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Interactive modular tactile maps of rooms for older adults with vision impairments

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Abstract. We present an interactive modular tactile map tailored for older adults with vision impairments, which should help them acquire spatial knowledge of rooms and their inner equipment. As the outcome of our iterative design process, we introduced a design concept that employs skeuomorphic interactive tactile objects that can be placed on a modular interactive tactile map to resemble real rooms. Qualitative evaluation (mean age was 81.5 years) indicates our concept's ability to help our audience build spatial knowledge of rooms and their equipment.

Keywords: Orientation; tactile maps; visually impaired; older adults.

1 Introduction

According to [2] the prevalence of blindness is globally 0.48 %, and 2.95 % of the world population deals with moderate to severe vision impairment. The majority of visually impaired people appear among older adults, as 52.9 % of visually impaired people are older than 70.

Unfortunately, the research attention on older adults with visual impairment (*VIOA*) is limited. We have analyzed 48 papers focusing on people with VI presented at the last three CHI conferences (2016-2019). When excluding studies focused mainly on children and young adults, the average age of study participants was 37,3 years (weighted average, sample sizes as weights). Hence, the current research focus is on VI people is biased in favor of the younger part of the population.

User research conducted in a specialized residential care facility for *VIOA* [15] showed that orientation and mobility training is a long and complicated process. This training starts in the client's room, and other locations and routes are included after the client masters the orientation around his/her room independently.

In our previous research, we focused on developing solutions to support orientation in space tailored to the needs and preferences of visually impaired older adults [15, 9, 19]. It indicated that needs, abilities, and preferences of *VIOA* might differ significantly from the younger and more active part of the community of

those challenged with vision impairments, especially when the onset of impairment was recent and at a higher age.

In this paper, we present a method and three generations of related prototypes that primarily aim to help create cognitive map of the environment at the level of detail corresponding to a room. Interactive modular tactile maps of rooms represent room layout and internal equipment like furniture, sinks, toilet, etc. Modular design allows modeling different spatial environments. Multi-modal interaction method involving touch, voice output (audio labels), and visual output allows efficient creation of a cognitive map of the environment for *VIOA*.

2 Related work

Montello [20] defines spatial cognition as the study of knowledge and beliefs about spatial objects and events worldwide. Term cognitive map refers to internally represented spatial models of the environment [21] which contain knowledge of landmarks, route connections, and distance and direction relations, non-spatial attributes [20]. Fazzi et al. [8] presents methods to teach Orientation and Mobility, including teaching strategies and materials.

According to O’Keefe [17], cognitive maps include at least two types of representations: specific routes to reach some target point in space and more general topographical representation that can be used for inferring shortcuts or alternative pathways. This knowledge can be acquired directly in the environment or by using external representations of the environment like topographic maps.

According to [11, 4] maps are two-dimensional, projective, small-scale representations of an environment, presented from an allocentric perspective. People with VI traditionally use tactile maps as a powerful tool for acquiring spatial information [22, 7]. Unlike classical maps, tactile maps allow only sequential acquisition of information. As a consequence, they have higher demands on memory.

Jacobson [14] presents a comparative study that showed the efficacy of audio-tactile maps for cognitive map accuracy. Similar results can be found in [7] where tactile maps served as the best means of gaining spatial knowledge. The efficacy of the reading may depend on the chosen scanning strategy. Ungar [22] states that more systematic strategies are better.

Witntjes, in his study [24] identified three strategies used by people with VI for exploration of tactile images: using one hand; using both hands, while a single hand moves and the other hand rests on the image (bimanual strategy); and using both hands simultaneously. Several studies like [24, 12] indicate that bimanual strategy is the most effective.

According to [4], using multiple modalities can break down the complexity of communicated information. In [13, 10] authors discuss the usage of interactive audio labels, which avoid the necessity to memorize the legend. Various types of gestures can be implemented to activate the labels, e.g., tap, double-tap (examined in [4]), but the sensitivity must be set correctly, not to trigger the audio events too often, and provide clear feedback, as mentioned in [10, 4]. Brito in [3]

employs conductive filament printed on an image. As the 3D-printed object is touched, the corresponding audio is played to help the user to recognize the object.

Analysis of the related work shows that tactile maps are an effective means to create and improve cognitive maps of environment [14, 7], especially when involving multimodal interactivity [4, 13, 10, 3]. However, there is a lack of research focused on suitable methods for *VIOA*.

3 Initial design - Low-Fidelity prototype

The design requirements stem from our previous research in a residential care home for *VIOA* [9, 19] and from a literature survey. The spatial orientation is essential for the target user audience of *VIOA*. Our previous work focused on creating a cognitive map of the spatial environment on a scale of building floor [19] and support of orientation while traveling indoors [9]. In this paper, we support spatial orientation of *VIOA* by helping the creation of a cognitive map of the indoor environment on a level corresponding to rooms and their equipment.

We set the following design requirements: 1) *Modular design*: The artifact enables representing indoor space of different size and layout by means of modules that can be attached to each other. 2) *Multi-modal interactivity*: Interactivity by means of touch and audio labels. 2) *Skeuomorphism* [18, 6]: The interactive objects on the tactile map will resemble their real-world counterparts by shape, texture, or even materials.

We propose an interactive modular tactile map that represents the indoor environment. It can represent a room (or few rooms when needed) and interior objects, including furniture and equipment like sinks, toilets, or even inner walls.



Fig. 1. Reference room (left) and Initial design Low-Fidelity prototype (right)

The 3D map elements that represent the objects are easily recognizable by touch as it is a promising direction for VI users [23, 3], especially the older adults [9].

As depicted in Fig. 1, the initial design consisted of a board with a matrix of 15×15 holes and handcrafted tactile modules. This early prototype was not modular. Its primary purpose was to enable fast evaluation of the concept with representatives of the target user audience. For this prototype, the projection ratio was 20 : 1.

3.1 Evaluation

The purpose of the evaluation was to get insights into the artifact’s efficacy to create a cognitive map of the environment in *VIOA*. Furthermore, we observed the interaction with the interactive tactile room map to evaluate the interaction method and detect the method’s potential usability issues. The relatively low number of participants was determined by complicated methods to reach such a specific user group and correspondingly high costs per participant. More information about choosing sample size for a hard-to-reach user audience can be found in [5, 1]. The recruitment and execution of all experiments were under the supervision of the special housing authorities.

Participants. We recruited five participants (P1-P5, all women, age $MEAN = 84.8$, $SD = 3.83$, $MIN = 82$, $MAX = 90$), representatives of our target user group, they were recruited from residential care institution we cooperate with. Demographic data about the participants are in Table 1.

Procedure. For the experiment, we created all necessary tactile board elements to represent objects in a reference room see Fig. 1. We presented a scenario of a fictive visit to a friend’s room to the participant. Before the actual visit, the client will use the tactile board to learn the layout of objects in the room to be visited. The experiment consisted of four phases: 1) *Exploration of objects*

Participant	Age/Gender	VI Category	Impairment onset	In Institution
P1	91/F	4	1.5 years	1.5 years
P2	82/F	4	2 years	3 months
P3	83/F	5	60 years	1 month
P4	86/F	4	8 years	6 months
P5	82/F	4	20 years	9 years
P6	52/M	5	27 years	8 years
P7	82/F	4	20 years	9 years
P8	70/M	4	8 years	7 years
P9	89/M	5	6 years	6 years
P10	95/F	3	7 years	6.5 years
P11	75/M	3	9 years	6 months
P12	91/F	4	10 years	4 years

Table 1. Participants of Low-Fidelity prototype (P1-P5) and High-Fidelity prototype (P6-P12) evaluation.

2) *Learning of the room layout.* 3) *Object finding and distance estimation.* 4) *Cognitive map – reconstruction from memory.*

Results and Discussion. The physical dimensions of the tactile map enable using both hands for exploring the represented room. Participants explored the model firstly around the perimeter of the map. They proceeded systematically from the entry door in either direction. Activation of audio labels by pressing the objects was easy to discover and comprehend by all participants. Participants commented in favor of audio labels. However, only P1, P3, P5 activated the audio labels automatically for each discovered object.

The participants recognized most objects. However, the bedside table (recognized by P1, P4), obstacles on high-walls (identified by P1, P2), and the table (none) were hard to recognize. We estimate that the participants did not recognize the table because of confusion caused by its small size compared with a chair. During the exploration, participants described the details of individual objects. A combination of different materials might improve recognizability, i.e., P5 replied, *“Because it has (textile) duvet and pillow.”* The evaluation indicates that the tactile map concept represented by the Low-Fidelity prototype is understandable for the target user audience.

4 Basic High-Fidelity Prototype

In comparison to the initial design, this High-Fidelity prototype consisted of modules as depicted in Fig. 2. There were nine modules, each with 16 holes (4x4). A matrix keyboard and micro-controller (ATTiny 48) were embedded into each module. All modules were connected to allow communication with a



Fig. 2. Basic High-Fidelity prototype – Interactive modular tactile map of rooms

PC. This technical solution enabled the detection of a press of any contact of any of the nine modules (144 contacts in total). Detected presses trigger audio labels with information about the pressed object. The projection ratio is 80 : 3, the distance between two holes is 1.5cm that reflects 40cm in reality.

4.1 Evaluation

Participants. We recruited seven participants (P6-P12, 4 women, age $MEAN = 77.7$, $SD = 14.0$, $MIN = 52$, $MAX = 95$), representatives of our target user group, they were recruited from residential care institution we cooperate with. Demographic data about the participants are in Table 1.

Procedure. The test procedure was similar as for evaluation of initial design, but the first phase (Exploration of objects) was omitted to test whether this phase is necessary. The objects were from the beginning of the experiment placed on the tactile map in the layout of a reference room with inner walls.

Results and Discussion. There were issues with the recognizability of some objects, mainly those with distinct holes. The water sink was recognized only by P9 and P11. P7 noted, “*Water sink? I could not have guessed*”, P12 noted, “*Isn't that a lamp?*”. Also, objects that have too varying real-world forms were not well recognized. I.e., waste bin. P8 noted, “*I have never seen rectangular waste bin.*”

The observation of participants indicated a possible issue with paying attention to long audio labels of objects. The participants did not listen to the full description for some objects and continued by pressing another object. Some participants (P8, P10, P11) also missed the beginning of some audio labels containing information about what kind of object was pressed.

The experiment indicated that modeling more rooms on one tactile map is possible. However, P6, P7 experienced issues with the bedroom’s mental projection to the rear left corner of the main room. P8 recognized the inner wall as part of the equipment. After removing the object that represented doors, it was difficult for all the participants to show entrance doors and doors to transit between inner rooms.

Evaluation of the High-Fidelity prototype indicated that the general concept is usable. We showed that the tactile map could create a cognitive map in VIOA. Most participants (P6, P7, P8, P10, P11) were after the interactive session able to describe the layout of the represented rooms and inner objects from their cognitive map. However, only P10 and P11 described routes between two objects without any error. We estimate that the primary reason was that the High-Fidelity prototype represented the room with higher layout complexity.

5 Advanced High-Fidelity Prototype

Advanced High-Fidelity Prototype is depicted in Fig. 3. We tried to address issues exposed by evaluation of the previous prototype. New modules have dimensions $75 \times 75mm$. Each module contains 25 holes (5×5) with push buttons

on PCB inside the module. Moreover, 25 (grid 5×5) individually addressable RGB LEDs are integrated into each module. The seamless mechanical connection of modules is assured using embedded magnets. Magnets are also used to connect outer walls to the tactile map. The data connection between modules is newly implemented using a chained serial link. This design enables the detection of any push-button press in any hole of any module in the chain.

From the interaction perspective, each module contains negative grooves to help with distance estimation. Outer and inner walls have equidistant pins that correspond to holes in modules. Their purpose is to improve the estimation of distances and make them distinctive from objects objects.

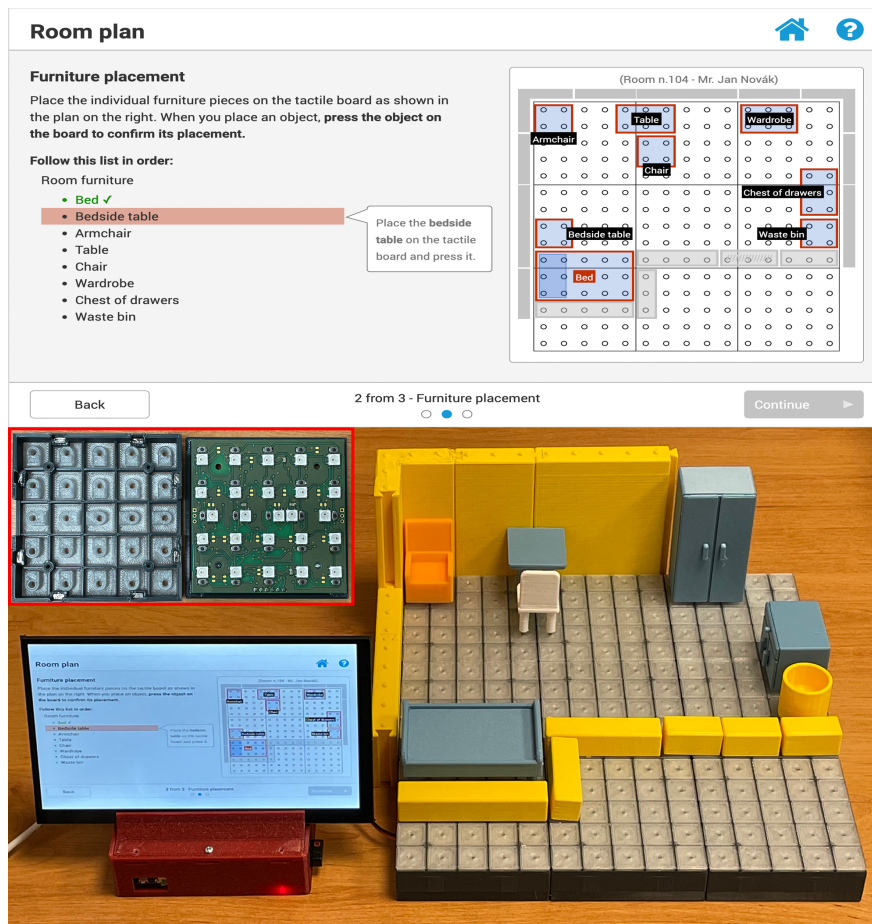


Fig. 3. Advanced High-Fidelity prototype. The user interface of support application for preparation of the tactile map (top). The latest prototype of the modular tactile map (bottom). Module printed combination of translucent and opaque materials and PCB with push buttons and addressable RGB LEDs (left).

The development of the Advanced High-Fidelity Prototype is currently in progress. The onset of COVID-19 prevented us from contact evaluation with representatives of *VIOA*. A VI expert, that is part of the development team commented and evaluated individual components during the development process. We implemented several improvements to tactile map modules and interactive objects, including a new representation of waste bin or toilet.

6 Discussion

We created three generations of interactive modular tactile map prototypes. The results of the evaluation indicate that our tactile map enables the creation of cognitive maps. The overall concept and most tactile objects are usable.

The onset of COVID-19 and related social-contact limitations compromised the possibility to evaluate the advanced High-Fidelity prototype fully. This can be a limiting factor to the validity of the presented results. An expert on tactile graphics with vision impairment is part of the development team. His comments helped assess the quality of individual prototype components and improve the chance that the prototypes will be usable for the target user audience of *VIOA*.

The community could use tactile exploration with audio-visual feedback in other scenarios related to education and entertainment of those with vision impairments. An example is teaching Braille script where modules connected a row let crating writing exercise book. Also, it is possible to simulate typing using different kinds of Braille typewriters, i.e., Perkins Brailler [16].

7 Conclusion and Future Work

We proposed mapping an indoor environment into a modular interactive tactile map tailored for *VIOA*. We focused on designing interactive objects representing standard equipment of rooms, mainly various kinds of furniture. We introduced a new modular hardware platform to be used in multiple scenarios involving tactile interaction, press detection, audio output, and visual output.

The onset of COVID-19 pandemics limited the evaluation with the *VIOA* as representatives of the target user audience. The health and ethical concerns did not allow in-person evaluation of the advanced High-Fidelity prototype.

It is the subject of future work to evaluate the prototype with the target user audience. We expect the community to use the modular platform in other scenarios to support various tasks related to the education and training of individuals with vision impairments, including those with remaining sight.

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