Visually Impaired Children with Special Educational Needs: Identifying Suitable Tactile Graphics Learning Materials

Anqi Rong[1,a] , Guanyu Li[1,*]

[1] University of Leeds, UK, LS2 9JT

Abstract. How to design and generate tactile graphics that have clear semantic meaning and are easy for visually impaired children to recognise using their sense of touch in special education is currently a challenge in China. This study summarises the advantages and disadvantages in different technologies for tactile graphics generation by analysing 12 papers in the last ten years on tactile graphics in education field. The insight from this work will help researchers, design professionals, visually impaired children and educators in China to make informed decisions about what they should focus on, how they should do it, and why they should do so.

1 Introduction

Special groups in China have previously experienced much neglect. Specifically in this study's scope, the country's many citizens with visual impairments have suffered a dearth of educational opportunities and, in particular, poor learning resources that lack bespoke concerns for their individual needs. This has had devastating personal, social, and national consequences. While China has, in recent years, been paying more attention to educating special groups by increasing its efforts for them, visually impaired children remain at much disadvantage regarding their overall educational development, even if they are provided with the same educational resources as ordinary children. Notably, most visually impaired children have been unable to access national education, but those who have accessed it have encountered failings regarding a key means of their educational and all-round development: working with tactile graphics. Even with recent movements towards such graphics, how effective the somewhat sporadic efforts have been and how suitable these resources remain questionable.

Children who are blind or visually impaired rely extensively on tactile graphics, which are raised-line pictures on paper that can be felt with the touch, to comprehend geometric concepts in school textbooks, represent a narrative in picture books, and conceptualise exhibitions in museums [1]. More precisely, because teaching materials in these subjects commonly use diagrams and geometric figures, tactile graphics are crucial for students studying science, technology, art, and mathematics. As such, both the lack of tactile graphics in the special education field and the poor suitability of many existing tactile graphics for visually impaired children in China thus have severe implications.

2 The present study

According to the 2019 yearbook data of the Chinese Ministry of Education, China has a total population of 277 million children, only about 40,000 (0.014%) children with visual disabilities are covered by the national education system. Indeed, most people with visual impairment in China are unable to access compulsory education because of their disability, travel conditions, and economic circumstances, which has severe ramifications for visually impaired individuals, society, and the country. Although the issue of visual impairment is receiving increasing attention in the country, it remains an area beset with issues not just with participation but also concerning quality of provision (both outlined above). Despite this, statistics from the Chinese paper search engine CNKI show that (Fig. 1), contrary to Google Scholar data, only a very limited number of studies are about tactile graphics, so more research is clearly needed on this subject.

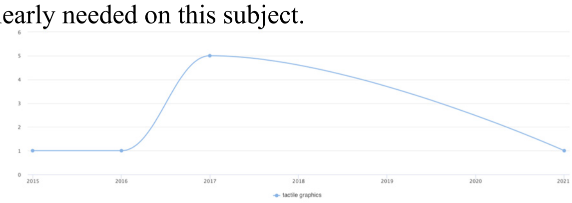

Fig. 1. Search results for the term tactile graphics

Effective learning and comprehension of tactile graphics and diagrams is a crucial requirement for educating visually impaired students. This process often necessitates substantial guidance and practise. Educators at the Beijing School for the Blind have noticed that visually impaired children face difficulties when exploring tactile graphics without personal assistance.

[a]sdar@leeds.ac.uk, *sdgl@leeds.ac.uk

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

Despite the significance of graphics in disciplines such as art, science, and mathematics, visually impaired children often struggle to access them due to a lack of appropriate resources and inadequate training in utilising such materials.

An exploratory study conducted at the Beijing School for the Blind revealed a significant obstacle to the academic success of visually impaired children across various subjects. The lack of access to diagrams and charts in training materials has far-reaching consequences for these students. Furthermore, visually impaired children may encounter challenges in discerning detailed distinctions between line styles or textures and navigating intricate arrangements of lines and braille. Consequently, these limitations impede visually impaired children's individual access to educational content depicted through tactile graphics, requiring additional explanations from sighted partners. To mitigate this issue, educators sometimes resort to orally explaining specific diagrams and figures to visually impaired students. However, this approach is not always sufficient.

3 Related works

3.1 Research on tactile graphics for visually impaired children

Tactile graphics play a crucial role in the academic achievements of students with visual impairments. Research consistently demonstrates that the combination of tactile graphics and textual information is the most effective method for conveying information to visually impaired students in educational settings [2]. Despite this, as nearly 70% of textbooks only use diagrams and don't provide written descriptions, the use of images and diagrams alone to convey information is growing[3], which according to Zebehazy and Wilton's [2] results suggest a problematic pattern for those with visual impairment. As the Braille Authority of North America (BANA, 2010) notes, materials for early grades (kindergarten through grade 3), by nature, are primarily presented in image (picture) form. While the previous authors say these alone will not produce best results, BANA says that because young readers are still establishing their reading vocabulary, new ideas must be conveyed using images rather than words. It nevertheless adds that not educational goals can be met as they are presented to print readers, and many of these activities do not provide students who read braille with meaningful learning experiences because many of the symbols used in print to represent objects cannot be easily recognised and understood by a braille reader, which seems to support Zebehazy and Wilton's [2] key point. While it is critical to include images in texts for young readers, then, for the visually impaired it is highly significant and much more delightful to count or group shapes or textures than to have merely braille dots to demonstrate information, though other factors may also be relevant.

As previously alluded to, for visually impaired students to interpret and employ these visualisations, they need sighted helper, but another problem lurks here as Zebehazy and Wilton [2] also mention that the capability to independently study tactile graphics, track information, and respond to questions is integral to the learning process.

3.2 The difficulties in designing tactile graphics for visually impaired children

The key differentiating factor between traditional graphic design and tactile graphics lies in the requirement to transform visual data into a format that can be perceived through alternate senses, primarily touch. Consequently, in order to achieve this, graphics must be simplified and abstracted to a certain extent compared to regular images. This adjustment is necessary because a typically sighted individual can discern points and lines as small as 0.15 millimetres apart [4], whereas the tactile sense allows for a minimum discernment of 2.4 millimetres [5]. This indicates the need for a higher level of spatial data generalisation when creating legible tactile graphics. The process of generalisation itself presents a complex research programme in graphic design, which warrants even greater attention in the context of tactile graphics due to the unique perceptual characteristics of touch [6].

Designing tactile graphics for visually impaired children is not merely about simplifying the content. When creating a graphic, it is crucial to consider the space available on the page where the graphic will be placed. Designing a template that accommodates the required space for each page size and production method is essential. Unfortunately, there has been limited emphasis on the development of textbooks containing tactile graphics [7, 8]. Consequently, there is a dearth of instructional materials that enable visually impaired students to fully engage in subjects such as art, science, and mathematics. The current challenge stems from the fact that nearly every tactile graphic needs to be approached on an individual basis, lacking standardised solutions.

3.3 Research on the current design methods and effective technologies for tactile graphics

Brock et al. [9] developed a prototype of an interactive map that integrates raised-line map overlays with microcapsule paper on a multi-touch screen. The setup comprises a computer connected to the screen, as well as loudspeakers for speech output. The researchers successfully showcased that interactive audio-tactile maps provide enhanced usability for blind users in comparison to traditional tactile maps with Braille text. They also validated that visually impaired individuals can effectively memorise and mentally manipulate spatial information, pertaining to specific routes as well as overall survey data, through the utilisation of these interactive maps.

The existing literature highlights a pressing issue faced by visually impaired children in education, namely, the inadequate availability of teaching materials. Numerous primary studies have proposed various solutions to address this problem. For example, Fusco and Morash [10] introduced a machine vision-based tactile graphics helper (TGH) that tracks the movement of blind students' fingers as they explore tactile graphics. The TGH system facilitates the delivery of detailed audio messages related to the tactile graphics, eliminating the need for sighted assistance.

In a separate study, Shaw and Hadden-Perilla [11] developed a software plugin that facilitates the efficient creation of tactile graphics representing proteins with varying heights. This plugin utilises the widely available biomolecular visualisation software, Visual Molecular Dynamics, in conjunction with protein structure data. The software plugin has wide-ranging applications in scientific domains such as biology, biochemistry, and biophysics. It leverages the knowledge of protein structure to elucidate the mechanisms underlying protein functionality. This tool can be instrumental in devising strategies to enhance or modify protein functions for disease treatment and advancements in human health. Another controlled study conducted by Yang et al. [12] involved visually impaired participants. The researchers compared four different tactile representations of networks: organic node-link diagrams, grid node-link diagrams, adjacency matrices, and braille lists. Network representations are commonly employed in the study and visualisation of social networks, biological networks, and software systems. This research contributes to understanding the most effective tactile formats for comprehending complex network structures. Additionally, Park et al. [13] introduced a technique that automates the conversion of printed books into electronic braille books. Their approach utilises algorithms to classify and analyse images obtained from scanned print books. The purpose of their method is to reduce the time and cost involved in designing braille books and provide visually impaired children with a broader range of study materials. This innovative approach significantly contributes to improving the educational and social experiences of visually impaired children.

4 Findings

This study finally obtained a total of 169 articles from Google Scholar, Web of Science, ACM, Scopus, and Springer databases for the last ten years on tactile graphics design. After performing the eligibility criteria and quality assessment processes, 12 primary studies met the purpose of this review in the education field (Table 1).

Table 1. The overview of 12 papers.

Author(s), year	Experiments	Results
Melfi et al., 2020	The system was utilised by two teachers and five visually impaired individuals across various subjects, including mathematics, social science, handicraft, computer science, and physics.	The TPad system has demonstrated its suitability for educational environments, offering enhanced efficiency in exploring tactile graphics.
Fusco & Morash, 2015	The TGH (Tactile Graphics Helper) was tested with six tactile graphics by three participants who were university students specialising in STEM majors.	The TGH offers a promising solution to address the challenges associated with tactile graphic formats.
Baker et al., 2014	A total of 10 blind participants were involved in testing the tasks using a smartphone application, employing three distinct modes.	TGV represents a valuable approach for accessing textual information in tactile graphics, particularly beneficial for blind individuals who may not be proficient in Braille.
Engel & Weber, 2019	A total of 48 blind participants responded to inquiries regarding the readability, content, data, specific design aspects, and provided personal ratings.	The participants demonstrated a high level of accuracy in answering nominal questions related to minima, maxima, and comparisons, achieving an impressive 80% correct response rate.
Shaw & Hadden-Perilla, 2020	Three-dimensional printed models and tactile graphics have proven to be effective tools for enabling blind students to analyse protein structures.	The outcomes of this study facilitated visually impaired undergraduate students in conducting high-quality research on protein structure.
Yang et al., 2020	8 visually impaired participants were involved in a comparative study, evaluating four tactile representations: organic node-link diagram, grid node-link diagram, adjacency matrix, and braille list.	All the participants noticed that the two node-link diagram representations were more natural and intuitive.
Engel et al., 2019	2 blind participants evaluated the bar and line charts and scatterplots in two-hour sessions.	The structure and elements of the charts and all properties were recognised by both participants.
Chase et al., 2020	1visually impaired engineering student assessed two developed applications designed for educational purposes.	All the participants and experts of tactile graphics commented for improving several technical functions.

Maćkowski et al., 2020	10 blind students solved 15 math exercises containing graphic content available in tactile form.	Research demonstrates better assimilation of math knowledge and improved participants' positive sentiment and their cognitive abilities.
Park et al., 2016	10 visually impaired individuals evaluated the electronic braille pages printed by the braille printer.	Time and cost were significantly reduced and more reading materials were provided for the visually impaired.
Gupta et al., 2017	N/A	The software was capable of enhancing the productivity of tactile designers.
Race et al., 2019	The schematics were evaluated by low-vision and blind participants.	The schematic symbols of popular textbooks and guidelines were produced.

Scientific diagrams, such aselectronic circuits [11] biological molecules [12], and node-link diagrams [14] offer visually impaired children the opportunity to actively participate in research alongside their sighted peers. The software plugin designed to convert proteins into tactile graphics provides compatibility with Windows, Mac, and Linux operating systems. It is accessible through a text console interface that can be utilised with a screen reader or Braille display [11]. However, it is important to note that this plugin relies on the Visual Molecular Dynamics (VMD) software package, requiring blind users to instal and navigate VMD. Additionally, the creation of a prebuilt 3D protein structure presents a challenging task. In the context of converting social network visualisations into tactile graphics, the use of node-link representation has been identified as the most effective method for comprehending the connexions between different networks [12]. Nevertheless, it is crucial to acknowledge that Yang et al.'s study suffered from limitations such as a small sample size and a lack of variability in the graphs examined.

Another intriguing study focused on generating tactile graphics from Braille books, wherein text and image areas were identified separately using computer vision techniques [13]. While the conversion of text to Braille achieved high precision, the researchers encountered several challenges in creating tactile graphics from complex-shaped images that remained unresolved. In a separate investigation, a microcapsule fuser and paper were employed to create tactile graphics of schematics found in school textbooks [14]. However, this process was rigid and required diverse configurations and human involvement for each electronic circuit. These studies demonstrate the advancements in creating tactile graphics for scientific content, yet they also reveal ongoing challenges and limitations. Further research is needed to address issues such as the reliance on specific software packages, the complexity of image-to-tactile conversion, and the need for more flexible and automated methods in creating tactile graphics for educational materials.

Stangl [15] organised workshops involving professionals from various fields who expressed a desire to assist visually impaired children. These workshops focused on experimenting with and interviewing participants regarding 3D printable tactile graphics. Since many of the workshop participants lacked sufficient knowledge in 3D modelling and tactile graphics, some results remained incomplete and were not tested with visually impaired children. Nevertheless, the integration of augmented reality techniques in generating audio-tactile graphics for visually impaired children using real objects has opened up new possibilities in this field [16]. This approach enables educators to develop their own pedagogical audio-tactile material based on existing objects. Nonetheless, it is important to note that integrating this system into classrooms requires both time for teachers to become proficient with it and additional financial support for schools.

The future development of tactile graphics entails various challenges and considerations. Standardised formats and guidelines are needed to ensure consistency and interoperability across different systems and devices, promoting seamless usage and comprehension. A critical factor in the advancement of tactile graphics is the availability of accessible content across diverse fields of study, including art, science, and mathematics. Efforts should be made to improve the production and accessibility of tactile graphics in these subjects. Additionally, scalability and affordability are key considerations for wider adoption of tactile graphics technologies. Enhancing accessibility and cost-effectiveness will broaden their impact on education and society as a whole. The exploration of novel materials with improved tactile properties holds potential for enhancing the fidelity and realism of tactile graphics, allowing for more precise and detailed representations. To further refine tactile graphic design methodologies, continuous research and user feedback are essential. Involving visually impaired individuals in the design process, while considering their specific needs and preferences, will lead to more effective and inclusive tactile graphic solutions. Overall, the future of tactile graphics lies in advancing technology, improving accessibility, and fostering collaboration among researchers, designers, educators, and visually impaired individuals to create more inclusive educational experiences.

5 Conclusion

The present phase of this study has delved into the realm of tactile graphics, aiming to enhance our comprehension of this field. Considering the significance of tactile graphics as learning materials in special education, numerous studies have put forth concepts and approaches to enhance the quality of education for visually impaired children. These endeavours aim to facilitate their successful integration into contemporary society and promote their overall adaptation. Roughly 66% of the primary studies that were examined focused on assessing and testing various methodologies, processes, and outcomes regarding technologies for the visually impaired. Despite some research studies not resulting in outcomes that have been put into practice, they have made valuable contributions to this tricky area and generated new ideas and results that go some way to improving resource quantity and effectiveness but also ultimately the lives and lived experiences of visually impaired children.

Overall, this study highlights the existence of numerous potential solutions to address the challenges associated with tactile graphics and their generation for visually impaired children. While some solutions remain unimplemented, many have been successfully deployed in practical scenarios and are readily available for commercial use. However, it is important to acknowledge that artificial intelligence (AI) and machine learning (ML) methods, platforms, and applications for tactile graphics design have their limitations and challenges. Based on the analysis results, it can be concluded that AI and ML methods applied in the field of assistive technologies do contribute to the educational progress of visually impaired children to some extent. However, it is evident that these approaches alone are not sufficient, necessitating further research and development. It is crucial to continue exploring new avenues to augment and refine the existing AI and ML methods for enhanced educational experiences. Moreover, in the context of China, there is still substantial progress to be made in the field of academic research and development concerning tactile learning materials for children with visual impairments. Efforts should be directed towards fostering the growth of this academic discipline to meet the specific educational needs of visually impaired children in China.

References

1. Asakawa, N., Wada, H., Shimomura, Y., & Takasugi, K. (2020). Development of VR tactile educational tool for visually impaired children: adaptation of optical motion capture as a tracker. Sens. Mater, 32(11), 3617-3626. https://doi.org/10.18494/SAM.2020.2939
2. Zebehazy, K. T., & Wilton, A. P. (2014). Quality, Importance, and Instruction: The Perspectives of Teachers of Students with Visual Impairments on Graphics Use by Students. Journal of Visual Impairment & Blindness, 108(1), 5–16. https://doi.org/10.1177/0145482X1410800102
3. Ferro, T., & Pawluk, D. (2017). Providing Dynamic Access to Electronic Tactile Diagrams. Universal Access in Human–Computer Interaction. Designing Novel Interactions, Cham. https://doi.org/10.1007/978-3-319-58703-5_20
4. Yanoff, M., Duker, J. S., & Augsburger, J. J. (2009). Ophthalmology. Mosby Elsevier. https://books.google.co.uk/books?id=u43MTFr7-m8C
5. Lederman, S. J., & Klatzky, R. L. (2004). Haptic identification of common objects: Effects of constraining the manual exploration process. Perception & Psychophysics, 66(4), 618-628. https://doi.org/10.3758/BF03194906
6. Touya, G., Zhang, X., & Lokhat, I. (2019). Is deep learning the new agent for map generalization? International Journal of Cartography, 5(2-3), 142-157. https://doi.org/10.1080/23729333.2019.1613071
7. Perkins, C. (2002). Cartography: progress in tactile mapping. Progress in Human Geography, 26(4), 521-530. https://doi.org/10.1191/0309132502ph383pr
8. Wabiński, J., & Mościcka, A. (2019). Automatic (Tactile) Map Generation—A Systematic Literature Review. ISPRS International Journal of Geo-Information, 8(7), 293. https://doi.org/10.3390/ijgi8070293
9. Brock, A. M., Truillet, P., Oriola, B., Picard, D., & Jouffrais, C. (2015). Interactivity Improves Usability of Geographic Maps for Visually Impaired People. Human–Computer Interaction, 30(2), 156-194. https://doi.org/10.1080/07370024.2014.924412
10. Fusco, G., & Morash, V. S. (2015). The Tactile Graphics Helper: Providing Audio Clarification for Tactile Graphics Using Machine Vision Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility, Lisbon, Portugal. https://doi.org/10.1145/2700648.2809868
11. Shaw, O. R., & Hadden-Perilla, J. A. (2020). TactViz: A VMD Plugin for Tactile Visualization of Protein Structures. Journal of Science Education for Students with Disabilities, 23(1), 14. https://eric.ed.gov/?id=EJ1267674
12. Yang, Y., Marriott, K., Butler, M., Goncu, C., & Holloway, L. 2020. Tactile presentation of network data: Text, matrix or diagram?. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, pp.1-12. https://doi.org/10.1145/3313831.3376367
13. Park, T., Jung, J., & Cho, J. (2016). A method for automatically translating print books into electronic Braille books. Science China Information Sciences, 59(7), 072101. https://doi.org/10.1007/s11432-016-5575-z
14. Race, L., Fleet, C., Miele, J. A., Igoe, T., & Hurst, A. (2019). Designing Tactile Schematics: Improving Electronic Circuit Accessibility Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility, Pittsburgh, PA, USA. https://doi.org/10.1145/3308561.3354610
15. Stangl, A., Cunningham, A., Blake, L. A., & Yeh, T. (2019). Defining Problems of Practices to Advance Inclusive Tactile Media Consumption and Production Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility, Pittsburgh, PA, USA. https://doi.org/10.1145/3308561.3353778

16. Thevin, L., & Brock, A. M. (2018). Augmented Reality for People with Visual Impairments: Designing and Creating Audio-Tactile Content from Existing Objects. Computers Helping People with Special Needs, Cham. https://doi.org/10.1007/978-3-319-94274-2_26