Situated and Prospective Path Planning: Route Choice in an Urban Environment

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Abstract

Prior research on route descriptions does not reveal much about the relationship between mentally planning and describing routes, and the routes chosen when actually traveling. This paper addresses route choice in a familiar urban environment under three different conditions: walking the route, planning and describing the route for oneself, and planning and describing the route for an addressee unfamiliar with the environment. Results show that the chosen routes differ systematically with respect to efficiency, number of turns and streets, and street size. These findings reflect the impact of incremental optimization by perceptually based updating processes along with aspects of communicability and formulation for an addressee.

Keywords: Route planning; spatial memory; spatial cognition; route descriptions.

Introduction

Imagine walking through your hometown when someone asks you for directions. Which route do you describe? Is it the same route that you would describe when asked how *you* would get there? And, is that the same route you would take if you actually walked there? Although all these situations require planning routes with the same start location and destination from spatial memory, the resulting routes will differ systematically. For example, when giving directions, you may want to choose a simple route that is easily remembered. In contrast, when describing a route for yourself, route complexity might be less important than length. In both of these scenarios, the entire route has to be planned in advance. When actually navigating to the destination, in contrast, planning might primarily be done en route, generating a detailed plan for immediate movement decisions only (a hierarchical planning process; e.g., Wiener et al, 2004). The present paper addresses human route choices in an urban environment (Freiburg downtown) in one situated and two prospective planning situations as just described. Comparisons of different properties of the chosen routes such as route length (i.e., route efficiency) and route complexity allow for an increased understanding of human route planning behavior.

Knowledge about human path planning behavior in urban environments is far from conclusive, as only a limited number of studies address this important topic (e.g., Golledge, 1997, 1999; Gärling et al., 1986; Wiener et al, 2004). Navigation and wayfinding experiments tend to focus on properties of spatial memory such as its content, form, and structure (e.g., Gillner & Mallot, 1998). Route descriptions have been investigated systematically with respect to the reflection of spatial cognition in linguistic representations (Allen, 2000; Klippel et al., 2005). However, it is unclear in how far the described routes coincide with routes actually travelled. On the one hand, both procedures involve planning processes dependent on spatial memory and knowledge (Klein, 1979; Denis, 1997). On the other hand, they differ in the availability of spatial detail and veridicality during the incremental development of the (planned or travelled) route (Tversky, 1981), as well as with respect to the requirement of *communicability* (Denis, 1997:417). Furthermore, although there is rich information in the literature on how addressees affect linguistic descriptions (Clark, 1996), especially in the spatial domain (Garrod & Sanford, 1988; Schober, 1993), little is known about how addressees might actually affect the route chosen for them in a requested description. In sum, the question of how route descriptions (for self vs. other) and actual navigation differ with respect to route choices has not yet been studied systematically, nor does the available evidence lead to unequivocal predictions.

The relationship of navigation, route planning, and route descriptions

In the present study, we focus on two main distinctions: (a.) whether or not planning and navigation coincide temporally (situated vs. prospective planning); (b.) the addressee of the description of the planned route (prospective self vs. prospective other). So far, the wayfinding literature does not reveal much about how route choice in actual navigation relates to prospective route planning or to route descriptions.

Theoretically, it is conceivable that planning is not affected at all by the ensuing task, be it actual navigation or an in-advance route description. In fact, some earlier accounts seem to suggest that mental route planning involves a full internal action plan prior to action onset (e.g., Leiser & Zilbershatz, 1989). In our scenario, this would entail that in both situated and prospective planning, the entire route is planned in advance, mentally represented in a pre-verbal format, and remembered. In actual navigation, this route plan is then simply executed. In the prospective planning tasks, the pre-verbal format is instead turned into a linguistic representation. Accordingly, no systematic differences in route choices should emerge. This possibility is henceforth referred to as the "no-difference" hypothesis.

However, a range of earlier findings point in a different direction. First of all, even if planning itself is not affected, the process of verbalization may not be trivial. According to Denis (1997) the description of routes requires a range of complex cognitive operations such as *activating a representation*, *planning a route*, and *formulating a procedure*. Here linguistic factors only come into play at a fairly late stage; in fact, it is consistent with this account to assume a large overlap between the operations involved in actual navigation, in-advance planning, and route descriptions. Nevertheless, the requirement to verbalize may affect the planning stage, as Denis (1997: 417) states:

> "[A]lthough route planning is mainly a preverbal operation, the choice of some routes or segments of routes may be constrained by criteria linked to their communicability. For instance, a detour may be easier to describe than a shortcut devoid of distinctive landmarks. As a consequence, the definition of a route not only takes into account the ease of its execution, but also the fact that the route has to be described verbally. The description is intended to be easy to process and compatible with the cognitive resources of its user."

Although Denis does not provide empirical evidence for this claim, it can be predicted from this statement that participants will choose simpler routes when verbalizing the route than when travelling it. We refer to this possibility as the "verbalization-difference" hypothesis.

Moreover, the argument also implies that there is a potential difference between addressees, as the latter part of Denis' claim is only applicable for users who are not identical with the speaker. Then, routes chosen for others should be systematically less complex than routes chosen for oneself. This assumption is henceforth referred to as the "differentiated-addressee" hypothesis. This hypothesis is consistent with the earlier literature on dialogue (Clark, 1996; Garrod & Sanford, 1988; Schober, 1993), although there is no empirical evidence so far that such considerations may actually affect route selection. It can be expected that effects of communicability as well as different requirements for self vs. other are (at least in part) subject to conscious decision and therefore accessible by way of questionnaires.

Furthermore, the assumption that the planning process itself remains unaffected by actual navigation seems highly unlikely. In fact, earlier findings in the general area of wayfinding demonstrate various incremental and hierarchical planning processes across a broad variety of spatial tasks (Golledge, 1999; Wiener et al., 2004). Applied to our scenario, this means that when actually navigating a route, planning can be expected to be at least partially incremental. Hierarchical route planning would then involve first devising only a coarse route plan (e.g., heading roughly in the intended direction). Then the route would incrementally be refined towards detailed movement decisions (for instance, at decision points such as junctions) on the basis of situated spatial information. In prospective route planning, in contrast, detailed spatial information needs to be derived from memory, which is often inaccurate, incomplete, and distorted in various ways (Tversky, 1981; Golledge, 1999). For example, small side roads or alleys that allow for short-cuts might easily be forgotten or overlooked during mental travel planning, but not during actual navigation. As a result, situated planning should lead to more complex and efficient routes. This possibility is referred to as the "efficient-travel" hypothesis.

Finally, one theoretical option remains. Conceivably, in situated navigation, participants make spontaneous local decisions without planning ahead and thus fail to consider any available short cuts. In contrast, the requirement of planning the entire route in advance in prospective planning may result in more thorough and therefore optimized planning processes. We refer to this possibility as the "optimal-planning" hypothesis, which does however not seem to be supported in the wayfinding literature.

Altogether, the evidence so far suggests that a) route choices should differ systematically between actual situated navigation and prospective planning due to incremental planning as well as verbalization processes, and b) addressees should affect route choice because of the additional considerations of cognitive resources and limited prior knowledge on the part of the addressee. We tested these hypotheses in a naturalistic real-world study which is reported next.

Methods

Participants

24 subjects participated in the experiment (mean age: 25.5 years; SD 6.0). All participants had lived in Freiburg for more than 1 year. Good knowledge of the Freiburg downtown area was a requirement, which was controlled for via a questionnaire. A 3x3 within-subjects design was employed (3 different planning tasks in 3 different conditions as described below).

Planning tasks

3 different start places were combined with destinations (here called "planning tasks") in the downtown area of Freiburg (see Fig. 1), each of them located close to prominent landmarks or places.

Conditions

The three conditions for each participant were as follows.

Situated planning (navigation): Participants were instructed to walk from their current position (S1, S2, or S3) to the corresponding destination (D1, D2, or D3, respectively) of the current planning task. Half of the participants were asked to *think aloud* while walking in this condition. The language was recorded and later transcribed.

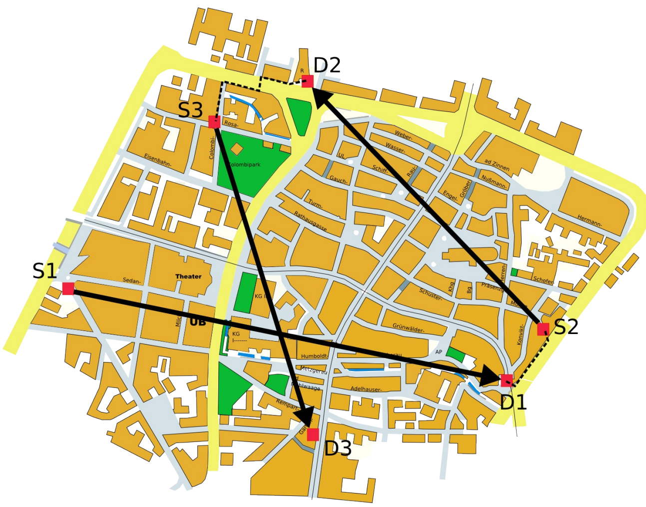

Figure 1: The three planning tasks: Start places are labeled as S1-S3, destinations as D1-D3. The solid arrows depict the beeline between them; dashed lines show the transfer routes between navigation tasks.

Prospective planning self (description): Participants were instructed to write down the route they would take if asked to walk from their current position to the corresponding destination.

Prospective planning other (description): Participants were instructed to write a route description for a person unfamiliar with the area, who would have to remember the route (rather than taking the description along).

In all three conditions, the participants were free to choose their own criteria for route selection; in particular, they were not instructed to choose the shortest possible route.

Procedure

Each participant solved all three *planning tasks* (routes) in the same order (cf. Figure 1). However, the order of the three *planning conditions* (situated, prospective self, prospective other) was balanced between participants. They were led to the start location of each planning task and given the relevant instructions for the current condition. Then they solved the task by either walking to the destination (in the situated planning condition) or writing a route description on a piece of paper (in the prospective planning conditions). Since the present focus is on route choice, it was crucial to ensure that the intended route could be unambiguously identified in the prospective planning conditions, in spite of errors and memory limitations. Therefore, experimenter and participant subsequently followed the written route descriptions and walked to the destination. Participants were allowed to correct errors such as wrong street names in their route description, using a differently colored pen, while travelling the route. However, they were not allowed to alter their choices concerning the route itself (cf. the distinction between error levels outlined in Reason, 1990).

Between different tasks, participants were led along transfer routes to the start location of the next planning task (see dashed lines in Figure 1). For the analysis, participants' route choices were either recorded by the experimenter during navigation (situated condition) or derived from the participants' route descriptions (prospective conditions). After finishing the third planning task, participants were asked to fill out a questionnaire addressing, inter alia, deliberate criteria for route selection in each of the three conditions. This was done only after performance so as to avoid raising the participants' awareness of the study's aims.

Predictions

Based on the considerations outlined above, we hypothesized that route choices should differ between all three conditions, in particular with respect to efficiency and simplicity. Specifically, actual navigation should result in shorter (and possibly more complex) routes involving minor streets and minimal short cuts, and planning for others should involve simpler (and possibly longer) routes, involving major streets, less curves, and an orientation towards salient landmarks, than planning for oneself.

Analyses

To analyze systematic differences in route choice behavior between the different planning conditions, we characterized the chosen routes according to the following criteria:

Route efficiency. For each planning task we identified the most efficient solution (i.e., the shortest possible path between start location and destination). Route efficiency was analyzed by calculating the length of the chosen routes and comparing it to the length of the shortest possible path. Route efficiency is described in percent above optimal (i.e., a solution that is 10% above optimal relates to a route that is 10% longer than the shortest possible route). Lower numbers therefore correspond to more efficient routes.

Number of turns. For each chosen trajectory (navigated or described) we evaluated the number of turns along the path. A turn was defined as a decision to deviate from the straight ahead by more than 45°. Only decisions at intersections where path alternatives were available were counted as turns.

Number of streets. For each route we counted the number of different streets used (i.e., not just crossed) by the participant. Together with the latter measure (number of turns) this measure can be seen as a measure of complexity of the chosen trajectory.

Street size. Three experts who were unaware of the experiment and its hypotheses rated the streets in the Freiburg downtown area according to their size on a scale from 1 (very small) and 6 (very big). To do so, they were shown a map in which all streets were sketched as simple black lines of equal thickness. These ratings were then used to characterize path choices in the three conditions in more detail. Each chosen path was subdivided into parts, with each part being a fraction of the entire path on a different street. To account for possible differences in path length between conditions, these fractions were normalized to sum up to 1 and were then multiplied by the specific average rated size of the corresponding street. By these means, a single value between 1 and 6 describing the average street size for the entire path was obtained.

Linguistic material. To gain additional insight into the underlying processes and motivations, we consulted the verbalizations produced during the navigation task (task concurrent thinking aloud, Ericsson & Simon, 1993) for evidence concerning incremental planning procedures. Also, we analyzed the results of the questionnaires with respect to the deliberate route selection criteria that participants mentioned spontaneously in answer to two open questions asking about criteria and reasons for choosing a particular route. These answers were categorized into main criteria; then the number of people who referred to these criteria in answer to one or both of these questions was counted separately by two coders, who agreed in 97.7% of the cases.

Results

Chosen Paths. Figure 2 displays the chosen routes for the three different conditions in the second planning task.

Figure 2: Route choices for the second navigation task (Route 2). The thickness of the lines reflects the frequency with which the corresponding street sections were chosen

Route efficiency. The efficiency of the chosen routes differed between conditions (Figure 3, left). Specifically, participants chose the most efficient routes in the situated planning (actual navigation) condition (8.1% above optimal). Pairwise t-test comparisons revealed significant differences between the situated planning condition and both prospective planning conditions ($t(23)=-2.47$, $p=.02$ for situated vs. prospective planning self; and $t(23)=-2.59$, $p=.02$ for situated vs. prospective planning other), while no difference was found between the two prospective planning conditions ($t(23)=-.41, p=.68$).

Number of Streets. The number of different streets along the chosen paths differed between conditions (Figure 3, right). On average, participants' paths went along 5.88 streets in the situated planning condition, 5.13 streets in the prospective self condition and 4.63 streets in the prospective other condition. Pairwise t-tests revealed significant differences between the situated planning condition and the prospective planning other condition ($t(23)=3.98$, $p<.001$). The comparison of the situated planning and the prospective planning self condition was marginally significant ($t(23)=1.94$, $p=.06$); the two prospective planning conditions did not differ significantly ($t(23)=1.66$, $p=.11$).

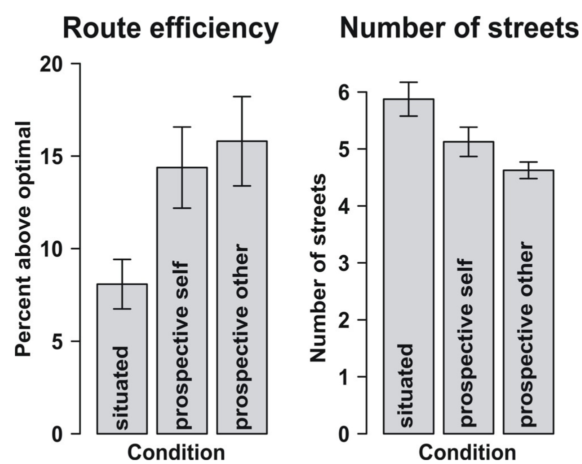

Figure 3: left: Efficiency of the chosen routes; right: Average number of streets used.

Number of Turns. The number of turns along the chosen routes differed between conditions (Figure 4, left). On average, path choices in the situated planning condition featured most turns, followed by the prospective self and the prospective other conditions. Pairwise t-test comparisons revealed significant differences between the situated planning and the prospective other planning condition ($t(23)=2.61$, $p=.02$), while neither of the other differences was significant (situated vs. prospective self: $t(23)=1.33$, $p=.20$; prospective self vs. prospective other: $t(23)=1.37$, $p=.19$).

Street size. The average size of the chosen streets differed between conditions (Figure 4, right). Specifically, participants chose smaller streets in the situated condition than in the prospective self and the prospective other condition. Pairwise t-tests comparisons revealed significant differences between the situated planning condition and the prospective *self* ($t(23)=-2.19$, $p=.04$), as well as between the situated planning condition and the prospective *other* condition ($t(23)=-3.84$, $p<.001$). The two prospective planning conditions did not differ significantly from each other ($t(23)=-1.34$, $p=.19$).

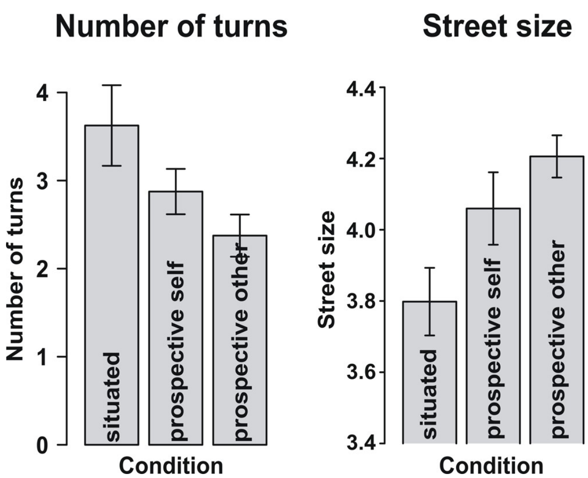

Figure 4: left: Average number of turns for the chosen paths; right: Average size of the chosen streets

Linguistic material. The informal inspection of task-concurrent verbalizations revealed that of all 12 participants whose linguistic data were recorded, 11 spontaneously referred to planning processes during navigation; for most participants this happened frequently rather than exceptionally. This is even true for one participant who describes a nearly complete route before setting out and then mentions that he does not really think about the route any longer, since it has already been planned. Nevertheless, after a few minutes new considerations emerge, inspired by the visual information provided by the environment. A more typical example of an incremental route planning process reflected verbally is the following: "I could now walk over the *Münsterplatz* – and now I consider whether I should do that, whether this might be a shortcut, that's possible – I think that's what I'll do now." While the verbal data will not be analyzed further at this point, they do contradict the "no-difference" hypothesis, and they also suggest that verbalization is not the only difference between the conditions (cf. the "verbalization-difference" hypothesis).

In the questionnaire entries, three criteria for route selection were mentioned significantly more often in the prospective other condition than in either the situated or in the prospective self condition: 1) the route should be *simple*, 2) it should contain *as few changes of direction as possible*, and 3) there should be *helpful landmarks and other orientation aids (main streets, street car tracks) along the way* (all $\chi^2 > 5.0$, $p < .026$; except for *simple*, situated vs. prospective self: $\chi^2 = 3.0$, $p = .084$). Like in the behavioral measures, the prospective self condition ranges between the situated and prospective other conditions but the difference between the two prospective conditions is numerically more than twice as big. Furthermore, about 25% of the participants mentioned choosing routes that were *attractive* or *not too busy* for their own routes (situated and prospective planning self conditions), while these criteria were not mentioned at all with respect to the prospective planning other condition. In contrast, the criteria *easy to find*, *suitable for strangers* and *distinctive* were mentioned exclusively in the prospective planning other condition (six vs. zero cases). Thus, with respect to the criteria mentioned spontaneously in the questionnaire, planning for others differed systematically from self-travel, at least in retrospect.

Discussion

Planning or describing a novel route through a well-known urban environment is an everyday spatial task. However, relatively little is known about the relationship between actual navigation, planning, and description with respect to route choice. In this work we studied route planning behavior in three different situations: (i.) route planning for actual immediate navigation (situated planning condition); (ii.) route planning for future navigation (prospective planning self); (iii.) route planning for a third person who is unaware of the environment (prospective planning other). In the prospective planning conditions, participants generated written route descriptions.

Results demonstrate clear differences between the different planning situations. Participants generated shorter routes in the situated planning condition than in the prospective planning conditions (contrary to the "optimal-planning" hypothesis stated above). Also, they chose smaller streets and paths consisting of more turns and more different street segments in the situated planning condition. These results clearly disprove the "no-difference" hypothesis which states that, when faced with a wayfinding task, routes are planned entirely in advance in a pre-verbal fashion that allows for plan execution in similar ways for both navigation and verbalization purposes. According to the "verbalization-difference" hypothesis, theoretically the different route choices could be entirely due to communicability, i.e., the requirement of verbalizing the planned route, rather than differences in the planning process itself. However, the verbal data collected during route navigation in the situated planning task demonstrate that humans do not consistently rely on a complete prior action plan. This result is consistent with prior findings in the wayfinding literature indicating that planning is incremental and hierarchical (Golledge, 1999; Wiener et al., 2004).

Furthermore, the aspect of communicability is relevant for both prospective planning conditions; if this factor alone was at work, no differences in route choices could be expected between these two conditions. However, this was not the case. As such, the behavioral results were not conclusive, as none of the route measures revealed significant differences. However, for all behavioral measures, results of the prospective planning self condition were between the other two conditions as if bridging between the extremes. Also, the participants' reported deliberate route selection criteria support the assumption that addressees are taken into account in the verbalization of route descriptions, consistent with the "differentiated-addressee" hypothesis based on Denis' (1997) suggestion. Crucially, with respect to route selection criteria, the difference between planning for self vs. other is greater than that between route planning for self and situated planning. This stands in contrast to the behavioral data, which reflect a more prominent difference between situated and prospective planning.

Taken together, these results are consistent with the assumption that, when planning in advance for themselves, participants aimed to plan the route in a similar way as when they actually travelled it, but did not entirely succeed. Their descriptions may have been affected to a certain degree by the aspect of communicability, but it is unlikely that this effect alone is sufficient for explaining the results. Even if the participants' spatial memory of the test environment was perfect, the mental effort of retrieving precise and detailed spatial information is rather high and time consuming, inducing the participants to rely on a simplified route network, dominated by large salient streets (Kuipers et al, 2003). In addition to these aspects that may be to a certain degree deliberate and conscious, the differences in route choice should at least in part be due to limits of memory and distortions of the mental map. During actual navigation, the immediate feedback navigators receive allows for resolving uncertainties, inaccuracies, and incompleteness of spatial memory and therefore to a constant refinement of the route plan. This effect is supported by the fact that actual navigation by foot takes time, which can be (and actually is, as the verbalization data show) used for optimization, constantly accounting for the current situation, updating, and refining the mental plan. Altogether, therefore, our results are consistent with the "efficient-travel" hypothesis which states that situated planning leads to more complex and efficient routes because the mental map can be constantly updated by perceptual information.

Further research may identify more precisely how perceptual information interacts with requirements of in-advance-planning and verbalization for different addressees. The present study has provided an important basis for such research by showing for the first time that different planning and navigation conditions do in fact result in different route choices, even though other situational factors influencing actual decisions in everyday life, such as attractiveness of routes, shopping facilities, etc., remained stable.

Acknowledgments

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