Verbally Annotated Tactile Maps - Challenges and Approaches

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Abstract. Survey knowledge of spatial environments can be successfully conveyed by visual maps. For visually impaired people, tactile maps have been proposed as a substitute. The latter are hard to read and to understand. This paper proposes how the cognitive disadvantages can be compensated for by Verbally Annotated Tactile (VAT) maps. VAT maps combine two representational components: a verbal annotation system as a propositional component and a tactile map as a spatial component. It is argued that users will benefit from the cross-modal interaction of both. In a pilot study it is shown that using tactile You-Are-Here maps that only implement the spatial component is not optimal. I argue that some of the problems observed can be compensated for by incorporating verbal annotations. Research questions on cross-modal interaction in VAT maps are formulated that address the challenges that have to be overcome in order to benefit from propositional and spatial representations induced by VAT maps.

Keywords: verbal annotation, tactile map, representation, navigation, representational modality, multimodality

1 Introduction

From the perspective of cognitive science, human knowledge and reasoning processes involve representations that serve as counterparts to real-world entities. There is strong evidence for an analogue nature of representation of spatial environments, i.e., they have intrinsic spatial properties [1]. Investigations into mental spatial representations suggest mental maps [2] and spatial mental models [3], have a spatial nature. These internal representations can be induced via linguistic or perceptual inputs from external representations.

External, diagrammatic representations, such as maps, can serve as a means for capturing and processing knowledge [4] and for solving spatial reasoning tasks [5]. Maps appear to be a promising aid for visually impaired people as well [6], although there are divergent results about spatial processes and representation of space in blindness [7, 8]. To accommodate the special abilities of users who cannot access visual information the substitution of visual perception by tactile perception allows the use of *tactile maps*. Such maps have become an option for supplying geographical knowledge to visually impaired people [9]. One class of maps, You-Are-Here (YAH) maps [10], can successfully support the task of navigating in complex in-door (for example, malls, hospitals, etc.) and out-door environments (such as, parks, zoos, university campuses, etc.). YAH maps are multi-purpose maps specifically made to provide an overview of the proximate surrounding of the geographical position that the map-user is situated in when reading the map. They have proven to be successful in facilitating wayfinding for sighted people [11]. By providing tactile YAH maps, visually impaired persons can be supported in the acquisition of *survey knowledge* [12]. Knowing about the structure of the surrounding environment could enable independent wayfinding. GPS-based systems, in contrast, are often made to provide the path to a specific locomotion or solution to a wayfinding problem. There is strong evidence that such systems have negative effects on the acquisition of spatial knowledge [13]. By consulting a tactile YAH maps before a trip, a model of the environment could be conveyed, exploration behavior could be guided, and the visually- impaired persons' self-dependency could be supported, particularly in environments visited for the first time.

A first objective of the research reported in this paper is to test tactile YAH maps for their effectiveness in conveying the spatial layout of an environment. I highlight the properties of YAH maps and discuss how those properties may be transferred into the tactile domain with the objective of *cognitive adequacy* [14]. A cognitively adequate map is an external map that results in an internal mental representation that enables the map-reader to solve spatial reasoning tasks successfully. Individual parameters in the realization of tactile YAH maps will be investigated. This paper offers some ideas for how these parameters might influence the acquisition of spatial knowledge. The study highlights some limits on the usage of tactile YAH maps and supports the usage of *Verbally Annotated Tactile maps* (VAT maps) as extensions of tactile maps.

The concept of a *Verbally Annotated Tactile map* is introduced. This is a map that incorporates verbal content (of the map or about the map) during the time of proposed exploration. The concept is discussed in terms of representational theory; it is identified as a *multimodal representation* integrating *spatial* and *propositional representations.* VAT maps might provide solutions to some current problems with tactile maps. Challenges with VAT maps are identified and a research agenda is described that points to some potential developments such as *Verbally Annotated Virtual Tactile Maps*.

In the next section I start with some background on tactile YAH maps, and then I report an experiment about how well participants performed in a wayfinding task with a tactile map. Section 3 details the concept of VAT maps, presents some theoretical considerations about a verbal annotation system for tactile maps, and ends with elaborating on future research. Conclusions are offered in Section 4.

2 Tactile You-Are-Here Maps

YAH maps have an intermediary status [15]: They are not specialized like a route description, which provides instruction for one single route from *one* location to *one* destination. Furthermore, they are not general like a multi-purpose city-map, which can be used to navigate from *many* locations to *many* destinations. Instead a YAH map enables navigation from *one* location, where the map and the navigator are co-located (i.e., the You-Are-Here position), to *many* destinations. As the YAH map has to serve multiple purposes it usually displays details at the same level of granularity over the map (in contrast to, e.g., focus maps [16]). YAH maps are often found at junctions or other main decision points. They enable people to localize themselves in a depictive representation of the environment. After self-localization map-readers might engage in further exploration of the map for an overview of the area or they might start to search for specific routes. YAH maps have one aspect that is usually prominent so that it can be found quickly, the YAH symbol.

Transforming a visual YAH map into a tactile equivalent offers some challenges. In some circumstances the tactile sense can substitute for other sensory modalities like vision [17]. For a review of *sensory substitution* from visual to tactile media see [18]. But tactile maps are not equivalent to visual ones [19, 20]. First, as consequence of the biological properties of the receptors in the skin there is a limitation in resolution of what humans can sense by touch. A consideration of the physiology and the psychophysics of touch reveals a multitude of receptors that make different types of sensations possible, for example the sensations of temperature, deformation, and lateral movements [21]. By touch it is possible to discriminate objects using their contours, surface roughness, and material, to name a few.

To clearly feel one entity and separate two entities from each other, the entities and the distance between them have to be greater than in vision. As a consequence, the distribution of objects in effective tactile presentations must be sparser than in visual ones (see [22] for exact figures). Thus, a reduction in content is necessary to represent a scene with a tactile map. Alternatively, the size of the tactile map would have to be increased to an unmanageable size. Second, abstracting graphical entities in reduced-detail maps may lead to significant errors, for example misinterpretations. Michel showed that additional transformations like distortions and displacements could be useful to direct attention and to make a tactile map and its entities meaningful to users [23]. Third, using a tactile map can limit some cognitive processes. Instead of having an immediate visual impression of a map, the user has to serially explore the surface of a tactile map with his fingertips and integrate the properties and impressions of single points of contact into one compound impression of the map. Systematic training of appropriate tactile scanning strategies was found to be necessary to help blind children improve their ability to orient themselves with a tactile map [24].

The investigation into the feasibility of communicating spatial knowledge with tactile YAH maps to form an internal representation that can be used to solve spatial cognition tasks, serves as a baseline for further research into VAT maps. The investigation of a unimodal type of map (i.e., the tactile maps) should be a basis for and inform further research about multimodal types of maps (i.e., the VAT maps). Here we report the results of a pilot study that addresses some of these basic issues.

2.1 Research Questions

In a simple form, the intuitive question is, how could tactile YAH maps be implemented with different tactile entities for the same conceptual function as in a visual map so that it is helpful? Specifically, is the map usable and at the same time useful? In this experiment it is assumed that YAH map-users want to locate themselves first before getting to know the environment. Therefore, they look for the YAH point – denoted by the YAH symbol – before exploring the map. Two concrete questions are considered:

1. Which (tactile) guide type for the You-Are-Here point in a tactile map is the most effective, i.e. has the shortest search time?
2. Which guide type is the least hindering when exploring the map to build up some survey knowledge in terms of objective time needed for exploration, objective quality of acquired survey knowledge, and subjective judgments of the map?

The comparison of the different measures should show if there is a mismatch in objective and subjective assessments, that is, whether people might subjectively regard one guide type better than another even if it is objectively not.

2.2 Experimental Design

The experiment had a within-subject design with one factor and three conditions. The independent variable was which guide type to the YAH symbol was used. The dependent variables that are reported here were the search time to find the YAH symbol, the exploration time, the time to draw a sketch, and the quality of a sketch.

1. Guiding Line Condition (GL): A unique line guided the user from a prominent starting point (marked with an arrow) on the frame of the map to the position of the YAH symbol in the map;
2. Grid Condition (GR): A grid of unique lines partitioned the map into regions that define the coordinates; the position of the YAH symbol was given in these coordinates;
3. Frame Marks Condition (FM): Four arrow-like marks, two on the vertical and horizontal borders of the map, defined the horizontal and vertical position of the YAH symbol in the map.

2.3 Materials

The tactile maps were in A4 format and produced with a ViewPlus® Emprint SpotDot™ Braille Embosser based on the TIGER® technology that embosses tactile pixels (following the convention in literature I call this entity a “taxel”) into a paper surface of size A4 (29.7 x 21 cm) with a resolution of 20 taxels per inch [25]. Assembling single taxels beside each other composes objects like (raised) lines, figures and regions. All tactile objects on the maps had the same surface structure and the same prominence in terms of height above the base material. The tactile maps were of uniform scale and each presented a grid of perpendicular tracks (4 horizontal ones and 4 vertical ones with a total of 12 intersections) with three landmarks (the

YAH symbol plus representations of two buildings). The maps were of a virtual environment to control for unwanted effects of familiarity, so that participants had to learn all spatial relations from the map. The structure of tracks in the maps was the same but the geometry was different (distorted and rotated) between the maps. Landmarks were placed near tracks in such way that no two landmarks occupied the same region. The shortest paths between the landmarks were of uniform complexity (measured in number of turns/legs) in each map: from the YAH point to landmark 1 with a single turn, to landmark 2 with two turns, and between landmark 1 and 2 with three turns. For two examples see Figure 1.

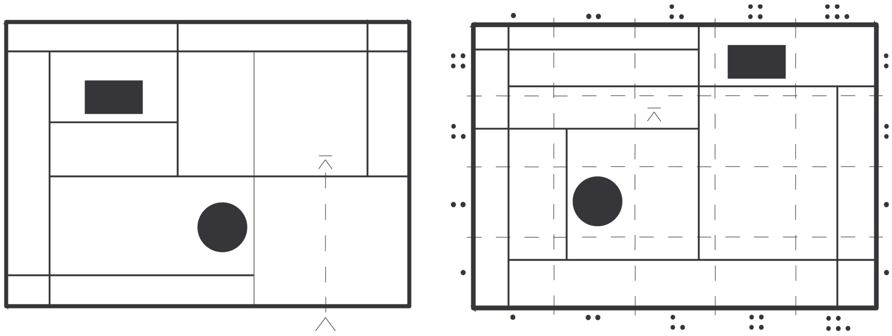

Fig. 1. Visualization of the tactile maps used as stimulus in the condition Guiding Line (left) and in the condition Grid (right).

2.4 Participants

The participants in all experiments reported here were 12 sighted individuals (all students, 4 male & 8 female, *M* = 28 years, *SD* = 5 years) with no impairment to the visual, tactile or motor system and no experience in solving task solely with their tactile sense. Sighted participants were chosen because they are familiar with maps and understand map concepts and conventions - many visually impaired persons have no experience with maps. The participants showed a reasonably high self-confidence in their abilities to read visual maps (*M* = 0.72, *SD* = 0.17, with normalized values) and to successfully solve tasks with visual maps (*M* = 0.79, *SD* = 0.07).

2.5 Procedure

The participants sat at a desk in front of a curtain to exclude direct sight of the tactile material behind the curtain. They put their hands and arms beneath the curtain to reach the tactile material. In the beginning of each session, participants were individually trained on sensing and interpreting tactile sensory input. Each tactile symbol that was used in the experiment was introduced in the training and participants had to pass a sensory recognition test before the experiment.

During the experiment, all participants handled the maps in all conditions. The order of the conditions was systematically varied between participants. In each condition before the tactile map was presented, participants explored a legend tactually and could ask about the meaning of entities. If requested a pre-defined explanation was read out. Instructions for how to use the map and how to find the YAH point were given verbally similar to what would normally occur if the legend and caption of a tactile map were given in Braille.

The first task in each condition was to find the YAH symbol in the map as quickly as possible. The time from touching the map until participants indicated they were sure they had found the YAH symbol was measured.

In a second task, the participants were asked to explore the map in a self-paced manner so that they would be able to explain routes and the structure of the environment without consulting the map. The participant's goal was to gain an understanding of the entire environment, without any specific route given beforehand. To check for a basic understanding of the environment, participants were asked questions after the exploration of a map: what buildings are in the environment, and how are those buildings distributed in the environment. If a participant could not answer both questions, they were allowed to further explore the map. The total time for all explorations was recorded.

In a third task, participants were asked to produce a complete copy of the map on a graphic tablet to test their survey knowledge of the scene. No time limit was given, but time to complete the drawing was recorded.

A fourth task describing two routes between landmarks was given but is not reported here because it cannot add any insights into the research questions. The complete experiment lasted about two hours (M = 2:02:55h, SD = 15:06min).

2.6 Results

The efficiency of the different guide types was assessed using the time to locate the YAH symbol. All participants except from one in the Frame Marks condition completed the task. In the Frame Marks condition map users located the YAH symbol the fastest, and were slowest in the Grid condition (see Table 1). After two outliers were excluded[1], an ANOVA test revealed that the differences among condition reached the .0001 significance level, $F(2, 31) = 15.13$, $p = .000026$.

Concerning which guide type was least hindering in the exploration phase, a comparison of the exploration times (see Table 1) showed that in the Guiding Line conditions participants explored the maps fastest. An ANOVA test confirms a significant difference between all conditions at the .01 significance level, $F(2, 33) = 7.23$, $p = 0.0025$.

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[1] The following convention is used: a data point that exceeds the range [(lower quartile - 1.5 * interquartile range) to (upper quartile + 1.5 * interquartile range)] is considered an outlier. See "What are outliers in the data?" In: *NIST/SEMATECH e-Handbook of Statistical Methods*, Chapter 7.1.6. http://www.itl.nist.gov/ div898/handbook/, retrieved 2010-04-12.

There was no significant effect of condition on time needed to sketch a map was found, $F(2, 32) = 0.097$, $p = 0.91$. A descriptive overview of search times, exploration times and drawing times is given in Table 1 below.

Table 1. The three main quantitative variables recorded during the experiment (in minutes).

	Time to find the YAH symbol	**Time for exploring the map**	**Time for drawing the sketch**	
GL	0:22	4:11	1:27	
FM	0:16	5:59	1:23	
GR	1:46	7:56	1:37	
	0:48	*6:02*	*1:27*	*Mean*
	0:50	*1:53*	*0:07*	*SD*

The sketches that the participants produced after the exploration of the tactile map (in total 12x3=36 sketches) were rated by two independent experts. The guiding question was whether a person that does not know the area could navigate it successfully with the sketch map. Grade 1 was awarded for a perfect sketch that showed the landmarks and streets in correct relation to each other (although there might be minor flaws in geometric details), grade 6 was given for a sketch if there was no resemblance to the structure of the tactile map. In total 6 sketches were rated very good or good, 26 acceptable or moderate and only 4 not interpretable. Together 32 of 36 sketches (>88%) were at least of moderate quality and indicated that the map-readers probably did build a mental representation of the environment depicted in the tactile maps. The tactile maps effectively conveyed spatial knowledge to the participants in almost all cases. See Figure 2 for two examples of sketch maps produced by two different participants.

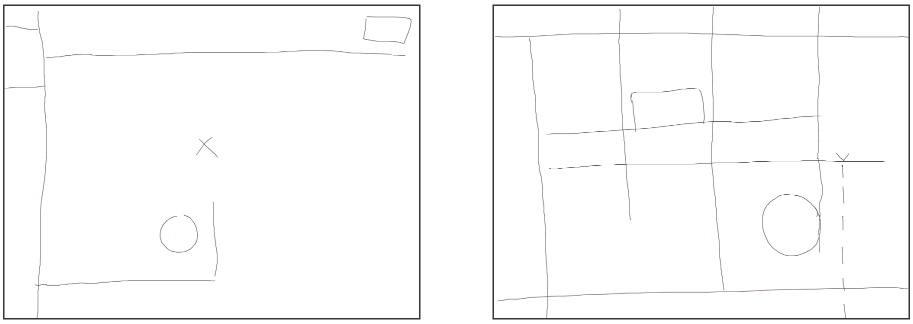

Fig. 2. The sketch to the left shows some route map characteristics, the one to the right is very similar to the stimulus (see Fig. 1, left) and shows survey characteristics, for example, there are many streets that are not used for direct routes between landmarks.

Participants' subjective ratings were also analyzed. They were asked to order the three guide types by their suitability for the two tasks – searching for the YAH symbol and exploring the tactile map – by considering these questions: (1) how much did the particular guide type help you find the YAH symbol, and (2) how much did it hinder the exploration after the YAH symbol was found? The average ranks can be found in Table 2.

Table 2. Participants ranked the guide types when used in different tasks (1: best to 3: worst).

Task	**Searching the YAH Point**			**Exploring the map**		
Condition	Guiding line	Frame Marks	Grid	Guiding line	Frame Marks	Grid
Average Rank	1.50	1.25	3.00	2.00	1.00	3.00

The frame marks were ranked best for both tasks, the guiding line second and the grid were rated lowest. This is partially consistent with the quantitative findings (where the Grid condition was always worst). Notably, people can objectively find the YAH symbol faster with the Guiding lines than the Frame Marks, see Table 1, but they subjectively rank it lower.

During the experiments participants occasionally reported tactile illusions, primarily shortening of lines when comparing horizontal and vertical lines at a T-junction shape. That length-distorting effect resembles the Müller-Lyer illusion in vision and was reported before for congenitally blind people (cf. [26]).

A final note: The structure of the tracks was not completely identical in all maps. In the map with the frame marks one line segment had been inadvertently omitted. This resulted in one missing region and a change of +1 in the cardinality of one region and might have influenced the topological complexity of the map. But the missing segment was in the non-central part of the map that was not frequently explored and had no potential to be included in a route. It is unlikely the omitted segment had a significant impact on the results.

2.7 Discussion

Why were sighted participants run in this experiment, instead of blind people? It is a common belief that visually blind people have to perform better than sighted when asked to solve tasks on the basis of touch. Nevertheless, on the sensory level, blind and sighted people depend on the same bodily sensor system. In objective measures the two populations do not always differ. For example, there was no difference found for judgments of smoothness by sighted and blind participants, nor for passive touch (in which a stimulus is applied to a static skin surface), or for active touch (in which a stimulus is engaged with by a moving skin surface) [27]. Those findings indicate that there are primarily preference differences for the use of touch in blind and sighted people [28]. When it comes to basic cognitive tasks like object matching, which includes for example shape processing and recognition, visually impaired people outperform sighted people in the initial trials but after a few trials there is no difference [29]. It seems that haptic experience increases the speed of identification of abstract, simple shapes, but blind people do not perform as well when active elaboration is required [30]. In contrast to sensing and object matching, the experiment reported here depends on higher cognitive abilities that demand tacit and procedural knowledge of how to interpret a map. Therefore sighted people instead of visually impaired people were our participants. A future experiment will test visually impaired participants.

A closer analysis of the ratings of the sketches reveals that the sketches graded with 4 or worse were the only ones that showed route orientated encoding schema. In those sketches, only routes or part of a route were drawn, no other structures like streets around the area or that go from one end of the map to the other were displayed (see Figure 2, left). This was true of all the grade 5 and 6 sketches and over one third of the grade 4 sketches. It is possible that there was too much clutter in the map that masked the important parts (the distinction between clutter and relevant parts might vary depending on the task given). Clutter puts high cognitive load on the reader. Map-readers might employ strategies to focus on the part of the map with a lot of semantic content, i.e. the area where landmarks are located and the paths between them. Another interpretation could be that route concepts were acquired during exploration and only those could be externalized.

3 Proposal for Verbally Annotated Tactile Maps

3.1 Audio-tactile maps

One might assume that some form of compensation is needed in tactile maps because of their limited information. Compensation could be necessary for at least two problems. First, the tactile sense in comparison to the visual sense is relatively sparse. Only a limited amount of content can be displayed as it clutters quickly. One option could be to convey complementary content through another sensory channel. Content could be presented that was not encoded in the map due to space constraints. Another option would be to redundantly present content. Second, the tactile features of the map have to be explored serially, demanding high attention over a reasonably long period of exploration. Solutions that reduce the need to explore wide areas with the fingers could lower the necessary attention and manual effort.

Some of these ideas have been tested. Previous work investigated the use of sounds to provide additional content. Parkes and Lötzsch first presented audio-tactile devices to navigate and access non-textual, spatially distributed content [31, 32]. During the last two decades studies have considered computer driven audio-tactile devices, for example [33, 34], and computer-driven virtual audio-tactile maps, i.e. maps that are equipped with sound, for example, [35, 36] and verbal labels [37, 38]. Another approach was a force-feedback mouse and auditory labels to give directions in a mixed modal interface [39]. The multimodal approach turned out to be more comprehensive than the unimodal approach [40]. In the NOMAD system [32] a touch-sensitive pad provided raised features (as an analogue to map features) and verbal descriptions of the location that was touched. The descriptions contained information about what the user was touching and where this point was. Other work described the integration of verbal descriptions into tactile maps as well [33, 41, 42].

3.2 Verbally Annotated Tactile Maps

VAT maps are external multimodal representations that should have the potential to convey meaning that is stored in different types of mental representations. During an exploration of a VAT map, perceptual input from the tactile map that is believed to contribute to some form of mental spatial representation (analogous to the represented environment) is augmented with linguistic input (that is believed to be represented propositionally).

The underlying assumption for proposing Verbally Annotated Tactile maps is that different formats of mental representations can facilitate spatial reasoning. Research about learning with geographic maps that are presented in conjunction with a related text generally support this view (see [43] for a review). The cross-modal interaction of mental representations, i.e. non-propositionally encoded and propositionally encoded, should contribute to a common mental representation of the represented environment. Through the activation of concepts from different representational formats it might be possible to achieve an integration that contributes to the better understanding or faster access to what was learned from a VAT map. Given the growing evidence for functionally equivalent behavior on different inputs, such integration is likely, independent of perceptual or linguistic encoding (see [44] for a review).

The research literature suggests that combining propositional and spatial representation can benefit from *cross-modal effects* [2]. Few researchers have investigated the interaction of propositional representation and spatial representation when exploring a Verbally Annotated Tactile map. In such maps that the activation of concepts encoded in a tactile map may be facilitated by concepts encoded in the verbal description accompanying that map. Conveying map characteristics through concepts that were activated when listening to the verbal content may help the map-reader to better understand what is displayed in the map and how entities relate to each other. Conveying spatial and propositional representations, VAT maps might be an aid for visually impaired people navigating the world.

3.3 The Verbal Annotation System

Some mechanism to connect a tactile map with its verbal annotations is required. Some guiding ideas and questions concerning conceptual design are presented here.

The verbal annotations system could be connected to the tactile map through references that link certain point-of-interest (POI) or areas-of-interest (AOI) on the

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[2] In this work and its context the concept does not mean learning in one modality and testing in another. Instead, human activities such as learning are supported by a cognitive system that is supposed to make use of spatial and propositional mental representations (see, e.g., the cognitive architecture proposed by Baddeley [45]).

tactile map with some entity in the verbal annotation system. If the map-reader explores the vicinity of a POI or AOI, the verbal description should be presented, perhaps customized for approaching, passing or leaving. Calculating AOIs, POIs and descriptions could occur on the fly from a (dynamic) database that provides the map content. For descriptions, the verbal annotation system would contain a set of propositions and it should contain a rule system to determine which piece of content is to be presented in what way with the tactile map and the motion the map-reader executes. More precisely, to conceptually realize VAT maps, two aspects have to be considered. Each aspect relates to one distinct part of the verbal annotation system. The first one concerns the content of the propositions; the second one concerns the process of knowledge acquisition by the map-reader and the best way to support combining verbal content with a tactile map.

- “Which”: Which content should be conveyed verbally that will not exceed the map-reader’s cognitive capacities? Which content is selected to be verbalized to ensure a significant increase in the effectiveness of such maps for the map-reader? With some user modeling incorporated in the system, one could detect and individually support the map-user’s exploration behavior.
- “How”: How is the content best brought to the map-reader (for example at what point in time, for how much time, depending on what parameters)? How should the content to be structured with respect to the salience of objects in the environment; what should come first, what next (in terms of linearization of the information about space) etc.? Different strategies could be chosen, for example, fostering a local perspective (by naming proximate landmarks before distal ones) vs. fostering global perspective, or focusing on the structure of the track network (by naming 2d landmarks, like intersections) vs. focusing on the structure of the built environment.

The verbal annotation system would also benefit from better mental models by

- Providing relevant redundant map content (as realized in some of the previous works reviewed above), or
- Providing relevant complementary map content, or
- Guiding the exploration strategies of the map-reader.

For providing redundant content, some knowledge captured in the map should be verbalized. For example, providing information about the intersection where the currently explored street ends. In this way, the map-reader does not need to extract the information from the map by exploring it in detail. Instead, she gets that information via spatial language sooner. Verbal complementary content could update a mental model with details that are not captured in the map. As there is lack of space in tactile maps, this content might add important details to be incorporated in planning or decision-making. To influence exploration, some survey information should be given informing the user about the local region, for example, which part of the map is she currently exploring and what other parts are located in which direction. In this way the exploration strategies that afford conceptualizing the content of the map could be supported. For example, when reaching an intersection (which is felt tactually) the user might hear an announcement about the points of interest that are in the vicinity (local perspective) and where the departing streets lead to (global perspective). Compared to a tactile map, a VAT map could be a type of map brings an advantage to visually impaired people, supporting them in gaining survey knowledge of the world for successful navigation.

3.4 Realizing Verbally Annotated Tactile Maps

In a VAT map the tactile map and the verbal annotations are independent components. The tactile map could be simulated or real: A simulated tactile map would be virtually explored with an actuator, for example, a force-feedback device that allows experiencing real forces when hitting a virtual object. Such a virtual map has the advantages that the interaction is very flexible and new environments can be simply loaded as new models. Unfortunately, 3d-models of particular environments are generally not freely available. On the other hand, it is fairly easy to build such artificial environments. Tracking with computer-controlled devices is also easy, as the actuator provides sensors to check the device's position in space. However, the spatial range of such devices is currently limited, usually smaller than a realistic tactile map. Additionally, there is, to my knowledge, no force-feedback interface that allows for multi-touch interaction or that lets the user employ kinaesthetic receptors to, for examples, feel deformations (with such a device there is only rigid, point-like touch). Furthermore, such devices are very expensive.

If the tactile map were physical, real touch would be possible. But, to allow for dynamic verbalization some tracking technology must be in place (computer vision could be an option). Many of the drawbacks of virtual maps are avoided, but some advantages would be lost as well, for example, the tracking integrated in the actuator. For real tactile maps, the technology to print them is affordable for small organizations or families.

The verbal annotations to a (virtual or physical) tactile map could be realized through synthetic speech (the quality of such speech has improved a lot over the last few years), through dynamic assembly of pre-recorded audio snippets (this offers the best quality but is not flexible), or for experimental purposes by an experimenter or in a Wizard-of-Oz setting. Timely coordination and synchronization of both components is an important issue in all scenarios.

3.5 Future Research with Verbally Annotated Tactile Maps

The experiment with tactile maps that was reported here serves as one kind of baseline for future work developing an understanding of the effects of cross-modal interaction and how they can be employed to ease cognition with tactile maps. The basic design will be repeated with late-blind people, because there is good chance that they are able to perceive tactile pictures [46] and the organization of spatial processes seem to depend on the nature of perceptual input [7]. There is a good chance that they will know how to read a map. Knowing their strategies could inform work on how to teach other visually impaired persons to read and understand tactile maps [8].

Although there has been extensive work on visual-impairment (see Sections 1 & 2), there is only limited work that investigates cognition in blind people in relation to tactile maps. There are many open questions. For example, what is the maximum complexity of an environment that can be conveyed? Answering questions in this area would open the door to customized multimodal representations, for example VAT maps that make deliberate use of different cognitive subsystems to convey (spatial) meaning. An immediate critical question is whether visually impaired people have an advantage when they engage in wayfinding tasks after having consulted a VAT map.

To develop VAT maps there need to be some initial guidelines for which content is selected to be represented in the verbal annotation system. It is likely that the combination of verbal presentation in conjunction with a tactile map will have an influence on the exploration behavior of the map-reader. It is likely timing, granularity of presented content and context (for example task, knowledge about map conventions and others) will all influence the effectiveness of such systems. Further investigation is needed in what ways the map-reader is influenced when presented with verbal material about (1) the direct surroundings, so that she is accommodated in her current situation, (2) the adjacent areas, so that she has some knowledge of the areas she might wander into soon, and (3) the survey perspective that makes more distant landmarks accessible. I hypothesize that people who are presented with many pieces of "local content" would be more likely to build a mental model from connected representations of local phenomena. Such a mental model would hold many local details but probably not much survey knowledge. As result, tasks that build on survey knowledge should take longer to accomplish, other cognitive tasks that need detailed knowledge should be solved faster. Conversely, people who are presented with many pieces of "survey content" would be more likely build a survey like representation and will be good in querying it, but would have trouble with questions regarding local details. Experiments to investigate these questions (and others) will tell us more about how a verbal annotation system should be constructed to accommodate different types of uses or contexts.

By measuring map exploration times, acquired spatial knowledge, and subjective measures, such as user satisfaction, the appropriateness of VAT maps to be used for spatial tasks could be evaluated and could be compared to tactile maps. If people have an advantage interacting with such maps then this would be an argument for trying to facilitate navigation with VAT maps. Comparison between tactile maps and VAT maps is needed.

4 Conclusion

The literature indicates that tactile maps are a valid option for conveying spatial knowledge non-visually. Comprehension and spatial reasoning were tested with tactile You-Are-Here maps. The results showed that tactile YAH maps were understandable and map-readers performed well in spatial reasoning tasks. Different guiding types of YAH-symbol were tested. The less the guides interfered with the map content, the more useful they were. Map entities that were only useful for finding the YAH symbol but not for exploring and learning the map were judged to hinder exploration. In some cases they interfered with learning in such harmful way that no survey model of the environment could be externalized (in sketch drawing). Having too many entities in tactile YAH maps likely hinder understanding the map.

To overcome this limit, some researchers favor a multimodal approach to conveying spatial knowledge to visually impaired people. Even if there is some evidence that in particular experiments there was no interaction between tactile and verbal channel [47], others have shown that reading tactile maps is improved by combining auditory and haptic information [41]. Going beyond the approaches that employ different *sensory modalities* this paper suggests an approach to employing different *representational modalities*. As an external multimodal representation I introduced the concept of a *Verbally Annotated Tactile map*. With this type of multimodal map, it might be possible to circumvent the bottleneck of low-detail and hard to interpret maps. Using VAT maps, inefficient navigation strategies might be avoided as people could build a richer model of what surrounds them through cross-modal interaction of propositional and spatial internal representations.

Issues that need to be addressed to fully realize the potential of VAT maps were discussed. The central issues to be addressed relate to the questions about which granularity of content best support navigation using a VAT map, which content should be verbalized or be represented tactually in a VAT map, and how should this content be structured and synchronized to map exploration behavior to best support the activities and strategies of the map-readers. Research in these directions has only just begun [48]. Through the investigation of the usage of VAT maps in spatial cognition tasks, and consideration of the value of such maps for visually impaired people when they engage in wayfinding tasks we may realize the goal of identifying the principles to successful construction of cognitively adequate tactile maps for navigation.

Acknowledgements. The research reported in this paper has been supported by the German Science Foundation (DFG) in the International Training Research Group 1247 “Cross-modal Interaction in Natural and Artificial Cognitive Systems” (CINACS). I thank all participants of the experiments, Prof. Habel and Kris Lohmann for past discussions, Franziska Dowall for the data collection and data processing, Doreen Dörfer and Niels Beuck for proof-reading, Pat McCrae and Thomas Shipley for their help with style and language, the Cognitive Systems Group at University of Bremen for the support and the anonymous reviewers for their helpful comments.

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