How Much Information Do You Need? Schematic Maps in Wayfinding and Self Localisation

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Abstract. The paper is concerned with the empirical investigation of different types of schematised maps. In two experiments a standard floor plan was compared to three strongly schematised maps providing only route knowledge. With the help of one of the maps, the participants had to localise themselves in two tasks and performed two wayfinding tasks in a multi-level building they didn't know before. We recorded map usage time and a range of task performance measures. Although the map provided much less information, participants performed better in wayfinding with an unambiguous schematic map than with a floor plan. In the self localisation tasks, participants performed equally well with the detailed floor plan and with the schematised map versions. Like the users of a schematic map, users of a floor map presumably oriented on the network structure rather than on local geometric features. This allows them to limit the otherwise potentially very large search space in map-based self localisation. In both types of tasks participants looked at the schematised maps for a shorter time. Providing less than standard information like in a highly schematised map can lead to better performance. We conclude that providing unambiguous turning information (route knowledge) rather than survey knowledge is most crucial for wayfinding in unknown environments.

Keywords: Schematisation, map, wayfinding, self localization, route knowledge, survey knowledge, multilevel building.

1 Introduction

Maps are a common tool for orienting ourselves in our environment, may they come in paper form or be displayed on our mobile device. Comparing a paper hiking map with one displayed on a mobile device or a subway map the amount of information provided in those maps can vary tremendously. In the paper map you might see individual houses whereas in the mobile or subway map only the coarse direction of routes is displayed. The question of this study is how much information in a map is necessary, how much is superfluous? Is a highly schematised map sufficient for orientation or do we need further details? Does this depend on the goal we want to

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achieve with our map: Is a schematic map sufficient for finding our goal, but not for locating our current location after getting lost?

To address these questions we, first, review several theoretic approaches to schematisation. We, second, try to classify these approaches by the distinction of route and survey knowledge and identify the relevance of this knowledge from empirical studies. Third, we propose cognitive processes underlying wayfinding and self orientation with maps. From these assumptions we derive hypotheses predicting performance in wayfinding and self orientation for normal and highly schematised maps. Last, we test these predictions in two experiments and discuss the results with respect to the literature.

1.1 Theories of Schematisation

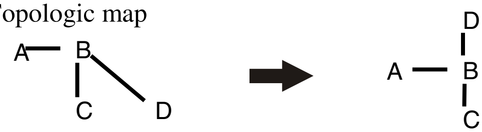
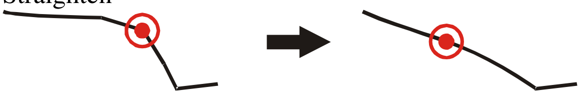
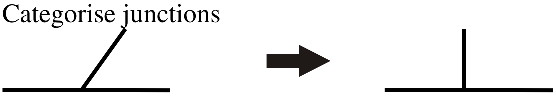
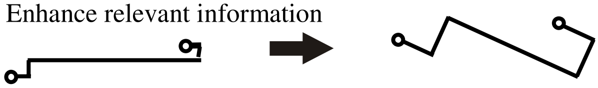
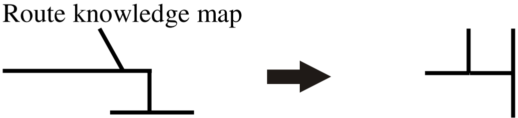
The question of what information is necessary for locating ourselves and finding our goals has found different answers. In cognitive science, this is often referred to as schematisation; the abstraction from unnecessary detail to concentrate on the essential information [e.g. 8]. For maps this involves omitting details e.g. the corner of a house or omitting dimensions e.g. colour information. We will introduce several approaches of schematisation. The reference point for all these approaches is the *topographic map*. In our terms a topographic map is a map which displays correct distances and angles between locations. Common hiking maps and also most city maps are topographic. It is important to notice that all maps, also topographic maps, do not display all spatial information available in our environment and therefore are schematic [27]. However, as metric relations are kept constant, a topographic map can be seen as a reference point to (more) schematised maps.

In a *topological map* only information about the network structure can be obtained. As a consequence a user located at B (see Table 1) can only determine to go into direction C, but not whether this implies turning right or left, as this information might not be displayed correctly in a map. Not knowing whether your path turns right or left is all right when taking the subway as your destination is written on a sign on the train, but it is beyond the pale for walking to your goal: Standing at an intersection the information of having to navigate to the city hall does not help at all, if you don’t know in which direction to walk in order to do so. Consequently, mere topology can be sufficient for using a subway, but not for walking to our goal.

One approach to schematise maps comes from discrete curve evolution [2]. The shape of routes is simplified. Curvature between two locations is *straightened* (see Table 1). Local arrangements are to be kept constant. E.g. there is a house adjacent on the right side of the street. When the street is straightened the new position of the house should not be far away from the street, not on the street nor to the left of the street, but again on the right side adjacent to the street.

Another approach to schematisation is to *categorise* the environment [12]. Categorisation doesn’t include the whole continuum of a route, but is focused on only e.g. the intersections. These intersections can be categorised again by reducing the possible angles of two intersecting streets to, say, only 90° or 90° and 45° (see Table 1). Especially for route maps which provide information about how to get from the start to the goal this is a feasible approach. In a second step it is also possible to

Table 1. Schematisation principles and pictorial examples for these principles. From a topographic, i.e., a metrically correct map (left of the arrow) a schematised map (right of the arrow) is derived. The amount of survey and route information preserved in the schematised map is roughly described in the columns on the right side.

Schematisation principle		Survey information	Route information
Topologic map		incorrect	incorrect
Straighten		rather correct	correct
Categorise junctions		rather incorrect	correct
Enhance relevant information		start & go-al correct	correct
Route knowledge map		incorrect	correct

cluster intersections [20]. E.g. if you have to turn right at a T-intersection you could omit all intersections before the T-intersection where you have to walk straight, like we often do in verbal directions like “at the T-intersection turn right”.

Another route map approach for cars is based on the principle to *enhance relevant information* and reduce or remove irrelevant information [1]. Most often when driving a car we have to cruise around several streets to reach a highway. Then we cover most of the distance on this highway before cruising again small streets in order to reach our goal. In a topographic map most parts will be occupied by the long highway. This approach enlarges the important parts of the map at the start and at the end of the route and shrinks the long distances on a highway (see Table 1). In doing so, the relative location of the goal with respect to the start is kept constant.

There is no general theory of schematisation yet [cf. 13]. All approaches omit certain information from the environment. This involves the curvature of a segment (straighten & enhance information), the length of a segment (enhance information), exact angles at branching points or even streets not necessary on a specific route (categorise junctions). As a consequence the exact metric locations displayed on a map, which provide so called survey knowledge, are distorted to a smaller (straighten) or stronger extent (categorise junctions) or do not provide meaningful information at all, as in the case of a topological map (see Table 1). We will review the importance of survey knowledge and its counterpart route knowledge in the next section.

1.2 Route and Survey Knowledge in Schematised Maps

The distinction between route and survey knowledge is fundamental in spatial orientation research [e.g. 24]. Route knowledge includes knowledge about a series of actions that have to be taken in order to reach the goal independent from knowing the exact position of the goal, e.g. turn right at the church, then the second street to the left. Survey knowledge on the other hand includes knowledge about the direction and distance between locations independent from knowing a path that leads there, e.g. the train station is about 300 Meters east from here.

Previous research strongly suggests that route knowledge is the crucial factor in finding your goal: In our daily life we recall route knowledge rather than survey knowledge. About 80% of all mentioned descriptions in verbal directions are concerned with actions and landmarks [6]. People very familiar with an environment have been shown to express only little survey knowledge of this environment [e.g. 16]. For reaching a goal in cities and buildings, survey knowledge was shown to play only a minor role [11, 15]. Orienting on survey relations could even be detrimental for performance [15]. Topographic maps displaying route *and* survey information have been found to provide no additional help in wayfinding compared to signs which only display route information [3, 10] or to verbal directions not providing survey information [15, 22]. So at least for wayfinding route knowledge seems fundamental, whereas survey knowledge can be omitted.

Transferring these results to schematic maps, one could think of a map only concentrating on providing correct route knowledge while omitting all survey knowledge. For our experiment we constructed such a schematic route knowledge map and compared it to a topographic map additionally providing survey knowledge. In constructing such a map (see bottom row of Table 1), we applied two principles: (1) Each junction in the map was connected to the closest junction by a straight line of normalised length, no matter whether the real distance was 5 or 50 meters. Mere turns between intersections were not considered. When walking between two junctions multiple changes in direction could occur. (2) All angles at junctions were changed to 90° or 180° angles. A turn to the right remained a turn to the right, but the turning angle in the map was always 90°. Local orientation of junctions in the map was correct. A T-intersection in the map always corresponded to a T-intersection in reality, a turnoff in the map always to a real turnoff, although the exact angles between streets might have differed. Despite the topologic network structure, only the local orientation of intersections was represented in such a map. The map was metrically incorrect. Route information was preserved: at any point the participant was able infer from the map whether to turn left, right or walk straight on in order to reach the next junction. Contrary to that survey information was omitted: no correct inference regarding distances and overall orientation could be drawn.

1.3 Wayfinding and Self Localisation with Schematised Maps

Starting from empirical findings we described two principles for constructing a strongly schematised map, which we compared to a standard topographic map. The basic idea is that the schematised map is sufficient for orientation, despite providing much less information compared to the topographic map. Does this hold true for all spatial orientation tasks? In the following we differentiate between finding a goal and localising oneself e.g. after getting lost. We propose that for wayfinding a schematised map is sufficient, whereas for self localisation participants lack important information and therefore should perform worse.

Wayfinding. When we want to reach a goal using a map, we usually know our current location and the location of our goal. Following Passini [19] we assume three steps in solving the wayfinding problem. The steps can be iterated several times:

Planning: The first step is planning a route from the start to the goal (or the general area of the goal) in the map. We could encode or learn the whole map, throw it away and plan the route based on our representation of the map. It has been shown, however, that planning is much easier using external representations like a map than using our own internal representations – possibly one reason why maps exist [21].

Transformation and encoding: When we have settled for one route, we have to encode, i.e., memorise the route. Only very few people walk around looking constantly at the map. Even if they do so, they have to transform the information from the map in order to use it for moving around. This transformation involves aligning the map mentally or physically with the environment so that “up” in the map corresponds to “forward” in the environment [e.g. 14]. For a transportable map, this could be accomplished by rotating the map. The transformation, however, also involves a perspective switch from the top down perspective of the map to the ground-level (egocentric) perspective in which we encounter the environment [e.g. 23]. As our memory capacities are limited we probably won’t encode the whole route, but only a part of it and start with this.[1]

Walking and monitoring progress: After transforming and encoding the map, we use our internal representation to guide our locomotion. E.g. we walk straight on to the next intersection and turn left there. In doing so we have to monitor our progress, i.e., to mach our internal representation e.g. of an intersection with our environment, before executing a behaviour e.g. turning left and then access the information of what to do next and where. Matching locations of the environment with corresponding internal representations helps us with monitoring our progress, identifying our goal and keeping us oriented. When we reach the end of the memorised (sub-)path and/or feel unsure, we look into the map again and go back to the planning stage or to encoding and transforming the upcoming part of our already planned route. When making a mistake (or using an erroneous map) we can get lost, i.e., our actual location does not correspond to our assumed location in the map or in the representation formed from it. After that, we have to localise ourselves again, before being able to plan, encode and execute a new route. Self localisation will be described in the next section.

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[1] The transformation process can also happen online during walking the route. For this, the map would need to be encoded beforehand. Again as argued for planning we assume that the transformation is much easier, when having access to the external representation of the map, than when having to rely on an internal representation of the map.

We described our assumptions regarding the process of wayfinding using a map. Within this model alternative strategies can be imagined. Our examples described a route strategy which includes a one dimensional string of actions at decision points. However, also a survey or least angle strategy is possible [9, 11]. This strategy includes identifying the direction and distance to a (sub-)goal (planning), encoding and transforming this into a horizontal perspective and trying to walk directly to this spot (walking and monitoring progress). The survey strategy is only applicable using a topographic map as the route knowledge map does not provide correct survey information.

Taking this model of wayfinding we assume that the schematised map provides sufficient information for all stages of the wayfinding process applying a route strategy. As lots of detail information is missing we predict that the planning, encoding and transformation process could be performed faster and less error prone than with a topographic map. Participants therefore should be quicker in consulting the map. For wayfinding itself we assume that participants with a schematised map perform at least as good as participants with a topographic map although the topographic map provides much more information.

Self localisation. When we are disoriented, i.e., when we do not know where in relation to our memory or a map we are, we try to localise ourselves. To regain our orientation in an unknown environment we have to *compare features of our surrounding with features of a map* [e.g. 26]. For example, when standing at a T-intersection we can search for all T-intersections in the map. Based on the individual geometry of our T-intersection we might distinguish this T-intersection from other T-intersections. In doing so, we localise ourselves using *local cues* which are visible from our current location. These cues could be the geometry, or landmarks displayed in a map e.g. churches, street sizes or doors in the map of a building. The literature on self localisation is very much focused on such local cues and emphasises the importance of geometric features [e.g. 7]. In contrast we can also orient on the *network structure* of our surrounding, i.e., only taking decision points into account, e.g. "if I am here in the map, then there should be a T-intersection straight ahead and a crossroads to the left". Localising on local cues or on the network structure is probably best described as a hypothesis testing procedure, i.e., we generate a hypothesis about our current location and try to confirm or reject this hypothesis by collecting more information.

Our experiments took place in a multi-level building. Compared to single layer spaces like cities, the relation and representation of multiple layers poses difficulties. Humans have trouble correctly aligning vertical spaces in pointing tasks [18]. Soeda et al. [25] observed wayfinding performance in tasks involving vertical level changes. They found people losing their orientation due to vertical travel, supporting more informal results of Passini [19].

Our schematised map only preserves the network structure of the environment and the raw layout of intersections e.g. T-intersections, but lacks exact local geometry. As geometry is considered an important cue for self localisation [7], we assume participants to localise better if using a topographic map which preserves geometry.

1.4 Hypotheses

We proposed a map schematisation approach providing route knowledge and omitting survey knowledge. Such a highly schematised map was compared to a standard topographic map additionally providing information about survey relations as well as local geometry. Due to local geometry which was shown to be important in self localisation, we predicted that participants with a topographic map would perform better in localising themselves. Due to the central importance of route knowledge for wayfinding, we predicted that participants with a schematised map would perform at least as good as participants with a topographic map. This would be despite the fact that the topographic map provides much more information. Due to the sparser information in the schematic map, we predicted that participants would be faster in encoding information from the schematic map than from the topographic map. This was expected in both types of tasks, wayfinding and self localisation.

In Experiment 1 we compared a topographic map, i.e. a floor plan of a multilevel building with our highly schematised map. In Experiment 2 we investigated the relevance of ambiguity, an issue which occurred in Experiment 1, with a set of two new schematized maps. Conducting both experiments with the same tasks and in the same setting allowed us to compare results between the experiments.

2 Experiment I

2.1 Methods

Participants were asked to participate in two self localisation tasks. They had to locate the position in a map corresponding to their actual position in a building unknown to them. They also performed two wayfinding tasks in the same building. For this they were shown their actual position in the map and had to find a goal also shown to them on the map. All tasks were either conducted with a topographic floor plan or with a highly schematised map.

Participants. Participants were attendees of an annual summer school for human and machine intelligence which takes place at a conference centre in Günne, near Düsseldorf, Germany. They were recruited from the list of participants of the summer school via e-mail, before the event started. 5 women and 13 men agreed to participate in the experiment. The participants were at the end of their twenties (M = 28.6; SD = 5.7), all were native German speakers.

Material. The conference centre was built in 1970 (see Figure 1). It consists of four floors connected with five staircases. Its complexity causes many visitors to get lost. For further discussion of the building see [11].

The participants either got a floor plan or a schematised map for the task. In the *floor plan* each level of the building was seen from birds eye view (see Figure 2 left side). Symbols for staircases were added and connected with dashed green lines. The metric distances in the floor plan were correct. Doors were not displayed. Participants were not allowed to enter rooms. The display of rooms enabled participants to judge the outlines of the building.

The schematic or *simple map* (Figure 2 right side) was derived from the floor plan following the principles described in 1.2. Each junction and staircase (node) in the map was connected to the closest staircase or junction (node) by a straight line of normalised length. Turns between nodes were ignored, except for one turn in the square in the middle of the basement, where this was not possible. All angles at junctions were changed to 90° or 180° angles. In comparison to the floor plan, the simple map provided route knowledge and omitted survey knowledge. Turning information was correct, but distance and global orientation information were not to be relied on. Despite the topologic network structure of nodes, only the local orientation of intersections was represented in the simple schematised map.

Both floor plan and simple map were presented on an A4 paper (29.7 cm x 21 cm) in an opaque folder which had to be opened in order to see the plan or map.

Procedure. The participants performed two *self localisation* tasks. They were taken to the starting points blindfolded (number 1 and 4 in Figure 1). In order to reach the start of the first task they entered the building from outside. They were able to guess that they were on the ground floor or in the basement. For the second task they were

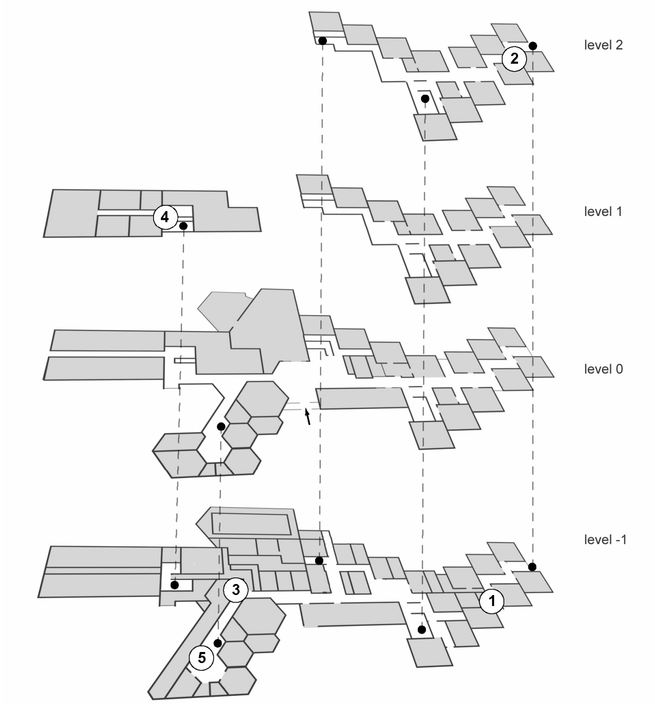

Fig. 1. The conference centre where the experiment took place. Starting points for the self localisation tasks (number 1 and 4) are shown. In the wayfinding tasks the participants had to walk from number 2 to 3 and from number 4 to 5. The numbers correspond to the order in which all tasks were performed.

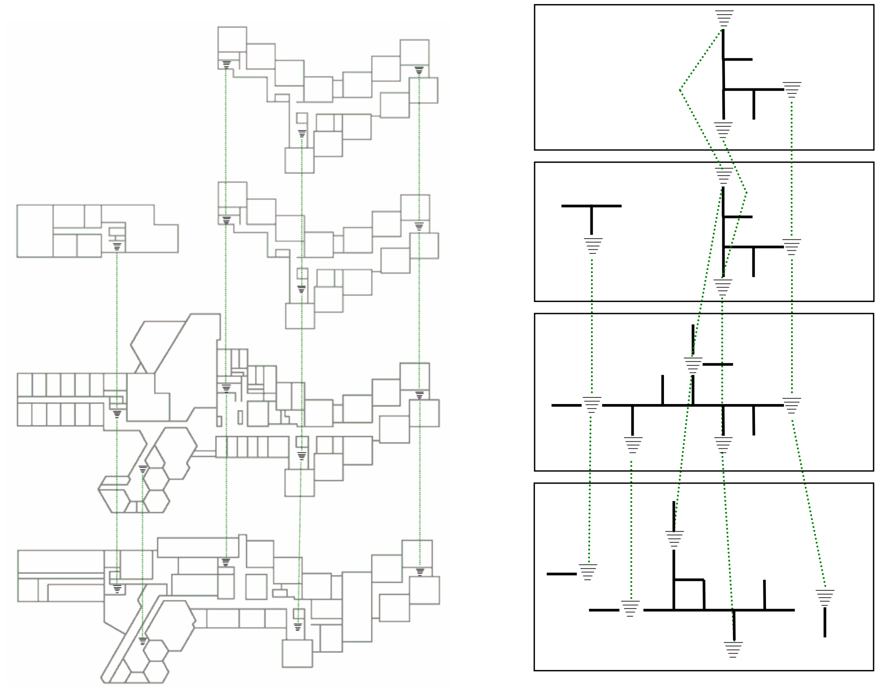

Fig. 2. The floor plan on the left and the schematised "simple" map on the right. Corresponding staircases on different floors are connected with green dashed lines.

also disoriented and brought to the correct floor via corridors only accessible to staff and by an elevator starting from the basement. They could, therefore, infer not being in the basement any more. The participants' task was to locate themselves in the map, i.e. to show their actual position on the map. For this they were allowed use the map and walk around, but not both at the same time. The experimenter instructed them to only answer when they were certain and not simply to guess where they were.

For the two *wayfinding* tasks the experimenter brought the participants to the starting point without blindfold (number 2 and 4 in Figure 1). He showed them their current position in the map and their goal. In the building the goals were marked with a red square on the floor (number 3 and 5). The participants had to find the goal as quickly as possible while moving with normal walking speed.

The participants started with the first self localisation task (number 1) followed by the first wayfinding task (from number 2 to 3). These tasks took place in the *large area*: For the self localisation task it was necessary to more or less consider the whole building as their possible actual location. In the wayfinding task they covered about ⅔ of the building. After the tasks in the large area they performed a self localisation and a wayfinding task in the *small area*. In the self localisation task (number 4) the participants could exclude the parts of the building already known to them reducing the number of available alternatives. The adjacent wayfinding task (from number 4 to 5) covered only about ⅓ of the building and was therefore much shorter than the first wayfinding task.

The participants were videotaped. From the video we derived the following dependant measures:

- *Time* to complete the task, taken from the video. Extra time, e.g., stops with explanations because of experimental issues was subtracted
- *Distance* covered
- *Detours* to locations visited before (only in wayfinding tasks)
- *Average detour distance* per detour (only in wayfinding tasks)
- *Map usage:* Number of stops to use map (participants were asked only to use the map while standing)
- *Average map time* per map usage, i.e., average time between opening the folder containing the map and closing it again.

Two experimenters conducted the tasks in parallel. During the experiment the participants were asked to verbalise their thoughts. They also accomplished two pointing tasks before and after the second wayfinding task (at number 4 and 5 in Figure 1). Pointing and verbalisations are beyond the scope of this paper and therefore reported in a later publication. One participant in the floor plan condition had to be excluded due to not being able to complete the tasks. The assignment of participants to experimental conditions was controlled with respect to gender and experimenter. Parameter values deviating more then three standard deviations from the overall mean were replaced by the most extreme value observed inside three standard deviations. We computed independent t-test to compare between maps, gender and experimenter. Since nonparametric U-tests revealed very similar results only the more common parametric t-tests are reported.

2.2 Results

The results did not differ due to experimenter (all 20 $t(16) < 2.1$, $p > .096$, $d < 0.87$). The data was therefore collapsed for further analysis.

Table 2. Average performance in self localisation for Experiment 1 and 2. Means and (standard deviations) are shown. Means displayed in italics differ in direct comparison at $p < .05$.

	Experiment 1		Experiment 2	
	Floor plan	Simple map	Comb map	Square map
Large area				
Time [s]	352 (240)	330 (218)	246 (82)	236 (99)
Distance [m]	87 (112)	116 (59)	80 (31)	66 (23)
Map usage [n]	4.7 (4.7)	6.0 (4.0)	4.6 (0.7)	4.1 (1.5)
Av. map time [s]	*65 (36)*	*32 (16)*	36 (17)	40 (15)
Small area				
Time [s]	106 (63)	100 (49)	165 (90)	141 (55)
Distance [m]	10 (10)	18 (15)	31 (13)	22 (17)
Map usage [n]	2.3 (1.0)	2.1 (0.8)	3.1 (1.4)	2.8 (1.3)
Av. map time [s]	31 (16)	39 (41)	37 (22)	35 (9)

Table 3. Wayfinding performance in Experiment 1 and 2. Means and (standard deviations) are shown. Means displayed in italics differ in direct comparison at p < .05.

	Experiment 1		Experiment 2	
	Floor plan	Simple map	Comb map	Square map
Large area				
Time [s]	305 (144)	264 (128)	286 (65)	266 (85)
Distance [m]	183 (62)	159 (28)	153 (17)	139 (23)
Detours [n]	1.8 (1.5)	1.2 (0.8)	1.0 (0.7)	0.3 (0.7)
Av. detour dist. [m]	25 (18)	20 (21)	21 (10)	22 (2)
Map usage [n]	5.3 (3.9)	5.4 (2.2)	6.6 (2.1)	4.9 (1.5)
Av. map time [s]	28 (7)	24 (21)	21 (10)	25 (11)
Small area				
Time [s]	143 (76)	165 (52)	191 (164)	199 (125)
Distance [m]	66 (18)	94 (35)	81 (25)	86 (31)
Detours [n]	0.9 (1.4)	1.6 (1.1)	1.0 (0.5)	1.4 (1.5)
Av. detour dist. [m]	*10 (4)*	*24 (9)*	18 (13)	14 (7)
Map usage [n]	3.1 (1.8)	4.4 (1.3)	4.9 (2.0)	4.9 (1.7)
Av. map time [s]	*26 (12)*	*14 (8)*	16 (10)	19 (10)

Self localisation. In the large area participants with a floor plan looked per stop twice as long at their plan than participants with the simple map (see Table 2 left side, $t(11.0)$[2] = 2.57, $p = .026$, $d = 1.21$). We did not find any further significant differences regarding self localisation neither in the large nor the small area (all seven $t(16) < 1.22$, $p > .243$, $d < 0.61$). No *gender* differences in self localisation performance were found (all eight $t(16) < 1.15$, $p > .270$, $d < 0.62$).

Wayfinding. In the *small area* participants with a floor plan performed better than participants with a simple map (see Table 3 left side). Their average distance of detours was smaller ($t(10) = 2.67$, $p = .024$, $d = 1.86$). There was also a trend to stop less often ($t(16) = 1.77$, $p = .097$, $d = 0.83$) and cover less distance ($t(16) = 2.07$, $p = .055$, $d = 0.98$). When using the floor plan they, however, stopped for longer times than participants with a simple map ($t(16) = 2.64$, $p = .018$, $d = 1.24$). The groups did not differ significantly with respect to time or number of detours ($t(16) < 1.13$, $p > .276$, $d < 0.54$). In the *large area* participants with a simple map performed numerically better. These differences, however, never reached the level statistical significance (six $t(16) < 1.08$, p > .300, $d < 0.51$). Wayfinding performance did not differ due to *gender* (all twelve $t(16) < 1.84$, p > .078, $d < 1.33$).[3]

[2] Both experimental groups differed in their variance. The degrees of freedom were therefore adjusted from 16 to 11.0).

[3] Due to unequal group sizes and adjustment of the degrees of freedom to account for unequal variances, some rather large effect sizes in favour of men did not become significant.

2.3 Discussion

When using their maps, participants with the floor plan looked longer in the map than participants with the simple map – both in wayfinding and in self localisation. Consistent with our predictions they encoded more information from the floor plan or they needed more time to extract the relevant information from the floor plan.

For *self localisation* we predicted a better performance in participants with a floor plan. Only the floor plan not the schematic map provided local geometry which was considered an important cue in self localisation. Contrary to our prediction both groups performed equally well in localising themselves. The performance measures did not even show a consistent numerical advantage for the floor plan, excluding a lack of statistical power as an explanation. We conclude that both groups mainly used the network structure available in both maps for localising themselves. Why was that? Using local geometric features might offer too many opportunities to look for in the floor plan. E.g. there were a lot of bends in a corridor to check for in the map. Focusing on nodes in the network structure instead reduced the possible search space to a reasonable size. Fewer hypotheses had to be tested and kept in memory.

For *wayfinding* we expected participants with the simple schematic map to perform at least as good as participants with the floor plan. Despite containing much less information, the schematic map should provide the relevant information for wayfinding. While participants using the simple map performed numerically better in the large area, participants using a floor plan performed better in the small area. Why did they perform better in one task? We assume that the simple schematic map provided ambiguous turning information after floor changes. After walking down the stairs, participants with the simple map could not know whether they should turn left or right next. Participants with a floor plan could disentangle this ambiguity by local geometric features e.g. the form of a corridor. Indeed in the small area task almost all detours using the simple map had their origin after exiting stairs. In the large area task no ambiguity occurred, as all stairs were located at the end or very close to the end of a corridor. Here, no advantage of the floor plan was observed. In order to address this problem we conducted a second experiment in which we varied the ambiguity of two schematic maps.

3 Experiments II

3.1 Methods

The goal of this experiment was to determine the influence of ambiguity in schematic maps. In the simple schematic map of Experiment 1 we identified an ambiguity for participants after floor changes. Especially in the small area participants could not know from the map which direction they had to go when exiting stairs. To disentangle this ambiguity we placed the symbols for staircases to the side of a corridor and oriented them facing the direction towards the corridor (see Figure 3 right side). Also the lines connecting floors via the staircases were changed and entered the stair from the back additionally indicating ones orientation when exiting a staircase. For the

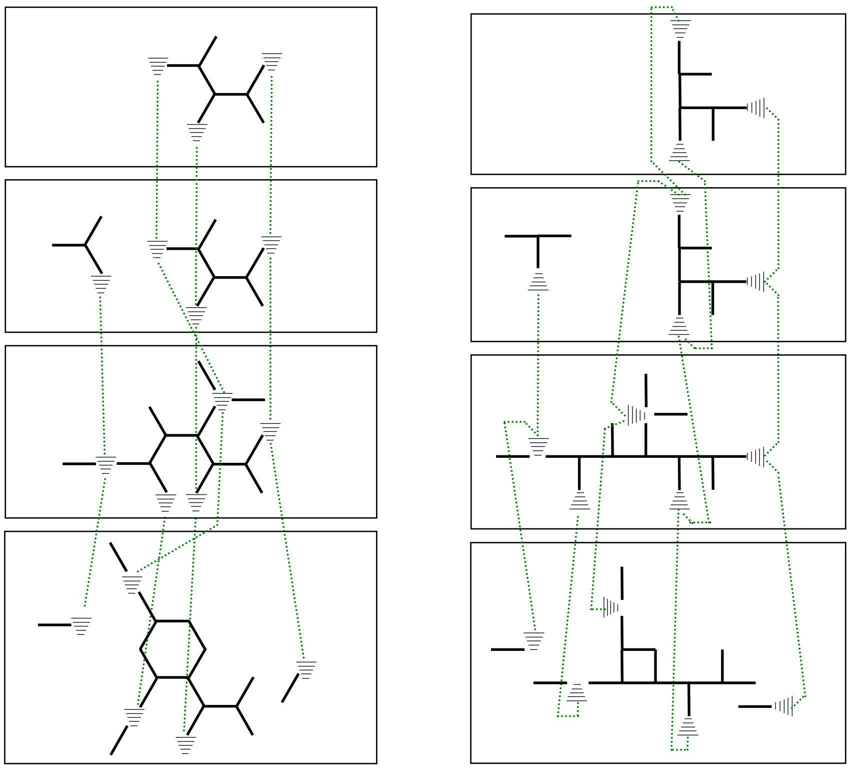

Fig. 3. The maps used in Experiment 2. On the left side the ambiguous "comb map", on the right side the unambiguous "square map".

ambiguous map the staircases and connections between the floors were the same as in the simple map of Experiment 1 (see Figure 3 left side). Additionally the structure of intersections was changed from 90° angles to 120° angles in order to provide two path alternatives branching off at the same angles. At an intersection the map always provided a left and a right alternative, no matter whether in the building this was a T-intersection or a corridor branching off to the left. In the later case the main straight corridor was indicated in the map not with a straight corridor, but with a turn to the right. Due to its honeycomb structure we called this map "comb map". In contrast to that we called the unambiguous map "square map".

The experiment took place at the same annual summer school as Experiment 1 one year later. Nine women and nine men agreed to participate in the experiment. Again, the participants were around the end of their twenties (M = 27.4; SD = 12.6) and spoke German fluently. One participant in the square map condition not reported here had to be excluded due to not being able to complete the tasks. The selection and assignment of participants, the tasks, procedure, instruction and data analysis were identical to Experiment 1.

3.2 Results

Except for detours in wayfinding in the small area ($t(16) = 2.39$, $p = .029$, $d = 1.13$), the results did not differ with respect to experimenter (all 19 $t(16) < 1.51$, $p > .150$, $d < 0.60$). No different results were obtained when including the experimenter in the analysis of this parameter. Therefore, only the collapsed data are reported.

Self localisation. The participants performed equally well in localising themselves, no matter whether they used the comb map or the square map (see Table 2 right side, all eight $t(16) < 1.24$, $p > .236$, $d < 0.59$).

In the small area women outperformed men. They were faster (109s vs. 197s, $t(16) = 3.12$, $p = .007$, $d = 1.47$), covered less distance (15m vs.. 37m, $t(16) = 4.17$, $p = .001$, $d = 1.96$) and used the map less often (2.2 vs. 3.7, $t(16) = 2.78$, $p = .014$, $d = 1.31$) before correctly localising their position. Women and men did not differ in time per stop or in the in the large area (all five $t(16) < 1.27$, $p > .224$, $d < 0.60$).

Wayfinding. Participants with the comb map and the square map did not differ in their general wayfinding performance (see Table 3 right side). In the large area there was a trend for participants with the square map to make less detours ($t(16) = 2.0$, $p = 0.63$, $d = 0.94$) and use the map less often ($t(16) = 1.94$, $p = .070$, $d = 0.91$; all ten other measures $t(16) < 1.42$, $p > .176$, $d < 0.68$). Wayfinding performance did not differ with respect to gender (all twelve $t(16) < 1.84$, $p > .302$, $d < 0.51$).

3.3 Discussion

Participants with the ambiguous comb map and participants with the unambiguous square map did not differ in localising themselves. As in Experiment 1 this findings indicate that the network structure was the main source of information used for self localisation. Unambiguous local intersections and staircases only provided in the square map did not lead to a significantly better performance. Local unambiguousness did not play a crucial role in these tasks.

We do not have an explanation for the better performance of women in self localisation. This did not occur in Experiment 1 where there were no significant differences, men even performed numerically better. Generally, men are known to perform slightly better than women in spatial orientation tasks (for a recent review see [5]). For the wayfinding tasks used in Experiment 1 and 2 which were the same as tasks used in another experiment [11] no advantage for women was observed.

We did not observe any significant differences in wayfinding performance with respect to the maps. There was a trend for participants in the large area to perform better with the unambiguous square map. With nine participants per group this difference, however, did not reach the level of significance. Ambiguity could therefore *not* be a crucial factor for wayfinding with schematic maps. A minor importance of ambiguity could, however, not be ruled out. To see how participants with ambiguous *and* unambiguous schematic maps perform in relation to a floor plan we compared the results of Experiment 1 and 2.

4 Comparison of Experiment I and II

4.1 Methods

In order to compare a floor plan with ambiguous and unambiguous schematic maps over both experiments we used three groups: a) The floor plan, b) the unambiguous square map and c) the two ambiguous schematic maps, consisting of the simple map from Experiment 1 and the comb map from Experiment 2. We compared these three groups using a one-way ANOVA with pair-wise planned contrasts between the groups when an overall difference was observed. Especially the contrast between the floor plan and the unambiguous square map was of interest as the other two contrasts were partially contained in the data already presented in section 2 and 3.

4.2 Results

Self localisation. In the *large area* the time participants looked at the map per stop differed as a function of the kind of map (see Figure 4 left side $F(2, 33) = 6.07$, $p = .006$; $\eta^2 = .27$). Participants with a floor plan looked longer at the map compared to participants with schematic maps (floor plan vs. ambiguous maps: $t(33) = 3.45$, $p = .002$, $d = 1.14$; floor plan vs. unambiguous square map see also Table 2 outer columns: $t(33) = 2.41$, $p = .022$, $d = 0.93$). In the *small area* there was a trend for the participants to differ in the distance covered before locating oneself ($F(2, 32) = 2.62$, $p = .088$; $\eta^2 = .14$). Here participants with a floor plan covered less distance compared to participants with ambiguous maps ($t(32) = 2.26$, $p = .031$, $d = 1.11$; two other contrasts: $t(32) < 1.67$, $p > .106$, $d < 0.86$). We did not reveal any further reliable differences in other parameters (six $F(2, 33) < 1.0$, $p > .380$, $\eta^2 < .06$).

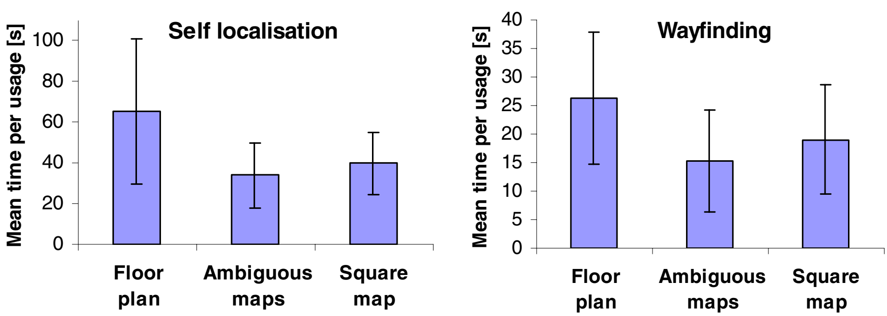

Fig. 4. Mean time of map usage in participants with the floor plan, ambiguous maps and the unambiguous square map in both experiments. Means and standard deviations are displayed for self localisation in the large area (left side) and for wayfinding in the small area (right side).

Wayfinding. In the *large area* task participants differed in the number of detours ($F(2, 33) = 5.0$, $p = .013$, $\eta^2 = .23$) and the distance covered ($F(2, 33) = 3.31$, $p = .049$, $\eta^2 = .17$) as a function of the kind of map they used (see Figure 5). Participants with the unambiguous square map performed better than participants with the floor plan (detours: $t(33) = 3.14$, $p = .003$, $d = 1.24$; distance $t(33) = 2.54$, $p = .016$, $d = 0.93$, four other contrasts: $t(33) < 1.96$, $p > .059$, $d < 1.06$). We observed no further differences in the four other parameters (all $F(2,33) < 0.61$, $p > .553$, $\eta^2 < .04$).

In the *small area* task the participants differed in the time of their average map usage (see Figure 4 right side, $F(2, 33) = 3.87$, $p = .031$, $\eta^2 = .19$). Participants with ambiguous schematic maps looked shorter at their maps than participants with the floor plan ($t(33) = 2.78$, $p = .009$, $d = 1.08$; two other contrasts $t(33) < 1.59$, $p > .122$; $d < 0.70$). There was a tendency for floor plan users to stop less often compared to participants with schematic maps ($F(2, 33) = 3.14$, $p = .056$, $\eta^2 = .16$). We observed no differences in the other four parameters (all $F(2, 23/33) < 2.44$, $p > .109$, $\eta^2 < .18$).

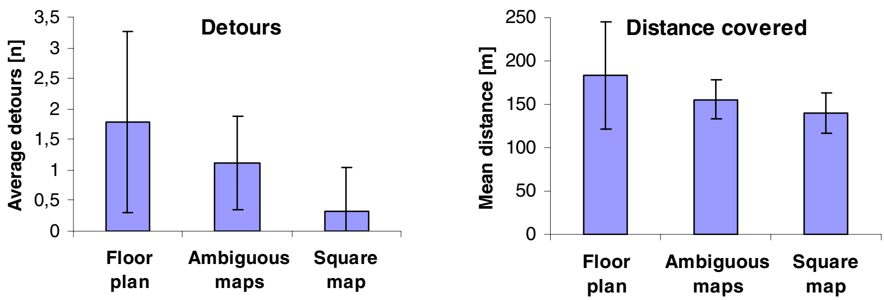

Fig. 5. Wayfinding performance in participants with the floor plan, ambiguous maps and the unambiguous square map in the large area compared over both experiments

4.3 Discussion

Participants with an unambiguous schematic map performed better in *wayfinding* than participants with a floor plan. In the large area task they made less detours and covered shorter distances. Despite its lower information content, using an unambiguous schematic map can lead to better performance than using a floor plan. This result is consistent with our prediction.

Why can it be better to use a schematic map? Time for planning and encoding alone could not be the reason. Participants looked at the schematic maps for shorter times, but this could only influence the overall wayfinding time and could not explain the fewer errors, i.e., fewer detours and the less distance covered. We assume that participants either encoded better information in concentrating on route knowledge or that they applied a better strategy, i.e., a route strategy. The schematic maps were constructed to provide only correct route knowledge which was shown to be central to wayfinding (see section 1.2). From such a map a user could learn where to turn at an intersection, but a user could not learn survey knowledge as distances and directions between locations on the schematic map did not correspond to the real distances and directions in the building. This fact was known to the participants. They were thus forced to encode and use only route knowledge. In contrast, participants with a floor plan could also encode survey knowledge or even local geometry. This information was less useful for the task (see section 1.2). Considering that memory capacity is limited, concentrating on relevant information should lead to fewer errors and therefore less detours and less distance covered.

The survey information from the floor plan might, however, not just distract from the more relevant route knowledge, it also enables the application of a survey strategy [9, 11]. Within a floor a participant could encode only the direction and distance of a (sub-)goal and try to walk there directly. In doing so, a route not leading to the (sub-)goal could be chosen resulting in more detours and distance covered. Although the survey strategy needs very little information to be transformed and encoded from the map, the encoded vector pointing to the (sub)goal has to be updated constantly. Consequently, the survey strategy implies a higher memory load during walking through the building which also could lead to more errors. With the route strategy the turning information at decision points had to be transformed and encoded from the map and maintained until it was used, but nothing had to be updated. So the memory load for the route strategy was high only during transforming and encoding when participants could use the map as an external representation to ease their tasks [21]. Further research has to clarify whether the advantage of a schematic route-knowledge map stems from applying a different strategy or rather from a memory effect, e.g., not encoding irrelevant survey information or additionally relying on verbal memory to encode route knowledge. In the comparison of route and survey knowledge it might also be interesting to produce a map only providing survey knowledge and no route knowledge. Such a map would include the correct topographical location of decision points, but connecting paths would not be visualised. But very likely such a map would be practically useful only for navigation tasks in open terrain, not for indoor environments.

One factor in route knowledge is ambiguity. Route knowledge should be unambiguous. We did not find any significant differences when varying ambiguity in the second experiment. Maybe our variation was not strong enough. If we had used a topological and therefore a completely ambiguous map for comparison, we probably would have found stronger effects. However, when comparing the floor plan to the schematic maps only the contrasts to the unambiguous square map became significant. Ambiguity, therefore, has to be relevant in some way, although other factors might be more central.

Consistent with our prediction, participants needed less *time for encoding* information from a schematic map than from a floor plan. This holds true for both self localisation and for wayfinding. With less information provided in the schematic maps, participants are limited in the amount of information to encode. Additionally, they do not have to search for the relevant information within irrelevant information.

In *self localisation* no general advantage of the floor plan compared to schematic maps could be revealed. There was a trend for participants with the floor plan to cover less distance. This, however, only holds true for comparing floor plans with ambiguous schematic maps. No reliable difference or even trends between floor plan and the unambiguous square map could be revealed. We conclude that most participants relied on the network structure rather than the geometric layout. Searching the floor plan for locations with a specific geometric layout probably offered too many possible alternatives. Limiting the search space to easily identifiable configurations of nodes like intersections and staircases reduced the number of possible alternatives to a reasonable amount that can be handled by humans. The higher importance of network structure over geometry stands in contrast to results from self localisation studies which emphasise the importance of geometric features [e.g. 7]. There are, however, substantial differences between these studies and our experiment: Our participants had to localise themselves in an unknown environment using a map providing an *external representation*. In research on self localisation participants most often had seen the environment before and judged their current location based on their memories of this environment which are *internal representations*. A further difference besides internal vs. external representations is the kind of space the experiments took place in. In most self localisation experiments only room sized environments were used. According to Montello [17] these spaces can be called *vista spaces* as all the space is visible from one point of view which also holds true for open places or even small valleys. Contrary to that, to understand *environmental spaces* we have to move around and take several views of the space into account which is the case for towns or buildings like in our experiment. So at least the kind of space (vista vs. environmental space) and the representation system on which the self localisation task was based (internal vs. external) differ between our experiment and most self localisation studies. Identifying, which factor or combination of factors do in fact cause participants to localise on the *network structure* rather than on *geometry* is subject to future research.

When comparing *gender* over both experiments (not shown) we did not observe significant differences like in Experiment 2. Reliable differences of any kind should be even stronger when comparing more participants. We, therefore, do not think that the gender differences observed in Experiment 2 should be emphasised too much.

5 General Discussion

Despite containing much less information, using a highly schematic map can lead to better wayfinding performance than using a topographic floor plan. Providing unambiguous route knowledge is central for this performance benefit. Self localisation with such a map is generally at least not worse than with a floor plan. Like the users of a schematic map, the users of floor map orient on the network structure rather than on local geometric features which would imply a very large search space. Both in wayfinding and self orientation participants are faster to encode information from the schematised map.

How do these results generalise to other situations and maps? All significant results in this study are based on large effect sizes with respect to Cohen [4]. In this field experiments we are not dealing with a highly artificial laboratory effect only observed under very specific conditions. The practical application for the results in self localisation will, however, be limited. In many maps today our current location is already marked, e.g. when using a wall-mounted you-are-here-map or a GPS-based system. For an old fashioned city map we often localise using street names or landmarks rather than comparing the network structure of our surrounding with the one in our map. Also the wayfinding results are not transferable to all situations: Our highly schematic maps can only be constructed for non-circular street layouts, as can be seen in the schematic maps of the basement. For the common route maps which only display one route this is not a problem. For other maps, the rather strict construction constraints have to be relaxed and e.g. turns have to be allowed, too.

From a navigational point of view, the floor plan might also be improved e.g. by marking corridors in a different colour, probably leading to faster encoding times and maybe also less errors. Our results might therefore depend on the kind of maps we used. The point we wanted to make, however, was how little information is sufficient for good performance. In any case, this information about where to turn at a decision point should never be omitted! More information could be helpful, but less information will probably be detrimental. This point also applies to generalising to other settings than multi-level buildings, e.g. cities. The building used was rather complex. For more simple environments, other results might be expected, but at the same time any map might be obsolete in a simple setting. The complexity of our building, however, shows the importance of unambiguous turning information for non-trivial wayfinding tasks. Unlike in a building, in a city there is only one “floor”, but this floor extends much further horizontally. Both are rather complex and they both are environmental spaces according to Montello’s [17] definition, therefore the results probably can be generalised.

Our results as well as wayfinding literature regarding maps in comparison to signs [3, 10] and verbal directions [15, 22] suggest: When trying to reach a goal in an unknown environment unambiguous turning information at decision points is more important than survey knowledge. May your route knowledge be communicated by signs, verbal directions or maps – this is the type knowledge you need!

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