel experience, and further, that people who are rapid travel learners are neither particularly accurate, nor inaccurate, in solving travel tasks.

In trying to explain these relationships, any number of hypotheses could be devised. Important variables one would want to look into would be the level of mastery wanted by the subjects, and the ease of self-assessment afforded by the various methods. However, the empirical basis is still slender, "hypotheses non fingo."

C. SPECIAL MAPS

I. MULTIPLE APPEARANCE MAPS (EXPERIMENT 3)

This minor experiment was run to test one of the consequences of our models of Map and Travel study. How would the presence of indistinguishable intersections in the network affect the study process and the behavior during the test in each case? Our prediction was that, for Map study, this would not matter. Map study consists basically in learning a geometrical shape, with certain labels associated to the intersections. Since intersections are identified primarily by their location with respect to the rest of the map, the presence of pairs of intersections with the same shape and label ought not to make any difference. In Travel study, however, such pairs of intersections should be very disturbing, as intersections are identified primarily by their shape and label. If two intersections share these features, subjects would have trouble distinguishing them, and this would make the integration of routes in a coherent system most difficult. Experiment 3 tested these predictions, by presenting subjects with such "Multiple Appearance" (MA) maps to study by either method, and comparing their performance with that of the subjects of Experiment I.

METHOD

<u>Subjects</u>: Two groups of twelve subjects who participated as a course requirement in introductory psychology.
<u>Design and Analysis</u>: Experiment 3 had to be run in a between-subjects design. As a result, the analysis was not very satisfactory. We can compare MA Travel with the Normal Travel subjects of Experiment 1, and also MA Map with the Normal Map subjects, both between-subjects. But there is no way of entering all four groups in a common design, and the interactions can therefore not be directly tested. Comparison was with Experiment 1 because the need to prepare for questions in Blind mode may have affected the study times and error rate in Experiment 2. Subjects came for two sessions. The one was devoted to study of an MA map, either by the Travel or the Map method. The other was devoted to either Passive or Problem Oriented Travel. (These methods will be presented below.)
<u>Materials</u>: Two of the maps used in Experiment I were modified in one respect: in the new "Multiple Appearance" (MA) maps, there were now two pairs of intersections which carried the same name. The shape of the intersection was in each case identical too, so that it was impossible to determine which of the two "twin" intersections was being displayed, solely on the basis of the information (shape and label) appearing on the screen. The two MA maps have twelve intersections, but only ten different labels.
<u>Procedure</u>: The procedure was identical to that followed in Experiment I. The same practice map was used. The tests were so constructed that none of the travel tasks began or ended at one of the "twin" intersections.

Instead of seventeen, there remained only thirteen questions, of which the first was discarded in the analysis.

TABLE 7

	Normal	MA
Reaction Time (secs)		
Travel	4.79	6.48
Map	5.62	6.04
Errors (percent)		
Travel	26	40
Map	22	19
Study Time (mins)		
Travel	11	14
Map	8	7

Comparison of Normal and Multiple-Appearance maps studied in Map and Travel mode.

Table 7 presents the performance of the new subjects, who studied MA networks, side by side with that of the subjects of Experiment 1, who studied Normal networks. All the measures present the same picture: MA-Map is equivalent to Normal-Map, whereas MA-Travel is far more difficult than Normal-Travel. Taking RT first, MA-Map and Normal-Map are very close [$F < 1$], while MA-Travel is much slower than Normal-Travel [$t(38)=3.13$, $p < .01$]. Because of the marked deterioration in MA-Travel, MA-Travel is even slower than MA-Map, thus reversing the relative speed of Travel and Map observed with Normal networks in Experiment 1. Looking now at Error, there is a small and non-significant decrease from Normal-Map to MA-Map; but a very large increase, from 26 to 40% of errors, in going from Normal Travel to MA-Travel [$t(28)=2.67$, $p < .025$]. A comparable pattern is also found in the Study Times: A slight and non-significant improvement between Normal-Map and MA-Map, and an increase in ST from Normal-Travel to MA-Travel.

Discussion

These results conform to our expectations. After studying a map, subjects have learned a geometrical shape, and are able to attach the appropriate labels to the intersections. The intersections themselves are primarily identified by their relative location, while the labels are secondary. If two intersections share the same label, this causes no difficulty. In fact, it may even simplify the task, since there are fewer labels to remember, and this would tally with the slightly better Study Time and Error rate. At any rate, the performances are closely comparable to that with normal maps.

The situation is very different with respect to the Travel method of study. With normal maps, the subjects manage to form a coherent representation on the basis of pieces of information of the form: "Going to the right from X brings me to Y." In the case of Multiple Appearances maps, this format is insufficient and leads to contradictions, since there may be two indistinguishable X. For the subject, this means that the information must become conditional: "If I came to X by going up from S, then going to the right brings me to Y. But if I came to X by going up from T, then going to the right will lead me to Z." The subject must identify and dissociate the "twin" elements. This is very difficult in Travel mode since the dissociation must be made on the basis of the connections only. Consequently, the Study Time is increased, as well as the Reaction Time, and the overall performance becomes very inaccurate.

II. ONE-WAY MAPS (EXPERIMENT 4)

This exploratory study investigates how the two study methods are affected by the existence of "one-way" links in the network. Digraphs should be more difficult to learn by either method. In the map methods, one would expect longer latencies and more mistakes, because the spatial shape of the network no longer is a reliable guide of the route to be followed (cf. our choice of "convex" maps). Integration of learning in Travel mode would also be hampered by the existence of one-way segments, which render the chaining of routes more risky.

METHOD

Subjects: Twelve first-year students at Ben Gurion University, who participated in fulfillment of a course requirement and did not participate in the other experiments.
Design: Each subject came for two sessions, four to seven days apart. Each session was devoted to the study of a different one-way map, by one of the two methods, Map and Travel. The order was counterbalanced, and so was the map assignment. The performance measures were then compared with those of Experiment 1 in a nested design.
Materials: The maps used were again modified versions of maps used in Experiment 1. The modification consisted in the transformation of four of the links into one-way passages. This new property manifested itself to the subject as follows: In Map mode, arrow signs in the middle of each of the one-way segments indicated the direction of travel allowed. In Travel, too, and later during the tests, an arrow sign across the middle of the road indicated the allowed direction, whenever any of the segments appearing on the screen was a one-way segment. In addition, if the subject attempted to travel in the forbidden direction, his command was not obeyed by the computer, and a "Stop" sign was flashed on the screen. The practice map was also equipped with two one-way segments.
Procedure: The procedure was similar to that used in Experiment 1. Each session started with the study of the practice map (with one-way segments), followed by a practice test. Then came the study of a one-way map in Map or Travel mode, in counterbalanced order, and the final test. The test consisted of questions such that the distance by the shortest route along the allowed links varied from 1 to 4. The actual distance could be less, as when the actual origin-goal distance was of 1, but that link was in the forbidden direction. In that case, the question was considered as a distance-3 question.

RESULTS

The Results are summarized in Table 8.

TABLE 8

	Normal N=26	One-Way N=11
RT (secs)		
Travel	4.8	6.3
Map	5.62	7.8
E (%)		
Travel	26	35
Map	22	28
ST (mins)		
Travel	10.7	14.7
Map	8	11

Comparison of performance with Normal and One-Way Maps

An Anova (Method nested in Directedness) for RT gave the following results: significant main effect of Method ($F(1,37) = 10.36$, $p < .05$) and of Directedness ($F(1,37) = 12.88$, $p < .01$), and no interaction. For Error, the same pattern is seen, but neither main effect reaches significance. Finally, for ST, the analysis had to be separate (because of the lost data of Experiment 1). For Travel $t(22) = 2.58$, $p < .025$; for Map $t(22) = 1.9$, (n.s.)

DISCUSSION

The basic conclusion from this experiment is simple enough: One-way maps are harder than normal maps, whatever the study method used. Study times are longer, more mistakes are made, and the latencies are longer as well.

The increase in difficulty is about the same for the two methods with the maps we used, but it may be unwise to assume that this will always be the case. If we are correct in our analysis of the mechanisms underlying performance following Map or Travel study, then the reasons for the difficulty of one-way maps are not the same for the two methods. In Map, planning is more difficult, since the search for an optimal route is not as fully guided by the direction of the goal. In Travel, the difficulty is to learn long routes, since they cannot be derived from shorter routes by extension of shorter ones without some precaution. The overall representation is therefore harder to organize, and the slower RT, longer ST and increased E are a consequence of this, as was the case with Multiple-Appearance maps. With larger and more complex maps, it may be found that one of the methods suffers more.

D. COMBINATION OF METHODS

1. MIXED

The two basic methods (Travel and Map) we compared can be combined in various ways, in the hope of devising a method which would combine the strong points of each. We experimented with two such methods. The first, called Mixed, consists in simply allowing the subject to use freely the two basic methods. The second, called Absolute Travel, will be presented later.

Subjects: the 28 subjects of Experiment 1.
Design: The results to be described presently were obtained in Experiment 1. To recall, the subjects came for three sessions, four to seven days apart. Each session was devoted to a different method: Travel, Map or Mixed, in counterbalanced order, and a different map was learned each time.
Procedure: The general procedure was explained in Experiment 1. The specific method, Mixed, consisted in letting the subject choose at every moment whether he or she wanted to learn the network by Travel or by studying the map. To this end, the input box had a key marked "Map," away from the direction keys. Pressing it erased the intersection where the subject was located, and displayed a complete map of the network, which filled most of the screen. That map was displayed during ten seconds. It was then erased and replaced by the intersection where the subject was located. Nothing prevented the subject from immediately pressing the Map button again, and some subjects did this repeatedly. The ten second periods were introduced to make study in Map mode a deliberate choice, rather than the effect of inertia. The study period was preceded by the practice period described above, and followed by the test described there. The Map button was disabled during the tests.

Results

The results are displayed alongside the results for Map and Travel in Figure 3 above. As can be seen, RT is not affected by the origin-to-goal distance. In general, the results are equivalent to those obtained for Travel. A *t*-test showed that both the differences in average RT and in Error rate between Travel and Mixed are not significant. A *t*-test for those 13 subjects for whom we have data on study time both on Travel and on Mixed conditions also showed no difference.

Discussion

These results are decidedly unexpected. We thought that showing the map to the subjects would greatly facilitate their learning, and lead to a shorter study time combined with fewer errors. If no improvement in the performance, we expected at least some changes in the results, since several subjects told us that after studying the network by Travel, they could form no image of the disposition of the intersections, even though they could solve travel problems, and most subjects request to draw the map. It, therefore, came to us as a surprise that free access to the map made no visible difference to the performance.

One possible explanation of the RT and E results would be that

Map and Travel experience induce different formats for mental representation, and that the two cannot be readily combined. When asked to travel from location X to location Y the subject who possesses the information in both formats -- as many of us presumably do for the town we live in -- must decide on which one to base his search: should he search for a known route linking these two locations, or should he locate X and Y on a mental map, and derive from it the route to follow? These are two different mental operations, and there does not seem to be a way of combining them in real time. Because the first is more direct -- it tells one what to do -- and therefore also faster (see Exp. 1), this is the one favored. However, this does not explain why ST is not shortened , and at any rate, it is a post hoc explanation of counter-intuitive findings which definitely deserve a more detailed study.

II. ABSOLUTE TRAVEL

The second method of combining Map and Travel was more subtle. One useful information available in Map and not in Travel mode is the absolute location of the various intersections on the screen. Subjects who learned the network from maps associate labels with specific screeen locations (cf. the Multiple Appearance maps of Experiment 3). As against this, the advantage of Travel mode is that it focuses attention on specific routes, which is a very relevant way of learning the network as a preparation to solve travel tasks. The Absolute Travel (AT) mode was designed to incorporate these two strong points.

METHOD

The data on AT Travel was collected in Experiment 2. We need therefore only explain the specific study method here.

Absolute Travel has much in common with the usual Travel method. The subject sees only a small part of the map at any given time (an intersection and a label) and uses four direction keys to travel a dot cursor to neighbouring intersections. The difference is in the screen location of the intersection where the subject "stands." In Travel, it is always in the center of the screen. In AT Travel, the intersection is shown at the location it would occupy if the whole map were displayed. This might be compared to studying a complete map by sliding a sheet of opaque paper over it, seeing at all times a very small portion through a small window in the sheet. The usual Travel method could then be compared to shifting the map under the opaque covering, while the window remains immobile. Except for the difference of location and consequently that of scale, the method is identical to Travel. In particular, the transition to another intersection during map study is symbolized by dot animation (see Fig. 5). The test, however, used the modified Travel method described in Experiment 2, not AT.

RESULTS

Study Time: ST for Absolute Travel are shorter than for regular Travel, and longer than for Map study. The mean values are: Map: 6.2 mins, AT: 13.09 mins, and Travel: 17.4 mins. The overall Anova was significant ($F(2,46) = 40.6$, $p < .001$) and the Duncan multiple range test showed that AT is significantly different from the other two methods.

Reaction Times: The values are given in Table 3 (see Experiment 2). The RT values are the slowest of the three methods, in all conditions: Feedback and Blind answering, distance-3 and distance-4 questions. However, this disadvantage is not statistically significant.

Leg Times: Here the values are shorter than for the other two methods (see Table 4), but again, not significantly so. The average LT for distance-3 questions are, for the three methods: AT: 2.84 secs; Travel: 2.96 secs; and Map: 3.16 secs. For distance-4 questions, the values are

At: 2.84; Travel: 3.07; and Map: 3.22 secs. The F-values for the two main effects are $F(2,42) = 1.51$ and 1.21, respectively.
Error rate: The same pattern is found here as well: better performance, but not statistically significant difference. The values are given in Table 6. The average for the three methods are AT: 15%; Travel: 18%; and Map: 18%.

DISCUSSION

The general conclusion to be drawn from all this is that unlike Mixed, Absolute Travel is an improvement over Travel. This is very clear in the Study Times. Whereas in Mixed, the availability of a Map made little difference, the mode of presentation used in Absolute Travel facilitates learning, diminishes the ST and lowers somewhat the error rate. The difference between the two ways of combining methods, Mixed and AT, is worth pondering: in Mixed, two different modes of representation are made available. The two are alternatives, and not readily combined. Hence the advantages of each are not well exploited. In Absolute Travel, some of the map-properties are integrated in the study of routes. Intersections are easily kept apart and one may safely expect AT to be as little affected by Multiple Appearance maps as the Map study method in Experiment 3. The intimate hybridization of Map and Travel can therefore produce offspring with the favorable properties of each. Additional experimentation may yet come up with other, even more favorable hybrids.

E. MODIFIED METHODS

I. PROBLEM-ORIENTED TRAVEL (EXPERIMENT 5)

While the subjects were free to study the network as long as they wanted, the error rate is rather high, following study in either Travel or Map mode. Since self-assessment is notoriously of variable accuracy (Stasz & Thorndyke[11]), a promising approach to lowering the error rate would be to provide the subjects with the means of testing their knowledge before they decide to take the test. This idea was implemented in a straightforward modification to the Travel method. An extra button marked "Problem" was added to the input box. Whenever the subject pressed that button during the study period, he was asked a test question in exactly the format later used in the test. The name of a location appeared at the top left corner of the screen, and the subject had to reach it from his present location, in the fewest steps possible. The name of the goal remained in view until the goal intersection was reached. A bell then tinkled several times, and the name was removed. The subject would then continue to explore the network in Travel mode, or request another test. The goals in these self-tests were selected at random.

Two benefits were expected from this procedure. First, subjects could evaluate the extent of their knowledge more objectively. This might decrease the error rate, presumably at the cost of a longer study time. But second, the study time could be used more efficiently, since the subject's attention was focused on specific routes by the tests.

Problems were only set to the subjects at their request. This was done after a pilot study had indicated that unrequested test problems are distracting, as they interfere with the study strategy the subject would normally use (such as studying regions of the network one by one, or travelling its perimeter repeatedly before exploring the interior terrae incognitae).

METHOD

We gathered information on Problem-Oriented (PO) Travel from two experiments. The first involved 12 subjects, who also had to solve one Multiple Appearance task (Experiment 3) during another session. The second, Experiment 4, was specifically designed to compare Travel PO to Normal Travel (and to a third method, Passive, described hereafter), in a within-subjects design. This involved 14 subjects, psychology freshmen like the others. Intrinsic properties of PO Travel are therefore based on 25 subjects, whereas comparisons with Normal Travel are based on 14 subjects only.

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[11] Stasz, C. & Thorndyke, P.W. The influence of visual-spatial ability and study procedures on map learning sill. The Rand Corporation, N-1501-ONR, June 1980.

RESULTS

Reaction Times: There was no significant effect of origin-to-goal distance on the RT. The mean values for the four distances were:

1	2	3	4	mean
6.85	7.11	6.97	6.79	6.93 secs

The mean value for the 14 subjects was 7.58 secs. That value for Normal Travel was 7.32 secs. The difference is not significant. In summary, both the pattern and the actual values of RT are equivalent in PO Travel and in Normal Travel.

Errors: The average E for PO Travel was 34%; for Normal Travel it was 33%. The difference is of course not significant.

Study Time: The ST for PO Travel and Normal Travel were reliably different. The mean values are 12.5 mins and 9.2 mins., respectively ($F(1,13)=5.05$, $p<.05$).

DISCUSSION

Contrary to our expectations, the availability of self-tests did not produce any improvement in the performance, whether in speed or in accuracy, in comparison with Normal Travel. The only significant effect was the increased study time, by about one third. This result is intriguing, especially when one recalls that in Normal Travel, there is no correlation between ST and E across subjects. Such a result could be explained by positing that knowledge, in the case of Travel mode study is not simply cumulative, and that organizational factors play an important role. Subjects may be more or less adept at integrating the route knowledge they gather during their travels, and increased study time is of no avail for a given method. Unlike Absolute Travel, Problem-Oriented Travel does not modify the way the information is presented. It merely informs the subject that he does not yet know the map well enough. But the subject may be aware of this, and still by incapable of integrating the many local bits of information into a coherent representation of the network. Self-tests therefore encourage him to go on studying, without providing him with the means for improving his representation.

II. PASSIVE TRAVEL

The importance of "locomotion" is often stressed in the literature about spatial learning (Siegel & White, 1975).[12] The claim is sometimes made that, for learning to take place, the subject needs to navigate freely in the environment, and choose himself what to do at decision points. We put this notion to a test, by contrasting Normal Travel with a method we called "Passive." Passive differs from Travel in that the subject has no control over the transitions from one intersection to the next. Instead of the interactive situation the Travel mode provides, the subject is now a spectator only.

While the subject cannot choose where to go, he is at least informed of his destination. The dot navigates throughout the network in successive cycles. First, a destination is randomly selected and displayed at the top left corner of the screen, where it remains posted until reached. There follows a 2 secs. delay, and the dot moves one step nearer to the destination, along the shortest route possible. There is another delay, and the dot moves another step. This is continued until the destination is reached. A new destination is then randomly selected, and the next cycle begins. In this way, the subject gets to see the whole network, and efficient routes are constantly demonstrated to him.

METHOD

As was the case with Travel PO, the information was gathered in two experiments. Eleven subjects came from Experiment 3. Fourteen others came from Experiment 5, which afforded us within-subject comparison of Travel and Passive (and Problem-oriented passive as well). The three methods were used in three distinct sessions, and the order was duly counter-balanced.

RESULTS

Reaction Times: The performance is equivalent to that following Travel study. There is no effect of distance on the RT. The values for the four origin-goal distances are, respectively,

7.21 7.67 7.24 7.34 secs. Mean value: 7.36 secs.

The mean value for the 14 subjects of Experiment 5 is 7.59, for Passive, compared to 7.32 secs. for Normal Travel. The difference is not statistically significant.

Error rates: More errors are made following Passive study than after the active, normal Travel study (41% vs. 34%). However, that difference is not significant ($F(1,13) = 3.5$, $p = .1$), with the small number of subjects involved.

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[12] Siegel, A.W. & White, S.H. The development of spatial representations of large-scale environments. In H.W. Reese (Ed.) Advances in Child Development (vol. 10). New York: Academic Press, 1975.

Study Times: The ST were significantly different: 15.3 mins for Passive, and 9.2 mins for Travel ($F(1.13) = 17.79$; $p = .001$).

DISCUSSION

Passive is a poor method for learning a spatial network. It takes longer than normal Travel study, and there are very likely more errors. This means that it is not sheer locomotion which is required for learning. The possibility of freely exploring the network is important. The interactive freedom of Travel could not be replaced by, for example, a movie, and this in turn means that individual study is needed.

However, these conclusions are tempered by another observation. Another feature of Travel is absent in Passive, besides control of the itinerary: the itinerary itself may be such that no subject would have chosen it. For example, some subjects prefer to study the network one region at a time, or go about studying it in some other orderly manner. "Passive" selected its destinations at random, and this may have been the main difficulty of the method. A deliberately chosen itinerary, selected for maximum convenience to the learners, may still turn out to be effective even in Passive mode.

Be this as it may, the deterioration of performance was not a foregone conclusion: subjects were shown a great many optimal routes -- unlike in Travel where they have to work them out themselves. That they could not replicate them during the tests is noteworthy.

F. CONCLUSIONS

1. Results

The results of this first series of experiments clearly establishes the usefulness of our experimental approach to the comparison of map study methods. We obtained reliable differences, which fall in with current ideas about the nature of mental representations of spatial information. Nevertheless, the conclusions are tentative only, having been obtained under laboratory conditions, using very artificial, impoverished stimuli (smallish maps, right-angled intersections and uniform distances).

It was confirmed that the choice of a map study method has important consequences for the quality of subsequent performance, since it determines the organization of the mental representation. Specifically, Map study leads to knowledge of a geometrical shape, with labels associated to its intersections, while Travel produced an integrated knowledge of routes. Subjects were free to study the maps as long as they wanted, and were later asked to demonstrate routes between locations in a simulated environment. The accuracy of the performance is equivalent for the two study methods, but the study time for Map is shorter. The study time for Travel can be significantly shortened by using the Absolute Travel variant, in which the different intersections are identified by their location relative to the map surroundings (e.g., the screen) and not exclusively by their relation to other intersections. By contrast, an attempt to improve the Travel study time by making a map available (Mixed) proved futile.

The reaction time patterns of Travel and Map are different. In Travel, RT are relatively short, and unaffected by the origin-to-goal distance. In Map, RT are increasingly longer for more distant goals. This was interpreted as reflecting the need for planning routes in Map; after Travel study, routes need not be planned, and can simply be retrieved. After the preparation time reflected in RT, the time characteristics of the performance is equivalent for the two methods: latencies at later decision points are shorter than RT, and completely uniform (except for an unexplained drop prior to the last key press). Our subjects demonstrated their knowledge by following routes between pairs of locations, and normally benefitted from feedback on their way, in that they could see the intersections reached during their simulated travels. When the feedback was removed, the error rate increased, as did the RT, and there occurred long pauses in the midst of the "Blind" travel. This indicates that travel normally relies on feedback from the environment.

Adding the possibility of self-test to subjects who studied by the Travel method did not decrease the error rate, but increased the study time. In the Passive Travel method, the subject watches efficient routes being demonstrated in Travel mode. These are shown in a random order and the subject has no control over the routes displayed. Subjects using this method required longer study times, and performed inaccurately.

Overall, study time and error rates are strongly positively correlated. They can be considered as two measures of task difficulty.

As far as individual differences are concerned, we found that there was a slight correlation between study time in Map and in Travel condition, but the accuracy of the performance in one did not predict the accuracy in the other. Further, study time in Travel was uncorrelated with error rate, but there was a reliable correlation between the two in Map condition.

2. Outlook

Recent research by Stasz and Thorndyke (ibid.) indicates that one important difference between good and poor map learners is the conscious use of effective map study technique (such as attention control, partitioning of the task, self-assessment and its exploitation, etc.). These techniques can be taught and they definitely enhance performance. However, not all subjects benefit equally from instruction in map study techniques. Only people with good spatial ability profit. Another series of studies by Goldin and Thorndyke (ibid.) identified the cognitive characteristics of 'good mappers': field independence, and proficiency of visual imagery.

What can be done about people who have to learn maps, but suffer from field dependence and have poor visual imagery? The Travel study method (and its derivatives such as Absolute Travel) is a promising candidate. The method requires no visual imagery, skirts the problems of field-dependence, and produces a mental representation which is functionally equivalent, and in some respects even superior to the representations constructed during conventional map study.

The advantages of the Travel methods are not restricted to those deficient in visual imagery. We saw that they produce different, route-based representations. People possessing this representation are able to start on a route to a distant location as quickly as to a neighbouring one. It is not difficult to think of circumstances in which this ability would be most valuable. In addition, there is reason to expect them to be more accurate when required to point at unseen locations (cf. Thorndyke and Hayes-Roth, ibid.), although this would have to be tested directly.

Finally, it should be stressed that the Travel method does not require a computer, which was used here primarily to assess knowledge. A traditional map, and an opaque sheet fitted with a window are sufficient props for study purposes. The Travel method is fundamentally a method for focusing attention on link patterns, rather than visual configurations.

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