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TNO-report

IZF 1990 B-6

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STRATEGY DIFFERENCES IN MAP INFORMATION USE FOR ROUTE FOLLOWING IN UNFAMILIAR CITIES; IMPLICATIONS FOR IN-CAR NAVIGATION SYSTEMS

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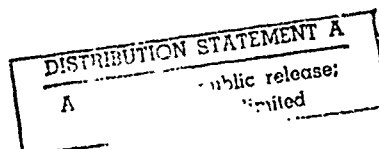
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Title: Strategy differences in map information use
for route following in unfamiliar cities;
implications for in-car navigation systems

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SUMMARY

The present field study was carried out with the aim of gaining more insight into the amount and types of information used by different groups of drivers when navigating in unfamiliar cities. Twenty-four drivers, twelve experienced and twelve inexperienced, twelve male and twelve female, took part in the field study. Subjects had to follow four predetermined routes through a city they were unfamiliar with. Subjects could consult copies of the city street map, of which there were two versions: normal maps, and the same maps containing stickers with names of road signs at particular crossings. Subjects were asked to think aloud while studying maps and while navigating, and their verbalizations were tape recorded. The results showed that subjects mainly used street names, landmarks, and road signs for navigation. Experienced and inexperienced drivers did not differ in the types of information used, nor in the number of navigation errors. Use of the road signs on maps led to fewer navigation errors. Subjects who used mainly street names for wayfinding made more navigation errors and could remember three navigation decisions at most on average.

Strategieverschillen in kaart-informatiegebruik bij het volgen van routes in onbekende steden; implicaties voor navigatie-systemen in auto's

J.M.C. Schraagen

SAMENVATTING

Een veldstudie is uitgevoerd met het doel om meer inzicht te verkrijgen in de hoeveelheid en soort informatie die verschillende groepen automobilisten gebruiken bij het vinden van de weg in onbekende plaatsen. Vierentwintig automobilisten, twaalf ervaren en twaalf onervaren, twaalf mannen en twaalf vrouwen, namen deel aan de veldstudie. Proefpersonen moesten vier van tevoren bepaalde routes volgen in een voor hen onbekende stad. De proefpersonen konden kopieën van de stadsplattegrond raadplegen. Van deze plattegrond werden twee versies gebruikt: de normale, en dezelfde plattegrond waarop stickers met namen van borden op bepaalde kruispunten waren aangebracht. Proefpersonen moesten hardop denken bij het bestuderen van de kaarten en het rijden. Hun verbalisaties werden op band opgenomen. De resultaten lieten zien dat proefpersonen bij het navigeren voornamelijk gebruik maakten van straatnamen, opvallende punten, en borden. Ervaren en onervaren automobilisten verschilden niet in de soort informatie die ze gebruikten, noch in het aantal navigatiefouten. Het gebruik van borden op kaarten leidde tot minder navigatiefouten. Proefpersonen die voornamelijk straatnamen gebruikten maakten meer navigatiefouten en konden gemiddeld ten hoogste drie navigatiebeslissingen onthouden.

1 INTRODUCTION

Finding one's way in an unfamiliar city while driving a car can be a demanding task. Several electronic navigation systems are now available that purportedly make this task less demanding. However, it is critical to ensure that consulting the navigation system does not seriously interfere with the driving task and hence make the navigation task even more demanding than it already is. Therefore, it is important to know the types and amount of information to present to drivers by navigation systems, taking into account the driver's capabilities and limitations.

In this report, we will describe the results of a field study on how drivers find their way in an unfamiliar city. The field study was part of the project 'Generic Intelligent Driver Support Systems' (GIDS), carried out under contract DRIVE V1041 of the European Community. One of the aims of the GIDS-project is to specify the amount and type of information to be presented to the driver by a co-driver system. This serves two goals:

- 1) Prevent information overload
- 2) Flexibly adapt the co-driver system to the driver's needs.

The present field study was carried out with three aims in mind. First, gaining more insight into the types of information used by drivers when navigating in unfamiliar cities. The types of information usually required by drivers should provide a baseline against which to evaluate proposals for electronic navigation systems. A second aim of the present study was to investigate whether different groups of drivers might need different types of information. To this end, we included experienced and inexperienced drivers, and men and women in our study. A third aim of the present study was to specify the amount of information drivers use.

1.1 Previous research

Previous research on navigation systems has mainly focused on the modality of information presentation to the driver (e.g. Varwey & Janssen, 1988; Streeter, Vitello & Wonsiewicz, 1985). For example, it has been found (Streeter, Vitello & Wonsiewicz, 1985) that drivers prefer auditorily presented route guidance messages to maps. It is, however, not clear from these studies why this is so. What we need are studies that first give a detailed account of how drivers navigate

under normal circumstances, then specify a number of general principles that may account for drivers' normal navigation behavior, and only then evaluate different support systems in terms of these general principles.

Research on the type of information used in urban wayfinding was summarized by us in a previous report (Schraagen, 1989). Suffice it to say here that several investigators found that urban travelers typically select salient environmental features to serve as aids in wayfinding activities (e.g. Allen, Siegel & Rosinski, 1978; Carr & Schissler, 1969; Lynch, 1960). Sometimes these salient environmental features act as the choice points of a route, at which navigation decisions are made. The representation of the route in long-term memory is segmented with respect to these choice points (Golledge, Smith, Pellegrino, Doherty & Marshall, 1985). Since there are normally more choice points than can be remembered easily, people divide routes into a small number of parts, based on a hierarchy of road types (e.g. frequently used thoroughfares, or base network, and secondary street system). People relatively unfamiliar with a city will try to get to the base network as quickly as possible and stay on the network as long as possible. When familiarity increases, the road hierarchy flattens, i.e. the secondary street system is used more and more in order to shorten the routes (Chase, 1983; Streeter & Vitello, 1986; Pailhous, 1969; Lynch, 1960). Use of the base network involves an active, attention-demanding planning process, whereas use of the secondary street system involves the recognition of familiar cues from the environment. These cues automatically retrieve the appropriate choice of route from the long-term memory knowledge base.

1.2 Theoretical framework

In our study, we adopted as a framework Kuipers' theory of navigation and mapping in large-scale space (Kuipers & Levitt, 1988; Kuipers, 1982; Kuipers, 1978). Kuipers distinguishes between four types of spatial knowledge:

- 1) Sensorimotor knowledge: The knowledge that supports recognition of landmarks from a strictly egocentric point of view.
- 2) Procedural knowledge: Knowledge of how to find and follow routes, stored in procedures. One may view these procedures as "travel

plans" (Garling, Bask & Lindberg, 1984), hierarchically organized around goals and subgoals.

- 3) Topological knowledge: A description of the environment in terms of fixed entities, such as places, paths, landmarks, and regions, linked by topological relations, such as connectivity, containment, and order. At this level of description, the traveler is able to go beyond strictly egocentric sensorimotor experience. He or she is able to recognize places as being the same, despite different viewpoints; identify places as being on a single path, in a particular order; define boundary regions to the left or right of a path. Using topological knowledge, a driver is able, for instance, to identify a street as being a main street that goes left of the center.
- 4) Metric knowledge: A description of the environment in terms of fixed entities, such as places, paths, landmarks, and regions, linked by metric relations, such as relative distance, relative angle, and absolute angle and distance with respect to a frame of reference. Using metric knowledge, a driver is able, for instance, to infer that place A is south of place B, that a turn should be made with a sharp angle, and that a particular route is two kilometers.

1.3 Individual differences

People may differ in their strategies for wayfinding. There seem to be two distinct 'wayfinding styles': linear and spatial (Passini, 1984; Thorndyke & Goldin, 1983). In the linear wayfinding style, people navigate by using sequences of verbal instructions, often containing landmarks, directional signs, and street names. In the spatial wayfinding style, people use topological and metric knowledge, if available. The different wayfinding styles may also show up in the information people extract from maps, e.g. street names (linear) versus regions (spatial). More attention to spatial information is correlated with better map learning (Thorndyke & Stasz, 1980).

1.4 Field experiment

In order to find out how drivers navigate under "normal" circumstances, and what difficulties they encounter, a field experiment was

conducted in which drivers unfamiliar with a city had to follow several prescribed routes indicated on maps. Since we did not know beforehand what different kinds of information drivers attend to, we opted for the situation where drivers could choose the different kinds of information for themselves. We used maps instead of verbal instructions because maps provide a large amount of different kinds of information and allow for a study of different strategies. We asked subjects to think aloud while studying the maps and while driving, in order to find out what types of information they attended to.

During each route, the following measures were recorded as dependent variable:

- map study time before each route
- number of navigation errors
- number of map consultations during driving
- subjects' verbalizations.

2 METHOD

2.1 Maps

The route guidance while driving was given by either of two versions of a commercially available city street map. Both versions were (black and white) photocopies of part of the (colored) city street map. Black and white photocopies were chosen instead of the colored map, because the route to be followed could more easily be marked with a colored pen on a black and white background. Every care was taken to ensure that the quality of the photocopies was high. Subjects did not report any difficulties with reading the maps. The photocopies (30x42 cm) were mounted on white 50x32 cm cardboards. One version simply consisted of the photocopied street map, with the particular route to be followed indicated with a yellow marker pen (see Appendix A). The other version was identical to the first with the following important addition (see Appendix B). At points where subjects had to change direction, a small (0.8x1.5 cm) sticker was pasted onto the map. On the sticker, a name was printed. This name corresponded with a name on a road sign that could be seen from the car at the particular choice point. If there were more names on the road sign, the topmost name was always chosen for the sticker. Not at every choice point a road sign was placed, so the number of stickers was smaller than the number of choice points. Since the names on the road sign corresponded to a

particular direction (e.g. a sign pointing to the left with the name "Soest"), the stickers on the map effectively indicated the direction to be taken by the subject.

2.2 Procedure

Prior to the experiment, subjects had to complete a questionnaire concerning self-appraisal of navigational ability, map experience, and navigational habits and preferences. Questions from this questionnaire were partly taken from Streeter and Vitello (1986).

Subjects were next familiarized with the car, a Volvo 240 station car with no special equipment attached to it, and subsequently drove from the institute to a parking place just outside Amersfoort. This took about 10 minutes and allowed subjects to get used to the car.

At the parking place, the experimenter read the instructions to the subject. Subjects were told that they had to follow particular routes selected by the experimenter. In order to follow the routes, they had to study a map beforehand. Map study time was recorded with a stopwatch. After having studied the map, subjects had to hand over the map to the experimenter and start driving. Subjects were told that they would not receive any help from the experimenter after having handed over the map. In case they made any navigation error, the experimenter would tell them as soon as possible, and would help them get back to the point where they had made the navigation error.

Subjects were allowed to consult the map again if they had forgotten the route. For safety reasons, they were not allowed to read the map while driving. Additional inspection of the map therefore required the car to be stopped.

Subjects were instructed to drive as they normally would when finding their way in an unfamiliar city. The experimenter emphasized that speed of driving was not important. Subjects were told that the first route was a practice route.

Subjects were also instructed to think aloud while driving. The instructions were taken from Ericsson and Simon (1984, p.376), with slight modifications. The exact instructions ran as follows:

"Please think aloud while driving. What I mean by think aloud is that I want you to say out loud everything that you say to yourself silently. Just act as if you are alone in the car speaking to yourself. If you are silent for any length of time the experimenter will remind you to keep talking aloud."

The verbal protocols were recorded with a cassette recorder. A microphone was attached to the subject's collar.

In the condition with signs on the map, the instructions were identical to those mentioned above. In addition, the experimenter explained to the subject how to use the signs on the map. The subject was also told that the names on the stickers were specifically designed for helping the subjects reach their destination.

After the subject indicated to have understood the instructions, the subject was given the first map and asked to think aloud while studying the map. The subject subsequently drove to the destination.

After two experimental routes, there was a coffee break of approximately 20 minutes. The total experiment lasted about 3.5 hours.

2.3 Routes

All routes were situated in an urban area of the medium-sized Dutch city of Amersfoort (approx. 100,000 inhabitants). Prior to driving the experimental routes, subjects were familiarized with the procedure by driving a 4.1 km long practice route with the aid of one of the two versions of the map.

There were four experimental routes (see Appendix C). Route I was 3.6 km long and contained eight decision points (relevant intersections), three of which could be indicated by stickers; Route II was 4.9 km long and contained nine decision points, six of which could be indicated by stickers; Route III was 5.1 km long and contained 10 decision points, 4 of which could be indicated by stickers; Route IV was 6.0 km long and contained 14 decision points, 7 of which could be indicated by stickers.

All experimental routes consisted of a mixture of road types. Mostly, the routes started in a residential area, then led to major urban roads, and ended in a residential area again. In the practice route

and in one experimental route, a stretch of highway was included. The end point of one route was the beginning point of the next route.

If driven flawlessly, i.e. without navigation errors, route I took about six minutes to drive, routes II and III took about 10 minutes to drive, and route IV took about 13 minutes to drive.

2.4 Subjects

Twenty-four subjects participated in the experiment, half of them male and half of them female. Male subjects ranged in age from 20 to 41, and the female subjects ranged in age from 19 to 47. The women had a yearly kilometrage of 6,400 km, while the men had a yearly kilometrage of 11,300 km. The women were on average 30 years old, the men 26 years old. Subjects were recruited by an advertisement in a local newspaper. They had no knowledge of the area where the experiment took place. Half of the male and the female subjects were experienced drivers, the other half were inexperienced drivers.

Experienced drivers were defined as follows:

- 1) one to five years driver's licence *and* more than 100,000 kilometers driven in total

or

- 2) more than five years driver's licence *and* more than 10,000 kilometers a year.

Everyone else was defined as an inexperienced driver.

On average, the experienced drivers drove 12,500 km a year, while the inexperienced drivers drove 5,200 km a year.

All subjects had normal or corrected to normal visual acuity and reported to have had no prior experience with any experiment of this kind. The subjects were paid Dfl. 50,- for their participation.

2.5 Design

Driving experience (experienced, inexperienced), sex (male, female), and time of the day (9.30h.-12.30h., 14.00h.-17.00h.) were between-

subject factors, whereas map version (with signs, without signs), and route (I, II, III, IV) were within-subject factors. Time of the day was varied in order to include possible traffic density effects (Verwey & Janssen, 1988). Each of the eight between subject conditions contained three subjects. Map version was counterbalanced across subjects.

3 RESULTS

The answers on the questionnaires are reported in Appendix D. Below, we will report the significant effects on the number of navigation errors.

3.1 Navigation errors in driving

The data were analyzed using SYSTAT (Wilkinson, 1988). A three-way ANOVA was used, with driving experience, time of the day, and sex as between-subject factors, and route and map version as repeated measures. There was no order effect of map version on any of the dependent measures. In all analyses, p-values below 0.05 are considered to be significant, whereas values between 0.05 and 0.10 are considered to be marginally significant. Values up to 0.10 are also taken into consideration because in field experiments like the current one much noise is introduced by uncontrollable factors like traffic density, weather conditions and diversions.

The average number of navigation errors across the four routes was 1.6 for males, and 2.4 for females. This was a marginally significant difference, $F(1,8)=4.68$, $p<0.10$. The effect of sex remained significant, even when age and yearly kilometrage were controlled for, $F(1,21)=3.28$, $p<0.10$ and $F(1,21)=4.87$, $p<0.05$, respectively.

Driving experience did not have a significant effect on the number of navigation errors, $F(1,8)<1$. In an unfamiliar environment, a large driving experience does not seem to benefit navigation performance.

The number of navigation errors in the no sign condition (averaged over two routes) was 4.3, and 3.6 in the sign condition. This difference was marginally significant by a Wilcoxon test, $p<0.10$. Hence, subjects were aided by the inclusion of road signs on maps.

1) street names:	51%
2) road signs:	11%
3) landmarks:	12%
4) topological knowledge:	23%
5) metric knowledge:	3%

Thus, when studying maps in order to follow a route, subjects formed a travel plan mainly consisting of street names and associated actions.

3.2.2 Information attended to during driving

During driving, the information attended to did not differ much from that which was encoded from the map before driving:

1) street names:	42%
2) road signs:	14%
3) landmarks:	15%
4) topological knowledge:	25%
5) metric knowledge:	4%

There was a strong relationship between the type of information used during driving and the number of navigation errors. If we subtract, for each subject, the number of street names from the sum of the four other categories, we end up with a score indicating the relative emphasis put on the other categories, such as topological and metric knowledge. This score has a high negative ($r = -0.61$, $p < 0.001$) correlation with the number of navigation errors. Thus, the more subjects attended to items other than street names, the fewer navigation errors they made. A more elaborate representation of the route seems to lead to more robust navigation performance, since whenever one type of information is forgotten or cannot be found in the environment, another type of information may be retrieved from memory.

If we enter this score as a covariate in a separate ANOVA, the main effect of sex on number of navigation errors disappears, $F(1,21) = 1.02$, $p > 0.10$. This means that the effect of sex was mainly due to differences in the information attended to. Women used street names more exclusively, while men focused more on landmarks and road signs, and used topological and metric knowledge to a larger extent.

3.2.3 Individual differences: "Good/Poor" navigators

In order to look at individual differences, "good navigators" were compared with "poor navigators". The top eight navigators made 4.5 navigation errors on average, the bottom eight 12.5. This cannot be attributed to differences in map study times (2.38 min versus 2.06

A more precise analysis than looking at the overall number of navigation errors is to look at the number of subjects making a navigation error at those intersections only where stickers of road signs could actually be used. The analysis was carried out over 14 intersections. Without signs, 3.7 subjects on average made a navigation error on those intersections. With signs, only 1.8 subjects made a navigation error. This difference was marginally significant by Mann-Whitney U-test, $p < 0.10$. The intersections where the signs helped the most were either highly complex or difficult to see from a distance. Complex intersections consisted of four or more non-perpendicular roads, where ordinary left-right instructions would be ambiguous. In this case, signs helped greatly to disambiguate the intersection. Where roads were difficult to see from a distance, signs helped the driver to anticipate.

3.2 Verbal protocols

The verbal protocols were literally transcribed. Partly based on Kuipers' theory, five categories were distinguished:

- 1) street names
- 2) road signs
- 3) landmarks (e.g. school, church, railroad)
- 4) topological knowledge
- 5) metric knowledge.

All the relevant terms that subjects mentioned were put into one of these five categories. In this way, a reference list resulted with 81 street names, 17 road signs, 25 landmarks, 62 topological knowledge items (e.g. road characteristics, road types, counting streets, recognition of places from various angles), and 21 metric knowledge items (e.g. compass directions, distance, angle). A computer program was written that compared the subject's verbalizations (stored in ASCII format) with this reference list. For this purpose, the four routes were considered as replications and taken together.

A distinction was made between the phases of map studying and driving. Separate analyses were carried out for these two phases. In this way, we could determine the relative emphasis a subject put on the various categories.

3.2.1 Map studying

The distribution of the subjects' verbalizations during map studying across the different types of knowledge was as follows:

min, $p > 0.10$ by Mann-Whitney U-test), but could be attributed to the different way of looking at maps by males and females: the top eight were 4 men and 4 women, the bottom eight 1 man and 7 women.

The difference between good and poor navigators could largely be attributed to the greater attention of the poor navigators to street names (51% versus 36%, $p < 0.05$ by Mann-Whitney U-test), mainly at the cost of attention to topological characteristics (21% versus 27%, although this difference failed to reach significance). Again this fits well with a corresponding difference in map study behavior. The poor navigators looked more at street names (57% versus 46%, $p < 0.05$ by Mann-Whitney U-test), again at the cost of attention to topological characteristics (18% versus 27%, $p < 0.05$ by Mann-Whitney U-test).

In order to look more closely at the causes of navigation errors, three types of navigation errors were distinguished:

- a) errors due to insufficient map inspection (this could very often be determined from the subjects' own verbalizations during driving, e.g.: "I must have overlooked that on the map")
- b) errors due to memory failures (forgetting of parts of the route to be driven, e.g. "I can't remember whether it was left or right")
- c) errors due to insufficient visibility of the environment (in this case, subjects actively searched for the correct landmark or sign or intersection, but could not find these).

Each navigation error was assigned to one of the three types.

The distribution of errors across these three categories for the two groups is shown in Table I.

Table I Distribution of errors across three categories for good and poor navigators.

	Map reading	Memory	Environment
Good	2.4	0.2	1.7
Poor	2.6	8.3	1.9

An interesting aspect is that the difference in type of navigation error between good and poor navigators only lies in memory failures, and not in map reading errors or errors caused by the environment.

Thus, the top navigators memorized well, the poor ones admitted that they had forgotten the relevant information.

Correspondingly poor navigators consulted maps during driving twice as often as good navigators (9 versus 3.9, $p < 0.01$ by Mann-Whitney U-test). On average, the poor navigators consulted the map after 3.1 correct navigation decisions, versus 6.5 for the top ones ($p < 0.001$ by Mann-Whitney U-test).

4 DISCUSSION

4.1 Summary of main results

Our main findings were:

- 1) Females do worse than males since they focus on street names exclusively.
- 2) Use of road signs at complex intersections leads to fewer navigation errors.
- 3) Poor navigators (mostly females) fail in particular because they cannot memorize more than three items.
- 4) Driving experience does not matter for navigation.

4.2 Interpretation

The relative emphasis on topological and metric knowledge of good navigators should not obscure the fact that, overall, subjects attend to street names, landmarks, and road signs the most before, during, and after driving. Apparently, it is difficult for subjects to use topological and metric knowledge derived from maps in unfamiliar environments. Thorndyke and Stasz (1980) also showed that virtually all of their subjects learned more linear (verbal) than spatial information on the maps. However, despite their frequent use of street names, subjects may differ in the way they use street names during wayfinding. From the protocols it seemed that the good navigators used street names as reassurance signs: they searched for them actively, but were not lost whenever they could not find them or did not recognize them. Some good navigators reported that they always looked at street names on maps, not so much to use them to navigate, but rather to be able to recognize them whenever they encountered them. Poor navigators, on the other hand, relied more exclusively on linear

sequences of street names for wayfinding. Whenever they forgot a name, they were either lost or anticipated a decision point later on in the route, as if a chunk of knowledge had disappeared from their travel plans.

This difference between subjects leads us to suspect that two different wayfinding styles or strategies may be distinguished:

- 1) Linear: in this strategy, subjects heavily depend on sequences of verbal instructions that they try to remember. Because of working memory limitations, subjects often forget instructions. This may lead to a navigation error, unless the subject recognizes a landmark or street name from the map. Poor navigators' navigation errors could largely be attributed to memory failures, whereas almost none of the good navigators' errors could be attributed to memory failures.
- 2) Spatial: in this strategy, subjects used topological and metric knowledge added on to procedural knowledge. We suspect that working memory limitations are partly overcome by a process of chunking. This chunking process recodes several simple left-right instructions into one higher-order unit. The higher-order unit is a piece of topological or metric knowledge. For instance, a left-right-left sequence may be recoded into "a Z-turn", and a left-right-right-right sequence may be recoded into "a circle". These sequences are only recoded when they follow one another closely. Sequences that are farther apart form different units. The chunking process is not based on driving experience. At present, we are unsure what type of experience underlies this process.

The spatial strategy led to more successful navigation. This is in line with previous results by Thorndyke and Stasz (1980) who found that the best map learners were those who employed spatial learning strategies when memorizing the map. Thorndyke and Goldin (1983) demonstrated that good map learners also had superior visual-memory ability.

The good navigators' performance probably cannot be explained solely by a chunking hypothesis. Good navigators also used a richer representation of the environment: they noted how roads winded, how sharp turns were, whether they should have the hospital to the left or right of them, whether they should take the first, second, or third to the left, what the general direction was (e.g. "in the direction of the

center"). They also used general knowledge, such as that the city hall is always in the center (following a sign "city hall" will thus lead you to the center), and that indications of regions on the map (e.g. "Bergkwartier") will probably not be indicated on signs in reality. In general, then, good navigators extracted more different types of information from the maps than the poor navigators. This helped them to navigate, since whenever one piece of information was forgotten, another piece of information could be recalled that was useful for making the correct decision.

4.3 Recommendations for navigation systems

Our main purpose with this study was to investigate the types and amount of navigation information used by different groups of drivers in order to adapt the information presented by navigation systems to the driver's capabilities and limitations. Present navigation systems sometimes uncritically present one type of information only, for example maps or left-right instructions, often without taking into account the existing infrastructure, such as road signs and landmarks. On the basis of our field study, we are now in a position to make a number of recommendations concerning the contents, timing, and number of messages to be presented by navigation systems.

4.3.1 Contents of messages

Subjects unfamiliar with the route they have to travel mainly use street names, landmarks, and road signs. Of these, subjects prefer landmarks (see Appendix D). Landmarks can indeed be useful for way-finding, provided they are presented in such a way that subjects can actually recognize them in the environment. A church that does not look like a prototypical church will not be recognized by drivers if it is just described as "church". It should at least be described as "modern-looking church", or a picture of the building should be displayed.

Street names should be presented thoughtfully, since they are often hardly visible from the road, only visible from one direction, or absent altogether. Street names are primarily identification signs, and should preferably not be used as direction signs. Our proposal would be to use street names mainly in the starting and destination zones, where drivers often drive slower, so that they can spend some time looking for street signs.

Road signs are very useful for navigational purposes. In our experiment, they often served to make complex decision points simpler, or could be used to anticipate junctions that were only visible from short distances. Road signs are often illuminated at night, so that they remain visible, in contrast to street names and (some) landmarks. Road signs already contain a direction within them, often an arrow pointing a certain direction, so drivers do not need to remember the direction, only the name on the sign. Road signs are mostly placed on main roads, where, in our experiment, most navigation errors were made.

Besides street names, landmarks, and road signs, one could provide topological and metric knowledge to the driver. This could take the form of a stylized map, with only the main roads indicated, the shape of the roads, etc. Compass directions were generally viewed by the subjects as least useful and should probably not be used at all. In North-American cities, with a grid pattern, and street names that use compass directions (e.g. "East 32nd St."), drivers may be more accustomed to compass directions, although King and Lunenfeld's (1974) study showed North Americans judged route names and compass directions the information types of least importance.

One should be aware of individual strategies in wayfinding. Subjects who tend to use linear strategies may have difficulty using maps, as indicated by this experiment. Since this difficulty is mainly one of extracting extra information, one could provide this information to ensure redundancy. Use of several types of information led to fewer navigation errors in our experiment.

A frequently employed strategy is to divide the route into different parts, using knowledge of a hierarchy of road types. One may distinguish three parts:

- 1) Roads within the starting zone, leading to the main roads
- 2) Main roads, where a limited number of navigation decisions have to be made, and that lead one to the destination zone
- 3) Roads within the destination zone.

Different kinds of information are suitable for each part:

- 1) Within the starting zone, street names and left-right instructions may be used.
- 2) On main roads, road signs and a stylized map may be used, with landmarks added on as much as possible; the exit from the main road into the destination zone should be clearly indicated.

- 3) Within the destination zone. street names and left-right instructions may again be used.

4.3.2 Timing and number of messages

When should messages be presented to drivers? Although this study was not explicitly concerned with this question, we may nevertheless make some comments relevant to this question. Generally, drivers should be able to anticipate changes of direction, instead of getting instructions at the last moment. Anticipation means smoother driving, and a better ability to attend to other traffic. On the other hand, giving instructions a long time before they actually have to be carried out, increases the driver's memory load and hence the chance of forgetting the instructions. Therefore, the number of messages to be presented is another important question, related to the timing of messages.

In our experiment, the poor navigators often forgot navigation decisions, while the good navigators anticipated decisions long before they actually had to be made. The poor navigators' forgetting may have been due to their inability to store information derived from maps. However, even the poor navigators were on average able to remember three decisions in a row, given some study time.

We would therefore make the following recommendations:

- a) The route should be divided into three or four different parts, depending on the types of roads involved. We distinguish starting and destination zones, and main roads leading to or from those zones.
- b) The amount of information to be presented should preferably not exceed three instructions in starting and destination zones, and should be limited to one instruction on main roads. Because of the longer time span on main roads, more than one instruction is not functional. With one instruction, drivers will have enough time to anticipate. In starting and destination zones, however, one could resort to short sequences of e.g. "left-right-left", in order to enhance anticipation.
- c) On main roads, when using road signs for navigational purposes, the next information should be presented as soon as a navigation decision has been made. In this way, the navigation system acts as the driver's long-term memory. In our experiment, we observed that drivers retrieved the next decision from long-term memory as soon

as the previous one was effected. On highways, information should be presented as soon as the driver can discern a road sign. Under normal conditions (no turns in the road, no mist, no trees obstructing the view, etc.), drivers can see a road sign coming up in front of them at least 1000-1500 m away. On Dutch highways, where the first signs are usually put 1200 m before the actual exit, the driver should be notified 2200-2700 m before the first sign.

5 CONCLUSIONS

One of the aims of the GIDS-project is to prevent information overload in future cars. Navigation information is only one type of information a driver is confronted with. There are also the car telephone, information that the car needs gas and where this can be obtained, a signal that someone crosses the road, a signal that the car in front comes dangerously close, etc. In the GIDS-project, a "dialogue controller" selects what information should be presented to the driver in specific circumstances. Whenever navigation information is suppressed by the dialogue controller in favor of other information, the driver should still be able to make the correct navigation decision. This is possible if the driver has received this information sufficiently in advance, and can remember this information. We have concluded that, on main roads, one piece of navigation information can be presented as soon as the previous navigation decision has been taken. On secondary roads, at most three navigation instructions should be presented at one time. The number three may have to be reduced to one in adverse traffic situations. Ideally, the information should remain displayed all the time in the same location, to be used as a backup whenever the driver forgets it.

A second aim of the GIDS-project is to flexibly adapt the co-driver system to the driver's needs. We concluded that drivers of varying driving experience do not have different needs as far as navigation information is concerned. What is important, however, is the particular wayfinding strategy drivers use, given a variety of different types of information. By this we mean that some drivers have general procedures for extracting topological and metric information from maps, whereas others do not have these procedures and stick to procedural information. A co-driver system should support the most effective strategy. Clearly, the most effective strategy is to attend

to several types of information at the same time. This can only be accomplished if the system provides more than just street names or left-right instructions. For main roads, the system may provide high-level maps with an indication of road characteristics. By "high-level maps" we mean maps stripped of all secondary roads, with the route to be followed set apart from the other roads, by using highlighting or different coloring, or even by eliminating all other roads except for the one to be followed.

Co-driver systems will fail if they do little more than mimic maps, at 1,000 times map price (Petchenik, 1989). Maps are application-neutral, but our co-driver system should show the route to be followed clearly apart from the other routes. Maps do not provide explicit guides to action. We observed in our experiment that most drivers used maps to extract street names, landmarks and road signs (when explicitly provided in the sign condition). This also applied to drivers with a spatial strategy. They only extracted extra information from the map in order to be able to better recognize where a particular action should be taken. Therefore, an electronic map should not be the primary mode of display, but only an additional source of information, to be consulted whenever drivers feel they need it. Drivers should be able to switch between linear and spatial modes. In linear mode, the system should present a set of verbal instructions, such as: "Turn right", or "Follow signs with direction Amsterdam", or "Turn left at hospital".

With these conclusions, we have indicated, in a general sense, how the aims of GIDS are met. What needs to be accomplished next, is evaluate a prototype navigation system based on our recommendations. What we plan to look at in particular is whether the use of existing road signs does indeed support the driver's need for anticipation and unambiguous information.

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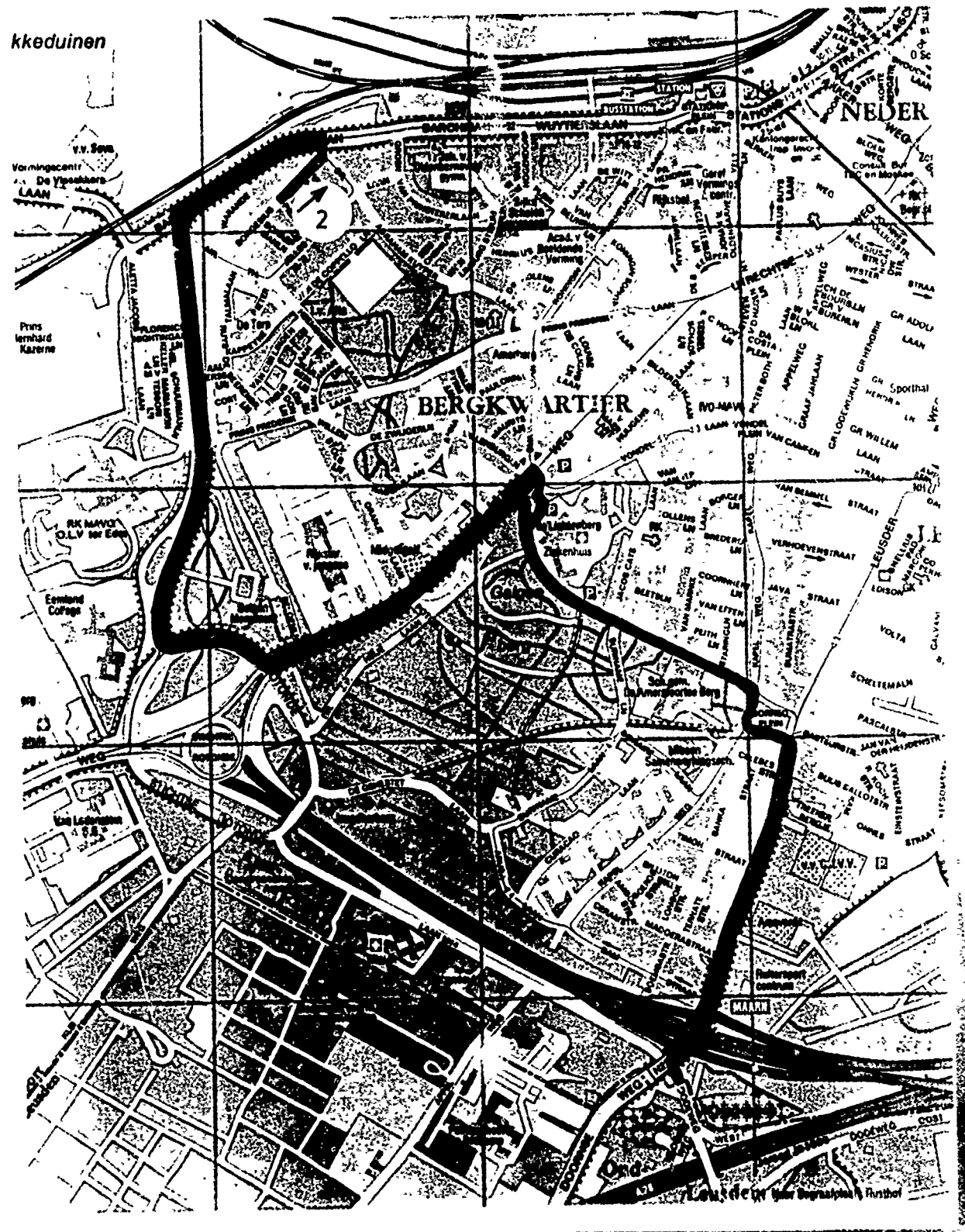
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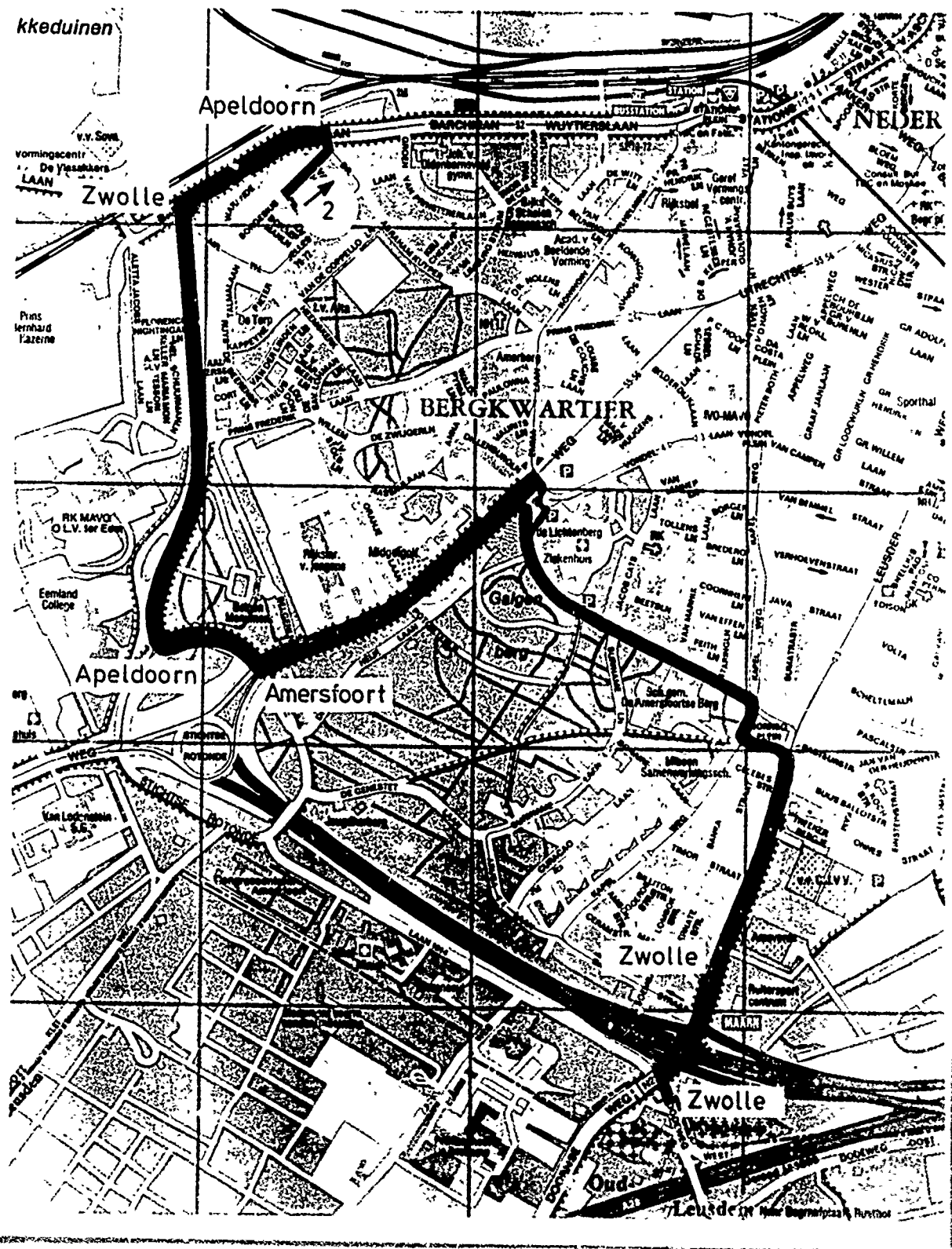
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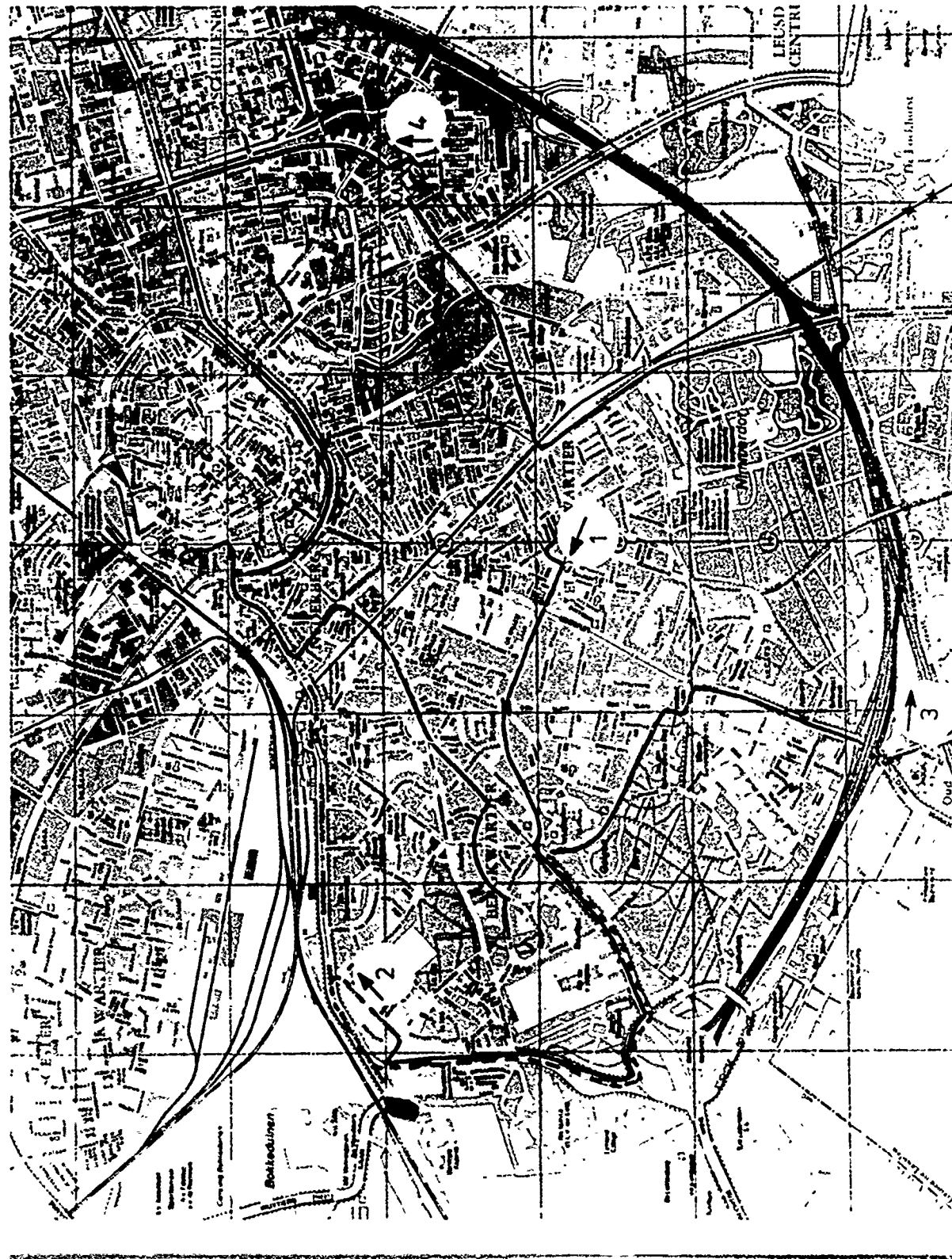
APPENDIX A Version of map without stickers



APPENDIX B Version of map with stickers



APPENDIX C Experimental routes



APPENDIX D Answers on questionnaires

Self-appraisal of navigational ability

On a scale from 1 to 7, the average subjective rating was 4.9. This corresponds to a "fairly good" navigational ability. The average rating for males was 5.2, that for females 4.5. This difference was statistically significant, $t(22)=3.15$, $p<0.01$. The Pearson correlation between navigational ability and number of navigation errors was very small: $r=-0.19$. This is in accordance with results reported by Kozlowski and Bryant (1977), that a good "sense of direction", assessed in ways similar to ours, was only predictive in familiar environments, and not in unfamiliar environments.

Map experience questionnaire

In this questionnaire, subjects were asked to indicate how often they used various types of maps. The median score on this questionnaire was 2, corresponding to the scale description of "less than once a month". Category 6, the highest category, was described as "almost every day", and Category 1, the lowest, as "seldom or never". There were no significant effects of sex and experience on map experience. The Pearson correlation between map experience and number of navigation errors was virtually absent, $r=0.08$.

Navigational habits and preferences

Subjects were asked what information they preferred when giving or when receiving directions. The four major types of information mentioned were:

- 1) clearly recognizable landmarks along the way (57%)
- 2) left-right instructions (19%)
- 3) road characteristics (13%)
- 4) street names/signs (11%)

Subjects also rated 17 items in terms of their usefulness for wayfinding in unfamiliar cities. Scales ranged from one to seven. The items considered most useful were rail roads (6.5), churches (6.4), bridges (6.4), hospitals (6.3), maps (6.3), traffic lights (6.2), and road signs (6.0). Items considered least useful were compass directions (2.4), doctors' offices (3.0), and neighborhoods (4.0).

The 17 items were classified into 4 categories by the experimenter:

- 1) near landmarks: landmarks not easily seen from a distance, hence not very useful for anticipation (e.g. house, doctor's office, factory, street names). These were the landmarks preferred by

subjects with low spatial ability in Streeter and Vitello's (1986) study;

- 2) far landmarks: landmark easily seen from a distance (e.g. church, railroad, river, bridge, traffic lights, traffic signs);
- 3) topological items: road characteristics and boundary relations (e.g. intersection, main road, neighborhood);
- 4) metric items: compass directions and maps.

Inexperienced drivers rated near landmarks significantly higher than experienced drivers, $t(22)=2.52$, $p<0.05$. Males rated metric items significantly higher than females, $t(22)=2.58$, $p<0.05$. There were no significant effects of driving experience and sex on appreciation of far landmarks and topological items.

As part of the questionnaire, subjects were asked what they would do first when they lost their way. Fifty-three percent of the subjects answered they would consult a map and solve the problem themselves, 27% would ask someone else for directions, and 20% would continue driving until they seemed to be at the right track again. There were no significant differences between males and females, $\chi^2(2)=4.04$, $p>0.10$, nor between experienced and inexperienced drivers, $\chi^2(2)=1.63$, $p>0.10$, on the different actions, although there was a tendency for males to continue driving and for females to ask someone else.

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