Developing Tactile Maps for Students with Visual Impairments: A Case Study for Customizing Accommodations

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Structured abstract: *Introduction:* The authors of this study evaluated the necessary features of tactile maps to provide independent, efficient, and safe travel across a university campus; and a process for developing tactile maps based on user needs and preferences. *Methods:* Participants who have low vision provided input, through interviews and field tests, regarding which features were critical for a tactile map. The four-phase development and research design process included: phase 1, semi-structured interviews about campus navigation; phase 2, creating draft maps using two different tactile media—microcapsule or braille embossed lines; phase 3, field-testing maps through site visits with participants; and phase 4, finalizing the map. Four undergraduate students with low vision participated in phases 1 and 3 to assess their experiences in navigating a campus; and the collected data were used in phases 2 and 4 to create, revise, and finalize the content, layout, and medium of the map. *Results:* Three of the participants preferred microcapsule lines to braille embossed lines, while one participant stated the usefulness of both media. The four-phase process allowed customization of local maps for individual users. *Discussion:* Map features that contribute to readability and efficacy of use include the medium; the layout; the combination of orientation maps, which provide an "overview" of a large area; and mobility maps, which contain more detail and are designed to help the traveler in unfamiliar areas (James, 1982). *Implications for practitioners:* Colleges and universities should gather data and create tactile campus maps for students with low vision or blindness following the four-phase process used during this study. Although the data show that the map's medium is a matter of personal preference, several features are essential to creating a map with maximum readability.

Tactile maps, like their print counterparts, are most often used by people with visual impairments (that is, those who are blind or have low vision) when they are becoming familiar with new geographical areas. Such maps can be critical to helping individuals with visual impairments navigate large areas such as college campuses. Printed campus maps are among the first items given to new students, and these maps are useful if the student is sighted. Tactile maps of college campuses are increasing in popularity, but few colleges offer portable tactile maps to students with visual impairments.

Tactile maps facilitate orientation and mobility (O&M), a critical life skill for people who are visually impaired (Higgins, 1999; Thinking Habitats, 2016). *Orientation* is a person's knowledge of their position within a space, and *mobility* is the act of traveling through that space safely and efficiently (Higgins, 1999). Although the Americans with Disabilities Act (ADA) (1990) mandates that O&M services must be provided, it should be noted that timely and sufficient services can be difficult to obtain, due to the limited availability of O&M professionals and the demands on their schedules. It would be a daunting experience for students with vision impairments to discover and navigate their surroundings independently without a tactile map.

The ability to navigate a campus safely contributes to the academic and social development as well as the conceptual, spatial, and psychological development of students (Holbrook, Kamei-Hannan, & McCarthy, 2017). Few colleges have tactile maps for students who are visually impaired, and little research exists on what makes one map better than another or how an effective map is developed.

Literature review

Tactile maps, or tactile maps on college campuses

An Internet search of "college campuses with tactile maps" yielded few results. The most promising list of approximately 10 colleges with tactile maps comes from a company that specializes in creating such maps (Cioffi, 2009). Other colleges identified as having tactile maps, by either an article in the college's newspaper or a paragraph from the disability services office, describe them as stationary rather than portable, giving limited access to students with vision impairments. A primary reason for the scarcity of tactile campus maps is the level of complexity involved in researching and creating them. According to Lawrence and Lobben (2011), when compared to print maps, "[t]actile maps contain less information, use rigorous spacing rules, have fewer overall symbols from which to choose, and use markedly different printing methods" (p. 684). The challenges of producing tactile maps often keep establishments from providing this mobility tool, but the process can be simplified by implementing best practices for their development.

Choosing the right type of map

Tactile maps have been used by people with vision impairments for decades. Orientation maps provide an overview of a large area, while mobility maps contain more detail that is designed to help the traveler in unfamiliar areas (James, 1982). Creating a usable, efficient tactile map requires knowing which features would most likely be used by people who are visually impaired and determining which medium presents the map's information most clearly, since the medium used affects the maps' usability and production. Previous studies have discussed the readability of various substrates and the use of different types of tactile symbols (Lobben & Lawrence, 2012; Papadopoulos & Karanikolas, 2009; Rowell & Ungar, 2003). In a study by Jehoel, Ungar, McCallum, and Rowell (2005), participants preferred and had a high rate of efficacy when scanning tactile maps that used rougher substrates.

Symbols

Symbols are an important feature of tactile maps. A 1999 study concluded that a map reader may be able to distinguish and remember four to seven symbols on a tactile map (Slocum, 1999). Information from previous studies, as well as the book *Guidelines and Standards for Tactile Graphics, 2010,* by the Braille Authority of North America (2010), were instrumental in the development of this study.

Line elevation

Previous studies have discussed how tactile perception in raised-line elevation affects a map's readability. Specifically, in a study by Jehoel, Sowden, Ungar, and Sterr (2009), the design guideline for acceptable line elevation was determined to be 0.4 mm. Of the available tactile mapping methods, the microcapsule printer and braille embosser created lines with the proper elevation.

Reading strategies

Despite a growing body of research, no best practices of accessing information from tactile displays have yet been identified. Based on his study, Berla (1972) suggested strategies of systematically exploring a tactile display horizontally or vertically and using three fingers rather than only one. There are many different factors that influence the reading efficiency and preferences of people who are visually impaired, such as size and discriminable symbols (Schiff & Foulke, 1982).

Emerging issues

Research on the effectiveness of tactile maps has shown that people who are visually impaired can use them effectively to learn routes through a new location (Siekierska et al., 2003): "Tactile maps and graphics are an important resource, as they can enable blind persons to obtain images of the world and to become acquainted with its changing (geographic and spatial) realities" (p. 483). Without a tactile map, mental mapping using a long or white cane, dog guide, or human guide may take much longer.

Tactile maps of facilities and grounds allow students with visual impairments efficient and safe access to a campus as well as opportunities to optimize their social, academic, and professional development, facilitating the O&M of these students. There is a need for universities and other educational institutions to continue improving O&M training (ADA, 1990), in particular the development and optimization of tactile maps that account for the input of their actual users on location.

Research statement

The purposes of this study were: to research and develop a tactile map that facilitates the ability of students who are visually impaired to travel independently, efficiently, and safely on campus; and to determine the most suitable medium for the map. The research followed a four-step development process, guided by action research principles and qualitative research methods. The goal was to be able to provide universities with a means to better accommodate

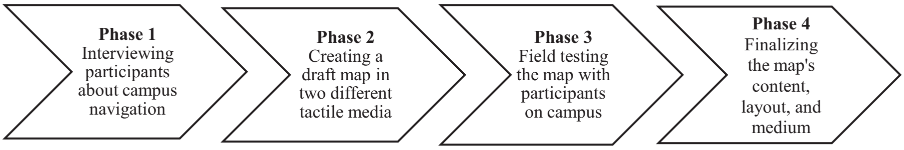

Figure 1. Processes of map development in four phases.

students who are visually impaired by creating tactile maps.

Research questions

1. What are the necessary features of a tactile map of a university's main campus?
   a. Which features pertain to the accessibility or ability to travel independently on the campus?
   b. Which features pertain to the efficiency of travel on the campus?
   c. Which features pertain to the safety of travel on the campus?
2. Which tactile medium is most suitable for users:
   a. when studying the map to get an understanding of the campus grounds in a stationary locale? and
   b. when traveling the grounds of the campus?

Methods

Developing the tactile map called for a four-phase research design and an iterative process. Using a portfolio of semi-structured interviews, observations, and site visits as data collection methods, four undergraduate students with low vision participated in phases 1 and 3 to assess their experiences in navigating campus. The data were used in phases 2 and 4 to create, revise, and finalize the content, layout, and medium of the map (see Figure 1).

Student population, campus, and participants

Student population and campus

The study was conducted at a four-year Midwestern university with approximately 23,000 students, including 18,100 undergraduate and 4,400 graduate students. Approximately 20 currently enrolled students qualified for accommodations due to low vision or blindness, with the degree of vision loss ranging from very mild visual impairment to total blindness.

Although the university has three campuses, the main campus was selected for the development of the tactile map, because it is home to most undergraduate studies and student life, along with all of the university's residence halls and classroom buildings for undergraduate courses, the student union, and the main library. The campus, divided by a small river, is surrounded by residential neighborhoods.

Participants and sampling strategy

Four undergraduate students (one female and three male) with low vision and an average age of 22.5 years participated in the study. Students were identified and recruited using the following selection criteria: a visual impairment that fell under the category of "legal blindness," the ability to read braille, attendance in an undergraduate program on the main campus, and study in a college in a different area of the main campus than the other three participants. This purposeful sampling strategy (Flick, 2002) facilitated identifying specific barriers experienced by the participants and guided the development of a tactile map beneficial to students with diverse visual impairments. Table 1 provides the participants' demographic information; pseudonyms were used to protect their identities and privacy. The ethics committee of the University of Toledo in Ohio approved the study, and informed consent was obtained from the participants.

Data collection

Semi-structured interviews

Semi-structured interviews were used to solicit the participants' demographic information and their experiences and knowledge of traveling across the main campus as part of field-testing of the tactile map (phases 1 and 3). Semi-structured interviews follow a given set of interview questions that allows researchers to ask ad hoc questions (Flick, 2002). These self-reported data were the main sources used to inform the development of the tactile map and were supplemented with general observations.

Observations

Observations are essential in the collection of data from field tests, allowing the researchers to probe and analyze intensively the multifaceted characteristics of an individual unit such as a student, a classroom, or a community (Flick, 2002). Participants in this study were observed reading and using the tactile map while navigating selected sites on campus (phases 1 and 3). However, no behavior-scoring rubric was operationalized to

Table 1
Detailed demographic information for individual participants.

Pseudonym	Age	Gender	Visual impairment (VI)	Implications of VI	Age of onset of VI	Primary mode of travel	Received campus O&M	Braille reader	Experience with tactile maps	Semesters attended
Katie	23	F	Retinitis pigmentosa	Light perception	Birth	White cane	No	Yes	Yes	10
Eric	21	M	Unknown	Central vision	5 years	White cane	No	Yes	Yes	7
Richard	26	M	Retinitis pigmentosa	Light perception	Birth	White cane	Yes	Yes	Yes	11
Simon	20	M	Optic nerve atrophy	Central vision	13 years	Dog guide	Yes	Yes	No	4

specifically report on their performance in reading comprehension and usage of the tactile map. This weakness is addressed in the limitations and future research section.

Site visits

Site visits are typically used to assess how participants perform in a certain workplace or living environment. In this study, site visits were used to assess the participants' ability to navigate the campus using their existing mode of navigation (white cane or dog guide) without a tactile map, and then with the tactile map (phases 1 and 3). Detailed field notes were recorded as participants completed three routes in an area in which the participants noted was familiar or easy to navigate, an area they indicated was difficult to navigate, and an area that was new to the participants.

Materials

Video recordings and field notes

Participants were recorded during the interviews and site visits using a standard video camcorder. Interview responses, observations, and handwritten site-visit field notes were transcribed with a word-processing program and subsequently summarized in a tabular format.

Tactile maps

Two otherwise identical 11″ by 11.5″ tactile maps were created using different tactile media, braille embossed paper, and microcapsule paper, allowing for the identification of the most suitable medium during field testing. The embossed map was developed using TactileView, a drawing software used in tactile graphic production, and it was embossed on braille paper with an Index Everest-D V4 embosser. The microcapsule map was created using Microsoft Word to draw the images and was printed on microcapsule paper that was fed through a Picture in a Flash (PIAF) machine until all lines on the page were of the appropriate tactile height. The maps, bound using a comb-binding machine, contained a cover page and keys to orient the user to the symbols used within the maps, along with a listing of buildings and abbreviations, as would appear on traditional campus maps.

Procedure

The research and development of the tactile map used an iterative, four-phase process (see Figure 1). In phase 1, participants were interviewed individually, using 30- to 60-minute semi-structured phone interviews to solicit demographic information and experiences in navigating the campus, including barriers, problematic areas, and easy zones and times for traveling. In phase 2, a draft map integrated the data collected in phase 1 with the existing nontactile map of the campus. Then identical tactile versions of the maps were created using two different media: embossed and microcapsule paper. In phase 3, both versions of the tactile map were field-tested with the same participants to assess the individuals' ability to navigate the campus with the maps. The field testing included interviews and observations of individual participants while they explored and read the tactile maps in a room on campus and during subsequent site visits using the tactile map to navigate three selected routes. The 60- to 90-minute-long field tests were video recorded and transcribed, and field notes were taken. In phase 4, the graphical content and layout of the map were revised based on the data collected during phase 3. Similarly, the best tactile medium in which to produce the final map was determined.

Analysis

The method of qualitative content analysis (Mayring, 2000) was used to analyze the transcripts of the semi-structured interviews and observations at the end of phases 1 and 3. This method uses three analytical procedures: summarizing aims and reducing data into manageable segments; explicating to explain, clarify, and further reduce data into explicatory categories; and structuring to compare and contrast categories across different data points in search of underlying themes (Flick, 2002). An inductive coding scheme was developed to answer the two research questions (about the necessary features of tactile maps and the most suitable medium) and to iteratively develop the final map (see Figure 1).

Results

This section follows the four phases of the development and research process.

Phase 1: interviewing participants about campus navigation

Necessary geographical features to travel independently

During phase 1, participants were asked to discuss, in relation to their experiences without tactile maps, what enhanced their accessibility and ability to travel independently across campus (research question 2). Participants mentioned features and strategies they used to navigate campus and identify their location.

Navigation using landmarks. *Landmarks* are easily identifiable objects or places that help individuals to know their location within an environment; they are stationary and allow for consistent location recognition (Professional Development and Research Institute on Blindness, 2014). All participants used the shapes, sounds, and textures of specific landmarks for navigation. The three students who used white canes also described distinct surfaces and textures of the ground that helped them with their orientation on campus. Each participant was asked to identify the landmarks they used to navigate the campus.

- Ramps and hills (changes in elevation): Three participants (Katie, Richard, and Simon) noted that changes in elevation such as a ramp or hill were useful in determining their location on campus. Changes in elevation could occur anywhere on campus and needed to be memorized as part of their mental maps of it.
- Streets (traffic sounds): Two participants (Katie and Eric) identified traffic sounds and patterns as landmarks, using traffic sounds on campus roads and parking lots to identify their position.
- Fountain (shape and sounds): Two participants (Katie and Simon) used the decorative shape of a fountain and the sound of splashing water as a landmark to identify their proximity to the student union and other landmarks in the center of campus.
- Bus stops and routes (shape and sounds): Two participants (Eric and Simon) identified bus stops and bus routes as campus landmarks. The bus shelters allowed them to identify fixed locations on campus; and the sounds of operating buses, such as running

engines, switching of gears, and use of brakes, permitted them to deduce their relative location along existing campus bus routes.

- Statue (shape): One participant (Eric) noted a large and uniquely shaped sculpture in front of one of the campus buildings as a landmark when traveling; he was able to see it and know his location.
- Bridges (surface texture and sounds): One participant (Eric) identified the walkway bridges in the middle of campus as landmarks. To orient himself, he used the distinct texture change from the general walkways to the bridge surfaces, along with sounds from the river that could be heard occasionally.

Navigation with cane. Participants mentioned a mobility strategy referred to as *shorelining* (that is, following a distinct part of the environment when using a cane). Participants said that it was easy to shoreline with streets and sidewalks, grass, and buildings, and they identified streets in general as an accessibility-enhancing feature of the campus. Two participants found that streets lined with sidewalks were particularly helpful in navigating the campus, since they could use the curb for orientation (Katie and Simon). Furthermore, two participants (Katie and Eric) also identified grass as a benefit to accessibility because shorelining was easier in grassy areas; when traveling, participants could touch the sidewalk on one side and the grass on the other to walk in a straight line. Simon, who has usable vision, could see the contrast between the grass and the cement sidewalks to facilitate navigation. Finally, two participants (Eric and Richard) discussed the importance of buildings and landmarks in facilitating independent travel and promoting the ability to deduce their position on campus relatively easily according to their mental maps of campus.

Efficiency of travel

A portion of the interview focused on how efficiently participants traveled on campus, according to their own perceptions. Traveling in specific areas frequently allowed them to become more efficient in navigating those areas. All participants said that they traveled the areas directly related to their academic college most often and that the campus bus system facilitated their movement around campus.

Safety of travel

The final portion of the phase 1 interview related to how safe the participants felt when traveling on campus. Three participants (Eric, Katie, and Simon) said that they felt safer traveling during the daytime than at night, which Eric and Simon attributed to the unsafe feeling of traveling with decreased usable vision and which Katie felt was due to the scarcity of people nearby. One participant (Richard) said that the lack of lighting in some areas on campus made it unsafe to travel after dark.

Phase 2: Creating draft maps using two different tactile media

The tactile map's first draft was designed specifically for ease of readability by a person with low vision and geographical accuracy. The first draft, developed based on data gathered during phase 1 and informed by the expertise of the author in her capacity as an O&M specialist on campus, comprised 16 pages in 11″ by 11.5″ paper format, comb-bound as a booklet.

The cover page stated the title of the map, "Tactile Map of the University Main Campus," the name of its creator, the date (edition), and information on obtaining additional copies. The next three pages, keys for using the map, were prefaced by the following statement: "The following keys are related to each individual map page. Most of the symbols and lines are consistent throughout the maps except minor changes due to the specificity of the area being mapped." According to Slocum (1999), a maximum of seven tactile symbols can be recognized and remembered by a map reader with low vision; none of the participants in the present study commented on the number of symbols being too great to recognize or remember. The tactile map created in this study included seven different symbols and a key for each section of the map that fostered independent use of the map.

Next were three pages of building names and their abbreviations, with the buildings identified by acronyms for efficient use of space. For example, the "Student Union" (13 total cells in contracted braille) was changed to "su" (two cells in contracted braille).

Geographical information was provided on nine pages: The first four pages featured the "general map," with buildings drawn as small as possible to depict the complete terrain of the main campus; these pages included only buildings, main roads, the river, and railroad tracks, while sidewalks and landmarks were omitted. This big-picture approach allowed readers to build a mental map of the campus. Pages of the general map were labeled A1, A2, B1, or B2, according to the corresponding quadrant of the university's main campus (A and B representing the y-axis, 1 and 2 the x-axis). The last five pages of geographical information were dedicated to the various locations the participants had identified as difficult to navigate during phase 1. Finally, almost every page in the booklet was embossed with three diagonal lines in the top right corner so the reader could easily orient the map.

PHASE 3: FIELD-TESTING THE MAP WITH PARTICIPANTS ON CAMPUS

Each participant was interviewed individually before embarking on three predefined routes (familiar, difficult, and new location) on campus. Their verbal responses and performance were video recorded and transcribed. All participants discussed key issues for the general improvement of the tactile map and provided feedback unique to them as individuals, including the most suitable medium for the map. The general observation revealed that Eric, Katie and Richard used the tactile map while traveling the familiar routes. Eric and Richard made slight errors while traveling and consulted the tactile map to reorient themselves and continue to the desired destination. Simon was able to travel the entire route without referring to the map. When traveling the unfamiliar routes, all four participants were able to navigate successfully to the desired location with the use of the tactile map. No behavior-scoring rubric was operationalized to measure the reading comprehension of the tactile map specifically; this is addressed as an opportunity for future research below.

General key issues

The following key issues were experienced and addressed by all participants during the interview or before, during, and after they walked the three routes:

1. Written description of map layout: Participants suggested short descriptions to explain the layout of the map in words; for instance, a short paragraph describing how the map is divided into quadrants and how the quadrants compose the general map of the main campus.
2. Table of contents: Participants identified the need for a table of contents after the cover page to help the reader move throughout the map quickly and efficiently.
3. Page numbers: Participants expressed the need for page numbers, preferably in the upper right corner of all pages in the map booklet, as found in most braille books. Page numbers would correspond to the table of contents to allow for quick and easy location of specific portions of the map booklet. In the final map, page numbers replaced the three diagonal lines, serving the purpose of orienting the reader to both the correct page and the way to hold the booklet.

Unique feedback of individual participants

All participants provided feedback unique to their individual needs and personal experiences of reading and using the draft map. Their feedback was accumulated into the following suggestions for improvement and consideration:

1. Adding parts to existing maps: Each participant identified at least one area that he or she felt needed to be included in the second draft of the map. For instance, Richard suggested increasing the scope of one of the maps to include the tennis courts as a landmark, and Eric suggested adding street names to the specific maps instead of the general map. Simon suggested abbreviating one of the buildings as it appears on the print main campus map (North Student Union = nsu and South Student Union = ssu, instead of only labeling the building Student Union = su).
2. Order of building abbreviations: Katie suggested reversing the order in which the building abbreviations were presented. The list included the full building name first, followed by the abbreviation, but when reading the map, the reader is presented with the abbreviation, so it made sense to use the abbreviation as the organizing principle of the list.
3. Compass rose: When planning a route or orienting to a new area, people with visual impairments frequently use the cardinal directions (north, south, east, and west). For this reason, it would be beneficial to include a compass rose on each map within the booklet.
4. Contrast on embossed map: While discussing his preferred map medium, Simon mentioned that he could see the contrast of the black line on the light-colored microcapsule paper. Adding similar black lines to the embossed map would allow readers with low vision to benefit from the map as well.
5. Protective cover and backing: A protective cover and backing could add to the life span of the map booklet by protecting the pages. All participants remarked on the durability of the microcapsule paper map versus the embossed map.

Suitability of the tactile medium for the map

After participants had read the map and completed a field test, they commented on the two media in which the tactile maps were produced: microcapsule lines or embossed paper (research question two). Three participants (Katie, Richard, and Simon) preferred the microcapsule medium for both studying the map in a stationary location and using it during travel. Katie and Richard noted that the microcapsule map was "easy" on their fingers, likely because tactile graphics on microcapsule paper tend to have a more rounded, softer edge compared to the rougher edge of an embossed image.

Although he also preferred the microcapsule map for studying details and for travel, Eric found a benefit in using both media. He said that the embossed map made it easy to distinguish the patterns or shapes he was feeling, while the microcapsule map could produce finer detail, likely because it is possible to create much thinner lines with microcapsule versus embossing paper. No participant thought the embossed paper was a suitable medium in its own right, but rather in combination with a microcapsule map.

Phase 4: finalizing the map's content, layout, and medium

During phase 4, the final draft of the map was created, accounting for all key issues and suggestions identified in phase 3. The map's finalized content, layout, specifications, and processes, as described earlier, included the student-centered approach to produce the maps in both media to suit users' tactile preferences. Finally, copies of the map were provided to the participants in their preferred media and to the university's office for students with disabilities. Box 1 includes a checklist of the content and features of the final version of the map.

Checklist for developing a tactile map

Individual needs of map user

- ☐ Visual impairment
- ☐ Implications of visual impairment
- ☐ Primary mode of travel
- ☐ Braille reader
- ☐ Main traffic routes (e.g., dormitory to college and student union)
- ☐ Safety needs of user

Orientation map

- ☐ Streets
- ☐ Buildings

Mobility map

- ☐ Streets
- ☐ Buildings
- ☐ Sidewalks
- ☐ Landmarks including, but not limited to:
  - ☐ Changes in elevation
  - ☐ Fountains, statues, etc.
  - ☐ Bus stops
  - ☐ Bridges

General suggestions

- ☐ Map keys/legends
- ☐ Table of contents
- ☐ Building abbreviation list
- ☐ Compass rose on each page
- ☐ Page numbering in upper right corner
- ☐ Protective cover and backing
- ☐ Braille and large print labels
- ☐ Print and raised lines for contrast

Box 1

Discussion

Necessary features of a tactile map of campus

In this study, four participants with low vision provided input about which features were critical in creating a tactile map with maximum readability for people with visual impairments. These features were included in the initial draft of the tactile map and were field-tested with the participants. Each participant traveled and successfully completed an unfamiliar route with the aid of the final map; thus, it can be assumed that the map contained the information necessary for participants to travel independently.

Suitability of the tactile medium for the map

The participants were asked to choose the most suitable medium, either microcapsule or embossed paper. According to the data collected in the present study, the most suitable medium is based entirely on personal preference. All participants agreed that both maps had a high degree of readability, yet most participants chose the microcapsule map over the embossed map.

Limitations and future research

The generalizability of results is limited because of the small volunteer sample, and no procedures were conducted to ensure that the data reported were trustworthy, dependable, or confirmable. In the future, this study could be used as a pilot to conduct large-scale intervention research to assess the effect sizes of the tactile map, including pre- and post-assessment of reading comprehension and campus navigation performances.

Implications for practitioners

In providing accommodations for students with visual impairments, a college or university campus should create a tactile map of the campus, the development of which should follow the four-phase process used during this study to create and adapt an initial map according to the individual needs of students. It is important to note that both an orientation map (that is, a general overview of campus), and an area-specific mobility map may be necessary in ensuring that the most comprehensive tactile map is produced. If possible, maps should be created in at least two different media to allow users to choose the most suitable map for them.

Conclusion

This study identified features that result in high degrees of readability and efficacy of use of tactile maps. It is suggested that map medium is a matter of personal preference, and that tactile maps should be available to students in a variety of media to allow for individualized needs. Future research in this area may involve participants who are unfamiliar with a campus and analyze their ability to navigate it with a tactile map, as well as test other high-quality media and conduct large-scale intervention studies.

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