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Signs and Maps – Cognitive Economy in the Use of External Aids for Indoor Navigation

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Abstract

Wayfinding in public buildings often proves to be a challenge especially for first time visitors. The experiment investigates the relative effectiveness and efficiency of external aids for navigation in a complex multi-level, multi-building ensemble. A previous experiment provided the performance baseline for the re-design and prototype evaluation of the information system. Navigation aids were tested in three conditions: maps, signs, and the combination of both. With respect of usage a preference for signs over maps was identified. Also, signage had the largest impact on wayfinding performance, while maps alone showed the smallest level of support and the combination provided yet further improvement. Analysis of individual tasks identifies limitations of each type of external aid. A comparative task analyses reveals higher cognitive costs of maps relative to signs. The results are discussed in a framework of cognitive economics and agent rationality, explaining both usage preference & performance differences.

Keywords: spatial cognition, wayfinding, map, sign.

Introduction: Indoor Wayfinding

Entering an unfamiliar building and searching for a particular room is a common, but sometimes difficult task in everyday life. Without the support of external navigation aids people have to rely on common knowledge about the structure of buildings in general, their experience with similar buildings and, mainly, on the visual input they encounter when moving through the building. An additional difficulty is imposed in multi-level buildings. People often have trouble remaining oriented when changing floors regardless of whether they use elevators or stairs (Soeda, Kushiyama & Ohno, 1997). Weisman (1981) identified four major variables that influence wayfinding: (a) visual access, (b) architectural differentiation, (c) floor plan complexity, and (d) signage and room numbers.

The present study is concerned with the latter issue and investigates the effect of signs in contrast to wall-mounted maps in a complex multi-level building. It is based on an earlier study conducted in the same setting (Hölscher, Büchner, Meilinger & Strube, in press), where we investigated wayfinding performance and navigation strategy in a building setting that combines vertical and horizontal complexity. While navigating this building proved quite difficult for all participants, substantial performance differences between first-time visitors and experienced users of the building were identified. In this previous study, we systematically varied access to the standard fire escape plans mandatory for public buildings in Germany. First-time visitors were found to use these maps extensively. However, no significant performance increase was observed: Users of the fire plans lost time reading the maps, but without substantial wayfinding benefit.

Collaboration with the Freiburg Graphics Design School provided the opportunity for a structured re-designing of the deficient information system in this building complex. The decision was made to combine consistent, highly salient signage at each potential decision point (Arthur & Passini, 1992) with wall-mounted maps at key locations. The main objective of this intervention was to enable even first-time visitors to easily navigate in the complex building ensemble.

Maps and Signs as External Representations

Gärling, Lindberg & Mäntylä (1983) presented evidence that showing a floor map to participants immediately prior to testing reduced the effects of familiarity with the building and improved wayfinding performance. Learning from a map can be equally effective as being a long-term user of a building as long as it concerns configurational knowledge (e.g., Thorndyke & Hayes-Roth, 1982).

When it comes to real life wayfinding performance, it is not unequivocally clear that access to floor maps does indeed have a positive impact. Wayfinders interacting with wall-mounted 'You-Are-Here' (YAH) maps may lose time without gaining any navigational advantage (Butler, Acquino, Hissong & Scott , 1993; Hölscher et al., in press). It is also well-documented that using a map that is misaligned with one's current orientation can be detrimental (e.g. Levine, Jankovic & Palij, 1982), a feature of many standard floor maps in office buildings. However, this problem could be excluded in the study by Hölscher et al. (in press) as well as the present one. Several studies have shown that signs can improve wayfinding performance (O'Neill, 1991), apparently outperforming maps (Butler et al., 1993). But these studies have been limited to signs that only include information about a single or a rather small number of destinations. It is likely that this is not generalizable to more complex settings (Butler et al., 1993,

p. 163). The present study tests the potential of both maps and signs alone and their mutual combination for complex navigation tasks with numerous potential task destinations in a realistic setting.

Cognitive Economy of Navigation Aids

Assessing the quality of an information system for wayfinding requires looking at the *effectiveness* of task performance as well as taking into account the *efficiency* of its usage. Whether or not an external navigation aid is accepted by potential users will largely depend on the cognitive cost structure associated with using it, both in terms of time and cognitive demands, especially attention and working memory loads. A principle of rational behavior (Anderson, 1993) implies that cognitive agents will choose task strategies with an optimal cost-benefit structure (see also McFarland & Bösser, 1993). Numerous examples in the 'external cognition' literature highlight the role of 'computational offloading' as a motivation to use external aids (cf. Scaife & Rogers, 1996). Recently, Gray, Sims, Fu & Schoelles (2006) have shown that the costs of usage are essential, because even a very small change in cost can lead to a radical change of problem solving strategies applied.

From this perspective the use of external aids like maps and signs in wayfinding appears to be a search for the most efficient behaviour – after all, people normally do not want to lose time by taking unnecessary detours.

Signs clearly support 'computational offloading': navigating from sign to sign requires virtually no route planning and no memorizing of multiple route segments. It does require a two-fold visual search task, however, searching (a) for the sign itself in the environment and (b) for the crucial information on the sign. The subsequent route decision process is primarily based on matching the room number of the target destination with the number range of each direction alternative on the sign (cf. Fig. 1).

Maps provide much more information than a single signpost. They allow for planning the route almost completely in advance. For navigation the user needs to (a) select information pertinent to the task at hand, (b) plan a route or identify the goal to approach it directly (c) translate the information from a birds-eye view to an ego-centric reference frame (cf. Shelton & McNamara, 2004). The specific route or the location of the goal must be (d) memorized, and progress must be (e) verified from time to time, often by consulting the map again.

The comparison of the cognitive costs required by using either signs or maps in wayfinding, is clearly shifted in favor of signs. Therefore, we expect people to use signs more frequently than maps. Because of the memory load incurred with planning from maps, we also expect signs to be not only more efficient, but more effective as well. The question remains whether maps provide an additional advantage if both maps and signs are present. You-are-here maps might, potentially, serve to aid self-localization and monitoring of one's progress towards the goal. The following experiment aims at testing these expectations.

Method

The study was conducted in the main building complex of the University of Freiburg. One section (KG I) is an Art Nouveau building from 1911, the other part (KG III) was built in the 1960s and is directly connected to the old building. The floor levels do not match between buildings: KG I level 4 is on the same height as KG III level 5, and on one level there is no direct connection. This, and the fact that the room numbering scheme is rather uncommon (first digit denotes the building, not the floor level) makes it particularly difficult to navigate through the building.

Materials: Signage & Maps

As the building originally contained only very sparse and incomplete signage and no graphical aids besides the fire escape maps, a full re-designing of the information system was necessary. The signs and maps were designed by the Freiburg Graphics and Design School in a iterative design-evaluation-re-design cycle with the authors. The goal was to create a clear signage system communicating the uncommon properties of the building. One criterion was to avoid visual clutter and informational overload while providing all relevant information with an emphasis on supporting error-free navigation for tasks requiring travel between building parts and between floors.

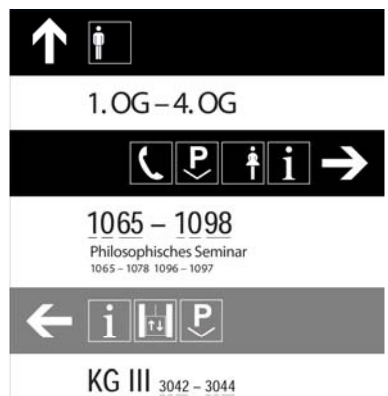

Figure 1: Example of the signs used in the study. (1.OG = second floor). The four digit numbers denote individual rooms, "KG III" denotes the adjacent building section. Note that original colors were blue (here black) and red (gray).

The signage system consists of a three-level hierarchy: main information boards near the main entrances, main distributor signs (cf. Fig. 1) and supplement distributor signs. Each level refines the resolution of information when the visitor moves further into the building. The signs had a width of about 60cm and were mounted on the wall at eye-level. They were intended to provide flexible navigation support: a) within a single floor, b) between floors, and c) between building sections. On both the signs and maps, the two buildings were color-coded (red and blue with maximum contrast). The distributor signs were placed at key decision points which were identified during the evaluation process. The information boards and the main distributor signs included a map in addition to the signs. The maps (for an example see Fig. 2) contained a 2D bird's eye view as well as a cross section view in order to communicate the non-matching floor levels as well as vertical connections to the user. Both, the bird's eye view and the cross section view were aligned with the environment so that the top of the map corresponded to "ahead" in the environment (Levine et al., 1982). In addition the information boards contained an explanation of the uncommon room numbering scheme. Pseudo-Isometric 3D maps (Fontaine, 2001) were considered not feasible, as detailed room number information needed to be included, leading to too much visual clutter. Similarly, room numbers for destinations in the other building section were only provided on the current floor and when a hallway directly linked to the other section.

Participants & Experimental Design

36 participants (16 of them female) between the ages of 19 and 53 years (M= 24.1, SD= 5.9) were recruited through postings on campus and e-mailing lists. Most of them were students from a variety of subjects. None of them knew the building before the study. Participants were paid or received course credit for participation.

Access to the external aids was varied as a between-subjects factor: In the 'maps-and-signs' condition both, the re-designed signs and maps were available to the participant. In the 'signs-only' condition only signage, and in the 'maps-only' condition only maps were available.

Procedure

The experimenters met the participants in a building close to the experimental building. The participants' main task was to subsequently find six locations in the building. All participants received the tasks in the same order, and the tasks were linked so that one task's goal location was the next task's starting point. There was no time limit for completing the task.

Tasks were designed to cover a realistic range of difficulty with respect to the number of floor changes and the requirement to change the buildings. They were also selected in a way that there was more than one path between start and goal (except task 1). Two tasks from Hölscher et al. (in press) were omitted because they included destinations that were not covered by the prototype of the new signage used for the current study.

In order to provide a fairly realistic situation, the experimenter gave oral instructions by providing the room number, for example, "Find room number 1019"[1]. This type of instruction provides the same information as students might have when they get it from their timetable. Participants were instructed to think aloud and thus verbalize their thoughts and considerations; performance was videotaped by a second experimenter, following the participant with a distance of about 2 meters. Usage and performance measures were coded from the video which allowed a thorough analysis of the participants' trajectory, the time required, detours and additional measures.

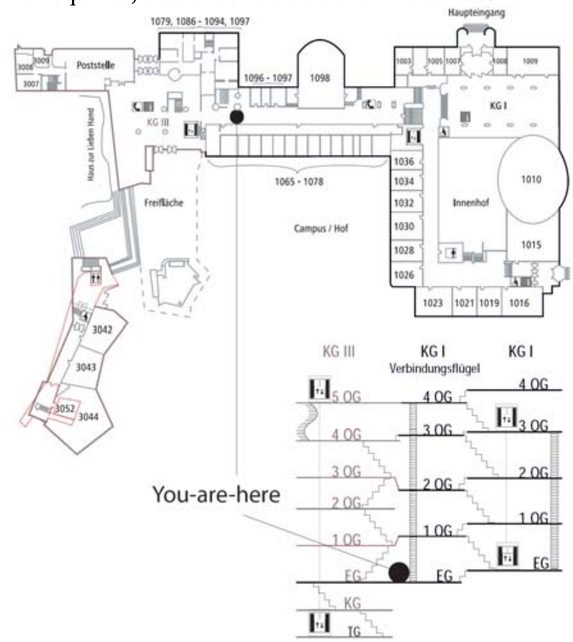

Figure 2: Example of maps used in the study; including plan & section view. KG III section on the left, KG I with mezzanine on the right (map edited for printing).

Results

Aid usage and performance measures were compared among experimental conditions. The data from Hölscher et al. (in press) served as comparative data (light gray bars in Fig. 3 and 4). Since map accessibility influenced neither aid usage nor wayfinding performance the data of the map and the no-map condition from Hölscher et al. (in press) were merged. We only differentiate between first-time visitors to the building (inexperienced) and regular visitors (experienced). The two conditions can be considered a baseline and a benchmark since the goal of the design intervention was to enable first-time visitors to perform as well as regular visitors.

The experimental conditions were compared in separate ANOVAs for each dependent variable with planned contrasts between them. For comparison the performance data of experienced and inexperienced participants from the earlier study were included resulting in a total number of participants of 68. For mean values refer to Table 1.

Usage

The frequency of map access per task, the average time per stop, and frequency of sign usage per task were measured. Frequency of map access varied across experimental

[1] In either task no. 4 or 5 the target was shown by marking the target room with an "X" in the window. These trials were not included in the analysis and will be presented elsewhere since the results go beyond the scope of this paper.

conditions [$F(3,54) = 8.701$, $p < .001$]. Figure 3[2] shows that participants in the maps-and-signs condition stopped at maps less frequently than those in the maps-only condition [$t(24) = 2.698$, $p < .013$], indicating that the presence of signs caused participants to neglect the maps. In addition it shows that they stopped at maps as rarely as the participants in Hölscher et al. (in press) who were not familiar with the building and only had the inefficient fire plans available [$t(24) = .013$, $p = .73$].

Table 1: Usage and performance measures (means).

	previous study		current study		
	inex-perienced *M*	ex-perienced *M*	maps only *M*	signs only *M*	maps &signs *M*
Usage					
map access per task [n]	0.68	0.27	1.83	--	0.62
time/stop at maps [sec]	23	20	21	--	25
sign usage per task [n]	0.43	0.29	--	3.02	3.13
Performance					
distance per task [m]	198	161	188	176	158
time per task [sec]	208	141	204	179	156
PAO* [%]	81	36	64	62	36
stops/task [n]	3.28	1.28	2.13	1.18	0.80

* percentage above optimal

The time spent at the maps per stop did not vary across the four map conditions [$F(3,33) = .342$, $p = .80$]. There was no frequency-accuracy trade off and the improved quality of the maps did not cause participants to spend more or less time at them. Sign usage was different across all conditions [$F(3,48) = 54.620$, $p < .001$]. This time, however, we found no difference between the signs-only and the maps-and-signs groups [$t(18) = .222$, $p = .83$]. Thus, the availability of maps did not decrease sign usage. In both the maps-and-signs condition and the signs-only condition, participants looked at the signs much more frequently than in the two conditions from Hölscher et al. (in press) [all $t(24) > 6.252$, $p < .001$; for means refer to Table 1]. The results suggest that the signs were salient and were consulted frequently, even when maps were available.

Performance

The following performance measures were recorded: mean distance covered [m], mean time to complete the task [sec], PAO ("percentage above optimal", i.e. the proportionate additional distance walked compared to the shortest possible path), number of stops (not including the stops at maps). Stops are considered as a measure of processing load during navigation (O'Neill, 1991).

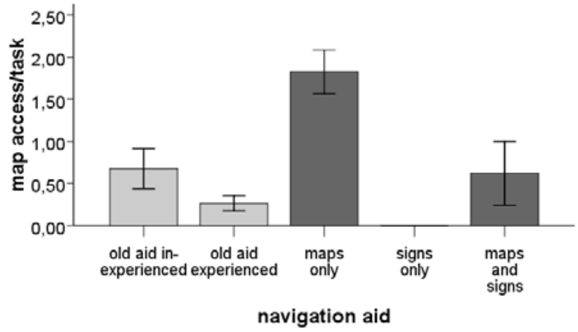

Figure 3: Mean number of stops at maps and SE.

Figure 4 shows that the distance participants covered in order to find the goal differed between experimental groups [$F(4,63) = 3.156$, $p < .020$]. In the maps-only condition and the signs-only condition participants walked slightly but not significantly shorter distances than inexperienced participants in Hölscher et al. (in press). Providing both, maps and signs, decreased the distance by over 20% [$t(22.275) = 3.451$, $p < .002$] in contrast to the distance covered by inexperienced participants with old aids. In fact it approached the distance experienced participants covered in the earlier study. PAO yielded a similar pattern of data [$F(4,63) = 2.923$, $p < .028$]. Providing both navigation aids helped inexperienced participants avoid redundant trips and perform like experienced participants [$t(24) = .007$, $p = .99$].

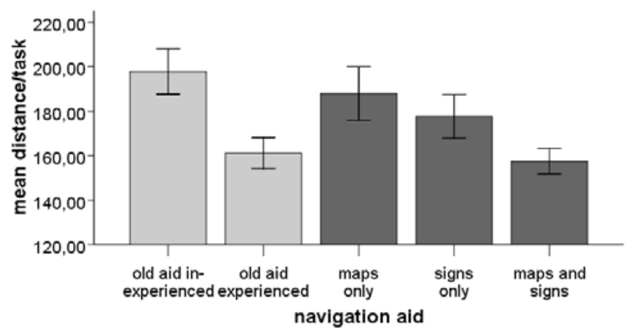

Figure 4: Mean distance covered and SE.

The time participants required to complete the task showed a similar pattern as well. The overall ANOVA showed significant differences between experimental groups [$F(4,63) = 6.500$, $p < .001$]. Participants in the maps-only condition and the signs-only condition required slightly less time than inexperienced participants in the earlier study. Providing both, maps and signs, reduced the required time by 25% [$t(24) = 2.64$, $p < .014$] in contrast to the time inexperienced participants required with the old navigation aids. They also approached the time experienced participants required in the earlier study. The number of stops also differed between experimental conditions

[2] Note that the figure shows all five conditions. The ANOVA analyses of each usage measure included only those conditions in which the participants had access to that particular navigation aid. e.g., for map usage the 'signs-only' condition was excluded.

[F(4,63) = 9.248, p < .001]. Here, participants in the maps-only condition stopped less frequently than unfamiliar participants with old aids [t(30) = 2.227, p < .034], so maps alone allowed participants to move more fluently with fewer stops. Participants in the signs-only condition stopped even less frequently than in the maps-only condition [t(24) = 2.148, p < .042]. Providing both maps and signs reduced the number of stops even further, though not significantly.

Discussion

The re-design of the information system in this complex building was a success, especially in comparison to the originally sparse signage and non-helpful fire escape plans. Combining new signs and maps allows first-time visitors of the building to exhibit wayfinding performance on the level of our benchmark group, users with substantial experience in the building. We found a clear, yet asymmetric trade-off in the *usage* of maps and signs. When the maps were presented without the signs, the maps were a highly popular navigation aid. In the co-presence of signs, map usage dropped by 66%. By contrast, the new signs were not only used more often than the maps (probably because there are more signs than maps *available* across the building), but whether or not maps were available had no impact on sign usage. In the presence of good signage, maps are used as a supplement, not as a replacement for signs. Interestingly, we found virtually no differences between any of the map conditions for the average duration of a map inspection: The fire escape plans in the old study were inspected for the same amount of time as the re- designed maps with their integrated section views and co-presence of signs had no effect either. It appears as if wayfinders in this setting have a constant upper limit of time they are willing to invest in any map interaction before trying their luck elsewhere. Regarding *performance*, the combination of signs and maps was more successful than each type of external information by itself. Yet some distinct differences are apparent: Maps alone provided the smallest improvement over the baseline performance from the previous study. Signs did better than maps alone, especially regarding stops and time. Finally, combining the two had the strongest impact on distance and PAO measures, i.e. avoiding detours and redundant paths.

Comparing the task structure for maps and signs

While reading a map is generally considered a complex skill, navigating by signs is ideally very straight-forward, especially for locating a room by its number: Having no further source of information, the navigator approaches a sign and reads the text on it. He needs to parse the options provided by the sign and choose the direction that matches the target room number most closely. In our case, this means comparing the room number ranges under each arrow with a single stored 4-digit target number. After that the user starts walking and proceeds until he encounters the next sign. As long as all upcoming decision points bear complete signage, no further information has to be memorized. Compared to floor plans most individual signs carry much less information, often allowing the navigator to read most of it without having to stop. The designer of the signage system has already planned the proper decision sequences (routes) between destinations. In this sense the navigator can 'outsource' the route planning almost completely, maximizing the amount of 'computational offloading'.

Navigating with wall-mounted maps and no signs in a complex building shows a remarkably distinct task structure. Reading a wall-mounted map requires standing in front of it for the duration of the map interaction. You need to identify your own position as well as the location of the target destination on the map. Then you must find routes on the map that connect to the target location, possibly deciding between several options. If the route consists of several segments, a sequence of actions needs to be memorized. The survey image of the map must be translated into route information (turning decisions). The computation of these turning decisions requires a perspective switch to a route perspective.[3] If the target room is on a different floor, map based route planning becomes even more complex. Vertical connections must be identified, ideally, with the help of the supplemental cross-section. In theory, the maps provided in the present study would allow for near-perfect route planning. But it appears that the cognitive costs involved kept people from even trying to perform such complete planning in the absence of signs, as the average duration of map interactions was constant.

Downs & Stea (1973) identify four basic operations of wayfinding: orienting oneself in the environment, planning the correct route, monitoring this route, and recognizing that the destination has been reached. Following signs eliminates most of the cognitive effort by translating the steps of orienting, planning and monitoring into a simple matching of numbers, while the user of a wall-mounted map faces inferences and memory load, increasing with the complexity of the route. In this light, it is easy to understand why users who have access only to maps need more time to complete the task. Also, the frequent stops en route can be tied to the fact that map users had to spend cognitive resources on route monitoring and possibly rehearsal of route segments. The cognitive load of map interaction is further illustrated by the fact that map users (irrespective of signage presence) more often forgot the target room number, hinting at working memory load. Processing costs of reading signs are extremely low compared to maps. This explains why their usage rate is independent of map availability.

Limitations & Future work

Naturally, the task analysis above is based on the very strong assumption that adequate signage is made available at each decision point. But providing complete coverage in the signage system has its practical limitations. Consequently, the apparent disadvantage of maps in terms

[3] While the map design in our study eliminates the alignment problem for the immediate surroundings of a map's location (Levine et al., 1982), subsequent turning actions are still subject to alignment mismatch of map orientation and ego perspective.

of cognitive economy can turn into an advantage. If there is no sign at a decision point, or the range of options covered by that sign does not include the desired target, wayfinding support will break down. Planning and memorizing a route with a map can avoid this limitation. With signs alone, participants performed less well than participants who could combine map and sign usage. This raises the question of what the additional benefit of the maps is, when sign usage is so dominant. Here maps provide an extra level of security and independence. Should a subsequent sign be missing or incomplete with respect to the target location, one can fall-back on map-based information. If a rational agent takes this into account, supplemental map usage is a rational behavioural strategy. In fact, the relative usage of maps in the maps-and-signs condition is declining over the course of the experiment: Although the last task (task 6) requires both a change of floors and building sections, none of the users refer to the maps. This may be due to general spatial learning, but it is likely that it also reflects increased trust that useful signs will always be available en route.

Further analysis of individual wayfinding tasks reveals additional limitations of each modality, map, and signs. For the simple, local task 1, signs alone performed even better than in combination with maps and for task 2 signs helped overcome the navigation challenge provided by arbitrariness in the numbering scheme for the mezzanine floors. By contrast, in task 3 – the first task to involve a change of building section from KG I to KG III – map usage provided the clearest performance boost (distance, PAO). We believe that the map most successfully communicates the general layout of the site and prepares the user for a potential move to the adjacent building.

Overall, the highly salient and omnipresent signage constitutes the central feature in this re-design project. The presence of such strong signage changes the wayfinding task almost entirely from an originally spatial, geometric task of navigating in a multi-level environment to following distinct propositional information. In a metaphorical sense, the signs serve as a skeleton of connections in the building, along which the users travel. They do not need to process the building's geometry (unlike with maps), since the spatial problem is translated into numbers and signs. If these signs actually capture most of the navigator's attention and avoid spatial processing, an unplanned side effect might be reduced *spatial learning*. Such effects have recently been reported for mobile digital navigation tools (Münzer, Zimmer, Schwalm, Baus & Aslan, in press). Therefore it is a priority for future work to investigate whether spatial learning is differentially supported by signs or maps in real world conditions.

Acknowledgments

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