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Spatial Descriptions as Navigational Aids: A Cognitive Analysis of Route Directions*

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Wegauskünfte als Navigationshilfen – eine kognitive Analyse

Zusammenfassung. Die Analyse von Wegauskünften gibt wertvolle Hinweise zur Untersuchung der Zusammenhänge zwischen Sprache und Raumkognition. Diese Forschungsrichtung untersucht das theoretisch wichtige Zusammenspiel zwischen verschiedenen Systemen kognitiver Repräsentation mit unterschiedlichen funktionalen Eigenschaften. Zudem bietet dieser Bereich eine einzigartige Chance für kooperative Forschung seitens der Psychologie, Linguistik, Informatik und Mensch-Computer-Interaktion, um durch ein tieferes Verständnis der kognitiven Prozesse zum Entwurf besserer Navigationssysteme beizutragen, die den kognitiven Fähigkeiten ihrer Benutzer angepaßt sind. Der Beitrag skizziert die kognitiven Prozesse beim Zustandekommen von Wegauskünften und identifiziert invariante Merkmale von Wegbeschreibungen in der Vielfalt protokollierter individueller Äußerungen. In natürlicher Umgebung gesammelte Daten wurden analysiert und zur Erstellung von „Skelettbeschreibungen" genutzt, die nur das enthalten, was zur Navigation entlang einer Route nötig ist. Der funktionelle Wert dieser Beschreibungen wurde gemäß ihrer Brauchbarkeit zur Navigation in unbekannten Umgebungen ermittelt.

Summary. The analysis of route directions provides a relevant context for the study of relationships between language and spatial cognition. This research examines the theoretical issue of the cooperation between differing cognitive representational systems possessing contrasting functional properties. In addition, this research domain offers a unique opportunity for psychology, linguistics, computer science, and human-machine communication to work together, thereby contributing to the understanding of cognitive processes and improving the design of navigational systems adjusted to the cognitive capacities of their users. This paper outlines the cognitive operations involved in producing route directions and identifies certain invariant features of route descriptions beyond the diversity of individual protocols. Data collected in natural environments were analyzed and used to construct "skeletal descriptions" that reflected the essentials needed for navigating along a route. The functional value of these descriptions was assessed by their ability to guide navigation in unfamiliar environments.

The development of theories on mental models, and more specifically spatial mental models, was most likely the stimulus for psychologists' recognition of the close connections between language and spatial cognition. These relationships between language and spatial cognition are not immediately obvious. After all, the task of speaking and that of moving in an environment seem quite different, presumably requiring different cognitive resources. However, because spatial information can be communicated verbally, the study of spatial cognition must include the investigation of the ways in which people exchange information about space, in particular regarding information on how to navigate in unfamiliar environments.

Concentrating on the role of language does not mean that we ignore other significant factors participating in the acquisition of spatial knowledge. Human beings first acquire spatial knowledge through perceptual and navigational experience (e.g., Cornell, Heth, & Alberts, 1994; Golledge, Klatzky, & Loomis, 1996). They also learn from symbolic information in maps (e.g., Kulhavy, Stock, Verdi, Rittschof, & Savenye, 1993; Thorndyke & Hayes-Roth, 1982). It is only in very recent years that the investigation of language as a means of acquiring

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and externalizing spatial knowledge has become the object of specific research programs in cognitive psychology (e.g., Daniel, Carité, & Denis, 1996; de Vega, 1995; Landau & Jackendoff, 1993; Tversky, 1991).

The relationships between language and space have been considered by linguists, who focused on understanding the use of locative prepositions and deictic expressions (cf. Herskovits, 1986; Klein, 1982). Other approaches have concentrated on modelling the social interactions in spatial dialogues and accounting for the pragmatic components of situations involving direction-giving questions (cf. Golding, Graesser, & Hauselt, 1996; Wunderlich & Reinelt, 1982). Computational models of spatial knowledge have also been developed, some of which are based on the concepts of cognitive psychology, such as the "cognitive map" metaphor, others based on the concepts of neuroscience, such as the distinction between "what" and "where" systems (e.g., Chown, Kaplan, & Kortenkamp, 1995; Gopal & Smith, 1990; Habel, 1987; Kuipers, 1978). These models rely on tools of formal logic for spatial reasoning, and some of them have been developed to serve as resources for designing human-machine communication systems. A prerequisite for the design of navigational aids and systems that are adjusted to the cognitive capacities of ordinary users is a detailed analysis of cognitive processes (cf. Briffault & Denis, 1996; Gapp & Maass, 1994; Streeter, Vitello, & Wonsiewicz, 1985). Thus, the construction of such systems presents a challenge for both computer science and cognitive psychology.

The present article concentrates on a specific subset of spatial discourse: the description of routes (or route directions). An interesting feature of this form of spatial discourse is that it is not aimed simply at conveying descriptive information about static environments. It is intended mainly to elicit navigational behavior, i.e. to help a user reach intended points in an unfamiliar environment safely and speedily. The intrinsic connection between this form of discourse and action is a relevant feature for psychologists inasmuch as their approach to cognition is essentially based on behavioral attestations of internal processes. It is also useful to consider route descriptions attentively because of the considerable variety of output produced by people trying to give navigational assistance. Consequently research needs to delineate the invariant features that lie buried in the diversity of individual descriptive protocols.

A general theoretical issue guides our investigation in this domain. This is our need to understand the way in which cognitive representational systems with highly differentiated functional properties actually cooperate. Language generates linear, one-dimensional output, whereas cognitive maps reflect entities that extend over several dimensions and are thought to preserve multidimensional properties. A major challenge for cognitive science is to account for the mechanisms that govern the interactions between the two modules of the cognitive architecture, language and visuo-spatial cognition (cf. Bloom, Peterson, Nadel, & Garrett, 1996; Bryant, 1997; Landau & Jackendoff, 1993).

Table 1. An example of (fictive) navigational instructions

"Proceed 15 meters; stop; rotate 90 degrees to the right; proceed 25 meters; stop; rotate 45 degrees to the left; proceed 20 meters. You are here."

Table 2. Percentages with which each class of items was used to describe three routes on the Orsay campus (Route 1, from the train station to the dorms; Route 2, from the dorms to the Presidential Building; Route 3, from the Technology Institute to the Supélec restaurant)

	Route 1	Route 2	Route 3
Class 1: Prescribing Action	14.1	19.6	16.4
Class 2: Prescribing Action with Reference to Landmark	35.0	32.1	40.8
Class 3: Introducing Landmark	39.7	32.4	27.6
Class 4: Describing Landmark	9.8	12.8	12.6
Class 5: Commentaries	1.3	3.2	2.6

1 Some specific features of route directions

While there are many forms of spatial discourse, route directions are specific because of their unique combination of four features: their purpose (or function), their content (a composite of several types of discourse), their structure (matched to the structure of the objects they describe), and the perspective they impose on their users (an egocentric perspective).

The primary purpose of route directions is to *elicit actions*, so that a mover is brought from a starting point to a destination that he/she intended to reach in an environment. For this reason, route directions clearly belong to the class of *procedural discourse*, and are thus expected to include a large number of instructions, such as "*Go straight*", "*Turn right*", etc. Route directions prescribe two basic sets of actions, progression (to reduce the distance between the current position of the mover and his/her destination) and reorientation (to reduce the angular disparity between the direction of progression and the direction of the destination as the crow flies).

Corpus analysis indicates that route directions include many instances of these two basic instructions, but the situation is somewhat more complex. Consider the navigational instructions shown in Table 1. These instructions are very precise and would probably prove to be highly efficient for guiding a robot or a person with no perceptual access to the surrounding environment. The most remarkable feature of this sort of discourse is that it is *never* produced by any sensible speaker in natural communication. Even the most concise instructional messages refer to landmarks and include a substantial descriptive element. These references are intended to serve several purposes, such as signaling the points along the route where significant actions (in particular, reorientations) should be executed, or describing the visual cues that the movers will encounter (thus providing them with the opportunity of checking that their current orientation is correct).

The importance of *landmarks* in route descriptions is well documented (e.g., Denis, 1997; Galea & Kimura, 1993; Klein, 1982). Table 2 shows data based on the analysis of descriptions of three routes that cross the Orsay campus. These descriptions were given by students familiar with this environment and collected in two independent studies. Routes 1 and 2 were described orally by the subjects, and Route 3 was in written form. The analysis was based on transformations of respondents' original linguistic expressions into minimal propositional units which combined a predicate and either one or two arguments. The propositions were divided into five classes. Class 1 included propositions prescribing an action without referring to a landmark ("*Go straight*"). Class 2 propositions contained an action associated with a landmark ("*Cross the parking lot*"). Class 3 propositions introduced a landmark without referring to an action ("*There is a bridge*"): they might also locate hit with reference to another landmark ("*The bridge passes over a river*") or with reference to the mover ("*There is a road in front of you*"). Class 4 propositions described non-spatial properties of landmarks ("*The bridge is made of wood*"). Class 5 contained commentaries ("*You can't miss it*"). As Table 2 shows, the proportions of items used varied only slightly from route to route. The most noticeable feature is the particular importance given to landmarks in route descriptions. The cognitive prominence of landmarks was confirmed by the fact that the items of Classes 2, 3, and 4 (which all relate to landmark location or description) accounted for 80% of the total number of items. This strongly suggests that landmarks play an important role in the guiding of actions. Their relevance for navigation is also indicated by the fact that most computational models of spatial knowledge and reasoning incorporate landmarks into "local views", these being the successive vantage points of the mover during his/her progression (cf. Chown et al., 1995; Kuipers, 1978).

The structure of route descriptions differs in another remarkable way from other types of spatial discourse. As has been long recognized, one of the major problems in spatial discourse is providing an appropriate *linear organization* to a set of data which extends over two or three dimensions. This situation forces speakers (or writers) to make choices among many possible sequences, resulting in an additional cognitive load for both the speaker and the addressee (cf. Denis, 1996; Levelt, 1982; Robin & Denis, 1991). However, route descriptions describe an entity that has an intrinsically linear structure, making it possible to directly map one structure (the succession of steps along the route) over another (the sequence of verbal output). Discourse linearity then adheres totally to the linearity of the described route. Nevertheless, friendly route descriptions are generally expected to provide their users with advance information by listing the main nodes or places that are to be connected by the route segments. Advance information regarding landmarks that punctuate a route is especially useful for vehicle drivers (cf. Briffault & Denis, 1996).

Closely related to the linear structure of route directions is the *spatial perspective* imposed on the user of the directions, typically a "route perspective". This contrasts to the "survey perspective" in which an environment is viewed from above (cf. Taylor & Tversky, 1992). Descriptions of local views are thus related to the successive positions of the mover. This perspective nevertheless allows the user to develop a series of successive views that he/she expects to have of the environment, or to reconstruct a survey representation of the environment and the route traversing it. This latter strategy has a cognitive cost, but makes available a potentially more integrated, map-like representation. However, the subjects traversing the environment must coordinate this survey representation with their frontal views of the environment.

2 The cognitive operations involved in producing route directions

In response to a request for navigational assistance, generally expressed as "*How do I get from X to Y?*" (X is usually not specified when the request is made on the spot), a responder is generally believed to implement three sets of cognitive operations (cf. Denis, 1997):

The first is to *activate an internal representation* of the environment in which the displacement is to be executed. Only the subset of "cognitive maps" that are relevant to the current task is activated, thus restricting the search space to the region of the route. Internal spatial representations are likely to include topographical information and visual aspects of the environment, seen from an egocentric perspective. They also include procedural components, derived from the subject's prior exploration of the environment. We do not assume that any route description has a corresponding single stored representation which is available on request. The most interesting cases, from a cognitive point of view, are those in which a subject has to provide the description of a route for the first time, thus having to solve a novel problem.

The second operation consists of *defining the route* that best fits the request within the subspace of the currently activated mental representation. The optimal route (in terms of economy of movement) is a straight line. This is, however, purely theoretical and of little cognitive interest. The presence of physical obstacles in the environment divides a route into a sequence of segments, so that the route skirts around obstacles and takes physical constraints into account (for instance, urban routes must follow the network of streets). Defining a sequence of segments and their terminal points (where reorientations are executed) may involve a variety of criteria (such as the shortest route, or the route with the smallest angular discrepancy with respect to the goal at each intersection, etc.). Thus, there are generally several distinct routes between any two points in an environment. Route directions actually respond to "ill-defined" problems which have several solutions, none of which are "right" or "wrong", but each of which is

Table 3. Two descriptions: subjects' protocols

Subject 1
"Cross the railroad tracks. Then, continue to walk down the street. You reach an intersection. Continue along a footpath. Continue walking to a little bridge. There, it will be the building just to the left."

Subject 10
"Go through the train station. There is a bar just opposite. Walk down the street. To the right, there is a photocopy shop. At the bottom of the street there is a bar on the street corner. Cross the street. To the left, there is a church. To the right, there is a driving school. Walk down the path without turning left or right. Keep on the same path. There is a residence on the right and a long slope. Walk down to the little bridge that passes over the Yvette river. There, you will see two buildings on the left. Go towards them. It is not the first building, but the second on the left. This is Building 232."

Table 4. Two descriptions: formatted versions

Subject 1
- Cross the railroad tracks.
- Continue to walk down the street.
- You reach an intersection.
- There is a footpath.
- Continue along the footpath.
- Continue walking to a little bridge.
- That's the building just to the left.

Subject 10
- Go through the train station.
- There is a bar just opposite.
- Walk down the street.
- To the right, there is a photocopy shop.
- At the bottom of the street, there is a bar.
- The bar is on the street corner.
- Cross the street.
- To the left, there is a church.
- To the right, there is a driving school.
- There is a path.
- Walk down the path.
- Do not turn either left or right.
- On the right, there is a residence.
- There is a long slope.
- Walk down to a little bridge.
- The bridge passes over the Yvette river.
- There are two buildings on the left.
- Go towards the buildings.
- It is not the first building.
- It is the second one.
- It is to the left.
- This is Building 232.

more or less optimal. Reorientation points at the end of each segment are critical components whose description requires special care. More landmarks are mentioned at these points than in any other part of a route, thus helping to ensure the mover's reorientation.

Once the route has been defined, the third and last operation is the *formulation of the procedure* required by the user to move along the route and reach the destination. This results in verbal output, which is particularly important for psychologists because it is objective material from which they can develop a picture of underlying cognitive operations and the structure of internal representations which generate the response. The verbal output is also important because it reflects selection by the speaker. The landmarks mentioned in a description make up only a fraction of those encountered along the route, or stored in the memory of a single person. What underlies this selection? Is it based on criteria such as landmark salience? The formulation of the verbal output also takes into account the cognitive and linguistic capacities of the addressees and their supposed prior (partial) knowledge of the environment.

Another interesting feature is that the three postulated cognitive operations may be brought into play concurrently. For instance, formulation may well begin before the previous operation (route definition) is complete.

The data collected in route description experiments always reveal large differences between the descriptions provided by differing speakers. Table 3 shows two descriptions of Route 1 on the Orsay campus, and Table 4 shows their transcriptions into standard, proposition-like format. These descriptions were produced by two students familiar with the environment, who intended to have their addressees execute the same sequence of moves along the same path. The differences in length and content are remarkable. Subject 1 produced a very short, compact description, while Subject 10 produced an extended description that included many details and which was about three times as long. Table 5 lists the landmarks mentioned in both descriptions. While Subject 1 based her description on five landmarks, Subject 10 referred to three times as many landmarks. This diversity is a serious problem for cognitive scientists concerned with designing systems which incorporate features of the human cognitive capabilities that provide optimal descriptions. Cogent methods must be found to reduce description diversity.

3 Analyzing individual protocols and constructing skeletal descriptions

This section describes our attempts to analyze the variety of individual descriptions and delineate the commonalities that all (or the majority) of these route descriptions possess. Thereby resulted the concept of a "skeletal description" that reflects the essentials needed for navigation. A simple statistical procedure was used to develop skeletal descriptions and objectively test their informational value. The aim was to test the meaningfulness and functional value of skeletal descriptions in actual navigation.

Our approach was to use subjects' protocols to build a reduced version of their descriptions. This reduced version should contain the essential directions and landmarks required by a mover, while avoiding the extremes of too much or too little information. Protocols were first collected from a sample of 20 subjects and rewritten in a standard format, expressing their content as propositions (as specified above; cf. Denis, 1997, for detailed report). The information was then compiled to give a "megadescription" containing every statement produced by every subject. The items mentioned by several

Table 5. Landmarks mentioned in the two descriptions

Subject 1	Subject 10
Railroad tracks	
	Station
	Bar 1
	Street 1
	Photocopy shop
	Bar 2
Intersection	
	Street 2
	Church
	Driving school
Footpath	Footpath
	Residence
	Slope
Bridge	Bridge
	Yvette river
	Building 1
Building 2	Building 2

Table 6. Skeletal description for Route 1

- Cross the railroad tracks.
- Walk down the street.
- Continue to the bottom.
- You reach an intersection.
- To your left, there is a church.
- To your right, there is a driving school.
- There is a footpath between the two.
- Take the path.
- Continue walking down to a little bridge.
- Cross the bridge.
- There are two buildings on the left.
- There are Buildings 231 and 232.
- Cross the road.
- Proceed toward the leftmost building.
- It is Building 232.

subjects were entered only once in the megadescription (using the most frequent formulation), and information given by even a single subject was also included.

The skeletal description of a route was then constructed using the judgments of a further group of 20 students from the Orsay campus about the relevance of each item for guiding a traveller along the route. All the pieces of information in the megadescription were said to be exact, but taken together were said to provide far more information than is necessary to guide a traveller unfamiliar with the environment. The judges removed those items that they considered to be superfluous. Their responses resulted in frequencies of selection for each item in the megadescription. A stringent exclusion criterion was used. Only items that were selected by at least 70 % of the judges were considered to contribute to the skeletal description of Route 1. Table 6 shows the skeletal description of this route.

In spite of its superficial resemblance to descriptions given by individual subjects, a skeletal description is not the same. It is an abstraction, reflecting the most important aspects of the route. Furthermore, the construction of a skeletal description does not yield a random patchwork or collage of independent items. In the example reported above, the skeletal description is fully informative, while containing the minimum of landmarks and instructions needed to navigate appropriately. In addition, as will be shown below, a skeletal description can be used as a reference for evaluating individual protocols.

The items most frequently discarded from the megadescriptions were directions for going straight (Class 1), references to secondary landmarks (Class 3), and descriptions of landmarks (Class 4). The skeletal descriptions contained a large proportion of Class 2 items (those combining actions with reference to a landmark), and this proportion was larger than the average proportion found in individual protocols. This selection reflects the judges' inclination to treat landmarks and associated actions as key components of route descriptions.

The production of route descriptions may be sensitive to contextual factors, such as a limit on the length of the description. We compared written descriptions of Route 3 of subjects under control condition with those of subjects who were asked to keep their descriptions as concise as possible. The space available on the response sheet was limited to five lines. The subjects were capable of taking into account such a constraint. They greatly reduced the average number of items mentioned under the constrained condition. Table 7 shows that this constraint reduced the number of times that all classes of items were mentioned, but for some more than others. Actions and action-landmark combinations were least affected, while landmarks not associated with actions and landmark descriptions were greatly reduced. Non-functional adjuncts intended to describe the environment to be traversed, but not closely connected with reorientations were rejected. The few commentaries that appeared under control conditions virtually disappeared from the constrained condition. Thus, the constraint selectively affected the description.

Skeletal descriptions were constructed using a stringent exclusion criterion (80 %). Table 7 shows that the constrained condition resulted in a greatly reduced skeletal description. Detailed inspection of this skeletal description revealed that it was almost entirely contained in the skeletal description based on control protocols. Of the 22 items in the reduced skeletal description, 21 were also in the control skeletal description, and only one was unique to the constrained condition. The strong bias in favor of landmarks was confirmed in the reduced skeletal description.

4 The meaningfulness of skeletal descriptions

It is thus possible to isolate a core structure from a set of individual descriptions. The resulting skeletal description has a sound content and organization. However, since individual descriptions differ considerably from one another, we also analyzed these protocols and their relationships with the corresponding skeletal description.

Because route descriptions are intended to help a mover navigate, the speaker must be able to create favorable conditions for communication, monitoring the

Table 7. Number of items of each class in subjects' protocols (average values) and skeletal descriptions of Route 3, in control and constrained conditions

	Average values based on individual protocols		Skeletal descriptions	
	Control	Constrained	Control	Constrained
Class 1: Prescribing Action	5.7	3.4	3	3
Class 2: Prescribing Action with Reference to Landmark	14.2	7.4	23	12
Class 3: Introducing Landmark	9.6	2.6	10	7
Class 4: Describing Landmark	4.4	0.8	1	0
Class 5: Commentaries	0.9	0.2	0	0

amount of information transmitted to maintain adequate specificity but refrain from overspecification. In sum, the describer should adjust the output to suit the processing capacities of the addressee. Not only should the content be exact, but the amount and organization of that content should not exceed the addressee's processing capacities. Heavy demands are usually placed on the user's short-term memory capacities, especially when the description must be retained during the displacement.

We collected ratings of the communicative value of individual protocols from a sample of judges and used them to compile a quantitative index. Five students familiar with the Orsay campus rated the original individual protocols. The highest rating was given to adequate descriptions enabling a reader to easily build a clear representation of the route and to reach the goal without error or hesitation. The lowest rating was given to poor descriptions containing insufficient information or more information than was really useful, that did not allow the reader to build a consistent representation.

The decisions of the five judges were highly consistent, and the average ratings of the descriptions of Routes 1 and 2 (produced by individual subjects) were strongly correlated, indicating consistency among the subjects who produced the descriptions. The descriptions that received the highest ratings generally provided a compact description, with clearly-positioned landmarks and a few very specific instructions. Most of the landmarks also appeared in the skeletal description for the corresponding route. In contrast, the poorly rated descriptions had several deficiencies. Some were extremely simple with very few landmarks, while others suffered from considerable overspecification, introducing far more information than most users could process.

While the judges were given guidelines on how to use the rating scale, the actual criteria remained implicit. Nevertheless, the significant agreement among the five judges clearly indicated that the ratings captured the key features of the descriptions. The judged communicative value of the descriptions was a consistent feature, and this required further examination of factors likely to account for it.

Measures such as the richness of the descriptions, indicated by the number of propositions in a protocol, or the number of landmarks mentioned, were not correlated with ratings. We examined the hypothesis that the similarity of an individual description to the supposedly "ideal" skeletal description was a sensitive predictor of the intrinsic quality of the description, as rated for its communication value. Two measures were considered. The first was the proportion of items in a description that belonged to the set of items in the corresponding skeletal description (the Richness index). The second reflected the extent to which skeletal elements saturated an individual description by measuring the proportion of skeletal items in each individual protocol (the Saturation index). The capacities of the Richness and Saturation indices to predict the evaluations made by the judges were examined. There was a strong positive correlation between these indices and the judges' ratings. Thus, objective measures reflecting the resemblance of individual protocols to the skeletal description predicted the judged quality of the descriptions. These analyses also validated the construct of skeletal description. This concept proved to be a meaningful one that reflects the essential components of a good description.

5 The functional value of skeletal descriptions

The communication value of the individual descriptions in the above studies was based on subjective ratings. We also assessed the quality of individual descriptions by the actual navigational performance that they produced. Very few studies have investigated the effect of verbal instructions on a subject's performance of a navigational task by measuring the time taken and/or the number of errors made along the route (cf. Streeter et al., 1985). This kind of investigation is costly in empirical terms, but its value is considerable, since the quality of navigational instructions is evaluated by a behavioral test, based on measuring the very behavior which is believed to be served by spatial discourse. This is the approach used in a study on navigation in the city of Venice. We examined the way in which subjects using "good" or "poor" descriptions moved through the city (cf. Denis, Pazzaglia, Cornoldi, & Bertolo, in press, for full report of the study).

We collected behavioral indices likely to reflect the qualities of descriptions designated as good or poor by judges. First, protocols describing three routes in the city of Venice were obtained from a sample of 19 people living in the city. The protocols were used to build megadescriptions and skeletal descriptions for each route, following the procedure described above. The commu-

Table 8. Average error scores during navigation per route for each type of description

	Good description	Poor description	Skeletal description
Directional errors	0.25	0.69	0.12
Hesitations	0.06	1.31	0.56
Requests for assistance	0.51	0.94	0.31
Total error score	0.82	2.94	0.99

nicative value of each protocol was also evaluated by 10 independent judges. The best and poorest descriptions of each route were selected, and new subjects took part in a field study which required them to navigate along the routes using these descriptions. If the purportedly good descriptions were really effective, they should have elicited more efficient navigation than poor ones. We also tested the effectiveness of the skeletal descriptions as navigational aids. If, as expected, skeletal descriptions provided ideal route directions, they should have produced behavioral indices reflecting adequate navigational performance, since they contained all the essential information.

Eighteen students who had little or no knowledge of Venice were taken to the starting point of each route and given a printed description of the corresponding route. They were invited to study it for two minutes. They then returned the description to the experimenter and began to follow the route. They were told that the experimenter would follow them to record their progress and provide help if required. When subjects took a wrong turn, the experimenter called them back and repositioned them at the intersection, informing them that the direction they had followed was not correct.

The directional errors, hesitations, and requests for assistance were recorded for each subject and route. Table 8 shows the average number of directional errors, hesitations, and requests for assistance from the experimenter per route, for each type of description. Overall, subjects produced few errors. Statistical analysis revealed that the poor descriptions produced significantly more errors than the good and skeletal descriptions. There was no difference between the error scores for the good and skeletal descriptions.

Thus, good descriptions resulted in better navigation than poor descriptions. The similarity of the performances of the good and skeletal descriptions also suggests that the latter captured the essential features of the best original descriptions. These results, therefore, provide behavior-based support for the ratings given by the judges. Navigation was indeed most efficiently guided by those descriptions assessed as good. This was probably the case because they possessed the essential features of good descriptions (e. g. clarity, completeness, absence of ambiguity, and conciseness) as stated by the subjects and judges of the previous studies. These characteristics were also present in skeletal descriptions. In spite of their different surface features (they were crude lists of landmarks and prescriptions), skeletal descriptions had the same communicative value as the best natural descriptions. In contrast, poor descriptions complicated navigation. Our data thus provide a good indication that the rated quality of directional instructions is likely to affect navigational performance.

6 Conclusion

While route directions are only one subset of spatial discourse, they are a universally-experienced form of human interaction and as such are strongly appealing to researchers. Our approach was to collect descriptions and conduct quantitative analyses. This approach is not merely descriptive but is guided by a set of assumptions about the cognitive operations necessary for producing route descriptions. It provides an opportunity to investigate the generation of verbal messages intended to externalize non-verbal components of human cognition.

Our research also provides pointers for further investigation of the cognitive characteristics of "good describers". Some individual descriptions are clearly better than others, but we do not know if people who are capable of producing "friendly" descriptions have special cognitive characteristics. There is some evidence that subjects with rich visuo-spatial memories ("high imagers") are more likely to refer to landmarks, which are crucial components of route descriptions. This is not surprising since high imagers are more likely to access visuo-spatial information when they consult their internal representations. This information is in turn more likely to be expressed verbally when a message is elaborated on the basis of these representations. But there is not yet any consistent evidence that high and low imagers' descriptions differ in terms of their rated quality or their index-based similarity to skeletal descriptions. There are still a number of individual capacities that must be analyzed to determine the cognitive mechanisms underlying the production of good descriptions.

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