EXTENDED-ABSTRACT

Data Fidget: Designing a Tactile Companion for and with Blind and Low Vision Data Readers

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Data Fidget: Designing a Tactile Companion for and with Blind and Low Vision Data Readers

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Abstract

Blind and low vision (BLV) people face challenges in accessing charts, often relying on assistive technologies with limited interactivity. This paper presents the design process of a tangible companion supporting data literacy for BLV people. Building on semi-structured interviews with five blind and six low vision participants and a review of current tools, we conducted a Story/Test/Story protocol with a low vision participant experienced in data representation. We compared a screen-magnified bar chart with two tactile probes: (1) a unit-based cardboard bar chart and (2) a static 3D bar sculpture, using a univariate public dataset. Insights from these activities informed the ideation of the Data Fidget, a prototype that communicates data through movement, expanding when values increase and contracting when they decrease, complementing existing assistive technologies. Future work will refine and test the Data Fidget with more BLV participants, contributing to an ecosystem of tactile and intuitive data engagement tools.

CCS Concepts

• **Human-centered computing**; • **Interaction design**; • **Systems and tools for interaction design**;

Keywords

Inclusive design, Disability, Dynamic data physicalization, Data charts

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1 Introduction

As society becomes data-driven, an increasing number of studies are highlighting the importance of accessing and exploring data autonomously [13, 16]. Yet data are most often represented in charts designed for visual engagement, creating significant barriers for blind and low vision (BLV) individuals which rely on interpretations provided by others, or tools lacking adaptation and dynamicity [23].

When approaching data literacy, we shall recognize that BLV people represent a diverse group, with impairments shaped by whether vision loss is congenital or acquired. Low vision refers to impaired visual acuity that cannot be corrected by regular glasses. According to the National Eye Institute, common types include central vision loss, peripheral vision loss, night blindness, and blurry or hazy vision. In turn, the lived experiences with data representation vary widely, as do the tools and strategies they use to access and interpret data.

Screen readers are the most common assistive tool used by blinds to access digital information [13]. They are often used with input devices such as mouses, keyboards, and braille keyboards, and when hovering on an image or non-text element, they read the embedded text. The major issue is that not all non-text elements are designed in an accessible way and embedding alternative texts [21]. Efforts are being made to improve the accessibility of charts, particularly by limiting as much as possible the information loss from raw data to visual representations when writing alternative texts [28]. Also, as of 28 June 2025, the European Accessibility Act requires key products and services placed on the EU market to meet standardised accessibility requirements.

Alongside screen readers for blinds, examples of assistive tools suited for low vision are screen magnifiers, high contrast and colour adjustments tools, and text-to-speech tools, which read out digital content while also displaying it on screen. To provide alternative accessibility options there are tactile tools such as tactile relief maps or embossed prints that partially support BLV people, but they have significant limitations, mainly due to their high costs and the limited amount of information they can carry [2]. To address these limitations, multi-sensory perception has been described as a valuable way to overcome the challenges of single modalities [14]. The most common combination pairs verbal speech with tactile and haptic feedback [13]. This approach can improve their levels of agency promoting interdependent exploration and interpretation [12, 18]. From this standpoint, this study explores how data can be made tangible to better accommodate the different needs and strategies of BLV people through dynamic, multimodal interaction. We introduce here Data Fidget, a tangible companion that extends familiar access strategies and supports more nuanced, personalized data exploration. The prototype was designed building on the findings from 11 semi-structured interviews and a Story/Test/Story protocol with one low vision participant selected for their frequent engagement with data representations. The paper outlines the design process, presents initial findings, and reflects on how tangible interaction can complement existing assistive tools to foster agency in data engagement.

2 Tangible Data Access for BLV People

Attempts to make data tangible and experienceable for BLV individuals span educational settings, museums, domestic technologies, and spatial orientation aids [3]. In 2015, the Prado Museum in Madrid showcased an exhibition titled "Hoy Toca el Prado" where the paintings were re-made adding textures [15]. Besides the three-dimensional images, the exhibition included didactic material such as texts in braille and audio-guides to facilitate the experience for sighted visitors. Similarly, the project "Tooteko" aims to support a deeper engagement of BLV audiences with art. The system transforms touch into sound thanks to NFC (Near Field Communication) tactile hotspots, smart reading ring, and responsive audio playback. In this way, the person "reads" a 3D or tactile representation of an artwork using their hands, receiving audio information on what they are touching [25]. Similar examples are also seen in educational contexts, where 3D printed models and interactive tactile maps support BLV learners in learning abstract concepts [2]. Tactile charts based on Braille are also common, but a significant attention to the design choices should be given to ensure tactile discernibility [4]. Technologies such as computer haptics provide tactile sensations to people as they interact with a virtual object [5]. The haptic hardware provides feedback that simulates physical properties, such as textures, viscosity, or elasticity, adding nuances to the exploration. Vibrotactile feedback has been coupled with a digital exploration of geographical maps using an audio-based screen reader, showcasing the potentialities of combining tactile-based interactions with assistive technologies currently used by BLV people [19].

In the context of physical data [10] there has been a growing body of work exploring BLV needs. For instance, a study conducted with BLV people used tactile encodings of datasets to understand how tactile components must be designed to be correctly understood [6]. Leveraging interactivity, other studies also investigate physical manipulatives (such as tokens and units) to construct and manipulate data representations starting from tabular data descriptions [16, 29]. Embedding more sophisticated technology, "Tangible Stats" is a learning platform featuring a tilting interface where students can hear and feel how statistical measures are changing in real time [7]. Feedback becomes essential when considering dynamic physicalization, particularly in the case of BLV people. By combining visual, auditory, and haptic modalities [27], multimodal feedback is a core principle in inclusive and accessible design, beyond enriching user experience.

Despite this emerging interest, existing research has primarily focused on static tactile charts, or task-specific learning tools. Fewer studies investigate dynamic, interactive, or multisensory physicalizations designed to support BLV individuals in routine experiences with data. As a result, questions remain about how dynamic physicalizations could enhance accessibility and autonomy when interacting with mundane or self-generated data. Our work builds on prior contributions related to material qualities, tactile variables, and the potential of haptic interaction for BLV users. We draw on research examining tangible encodings such as spatial location [17] and metaphorical mappings that leverage embodied schemas (e.g., near–far, in–out) to convey meaning in alternative ways [1]. In our case, temporality becomes an explicit design material: following Vallgårda and colleagues [26], we approach interaction not as a static encounter but as a "temporal composition", where form, computation, and time evolve together to create meaning.

Addressing the identified gap, our ongoing research applies principles of tactile encoding, embodied metaphors, and temporal form to prototype, test, and evaluate new dynamic data physicalizations co-created with and for BLV individuals.

3 Context of the Study

This study is situated within broader research conducted at Moholy-Nagy University beginning with five preliminary interviews with blinds and six with low vision people. Participants were recruited through the Blind Institute of Budapest, with the support of an institutional member who facilitated contact and coordination. The selection criteria required that participants had some experience interacting with data at varying levels of complexity, while also ensuring diversity in terms of visual impairment, age, gender, and occupation. The interviews contributed to frame the focus of the study, covering past experiences, tools used to access information, challenges, and strategies employed. We report here only the key insights, as the full interviews analysis lies beyond the scope of this paper.

Despite individual differences, the interviews revealed that participants assemble a personal ecosystem of tools and practices for everyday data access. They heavily rely on digital tools such as laptops, tablets, and phones, preferring documents that can be zoomed at their convenience. They widely use digital magnifier, and to accommodate their visual needs, they adjust displays to high contrast and larger fonts, trusting clear shapes and strong outlines more than colour cues alone. At the same time, barriers persist in displays with poor contrast, images without alternative text, and data representations relying on dense visual cues. When visual access is limited, they change modality by, for instance, listening through recordings and text to speech. A common tendency among participants reported breaking down complex information into smaller, more manageable parts, analyse each individually, and then reconstruct the whole. These accounts highlight the value of multi-sensory approaches that complement, rather than replace, the tools BLV people already use, helping to reduce cognitive load when interpreting complex information.

Table 1: Adapting the Story/Test/Story protocol

	Phase description	*Phase description (in this study)*	*Modes of recording*
Test	Participants interact with the prototype(s) while being observed, generating semi-structured usability data such as task completion, errors, and time.	Tasks: •Read the graph provided in printed form. •Read the same graph on the laptop, using your magnifier or screen reader. •Explore the graph in tactile form. •Explore the graph in three-dimensional form.	Notes taking, pictures, audio recording
Story	Reflective discussion allows participants to explain their actions, clarify motivations, and propose improvements.	Prompts [11]: •Which tool worked best for you, and why? •How would you imagine a dynamic tool that adapts to different types of graphs? What would it be useful for?	Notes taking, audio recording

We continued to engage with participants over several months during an elective Master's-level course at Moholy-Nagy University, focused on co-creating inclusive design solutions with and for BLV people. Within this course BLV participants attended as "design experts" [9] rather than as end-stage testers, contributing actively to the design process. Building on this ongoing collaboration, we developed the specific case study presented in this paper together with one low vision participant reporting having optic atrophy, a condition caused by damage to the optic nerve that leads to a progressive loss of visual function. They had expressed particular interest in tactile data solutions, given their regular engagement with data in their professional context. We decided to expand on their feedback given during the semi-structed interview through a session focused on the Story/Test/Story protocol [8] supported by two tactile probes: (1) a unit-based cardboard bar chart and (2) a static 3D bar sculpture, both based on a univariate public dataset.

4 Method

We refer to the co-creation framing of Sanders and Stappers [20], locating this activity within "lead-user innovation", positioned between user-centred design and participatory design approaches. In this area, users are not mere subjects of the study but active contributors who provide insights grounded in their lived experience, while the process remains structured and research-led rather than fully generative. As mentioned above, we adapted the Story/Test/Story protocol [8], a hybrid one combining usability testing with generative ideation. Typically, the protocol begins with semi-structured questions on lived experiences, followed by a prototype testing phase and concluding with open reflections. In our case, because those preliminary questions had already been addressed during the semi-structured interview, we began directly with the Test phase (Table 1).

We prepared a univariate dataset, the "Happiness Index of Hungary" from 2013 to 2024, in both visual and tangible forms. The dataset was first represented as a bar chart with embedded alt-text, making it readable through screen readers. Then, two corresponding tangible probes were created (Figure 1). One was a cardboard tactile bar chart, where each bar was constructed from discrete units measuring 2 cm each. The other was the same bar chart represented as a three-dimensional data sculpture, allowing participants to perceive changes through the height difference of each bar. Previous research informed spatial dimensions of the physicalization [6, 24], as well as the dimension of each data unit [22]. In the second Story moment we used prompts, concise cues that elicit richer, more nuanced narratives about priorities, norms, understandings of cause and effect, and approaches to sensitive issues [11].
Insights from both the 11 interviews and the co-creation session were analysed and translated into a set of design requirements, which guided the transition from our early exploratory probes, whose purpose was to test assumptions about tactile variables and interaction modalities, toward the development of the Data Fidget prototype. While the exploratory prototypes allowed us to examine the usability and interpretability of different tactile encodings, the final design synthesised the validated requirements into a coherent multisensory concept. Overall, the data from both phases helped identify which design parameters required refinement and which interaction principles should be prioritised, ensuring that the resulting prototype aligns with the needs and strategies of BLV individuals. These design requirements provided the foundation for the next stage of analysis, detailed in the following section, which reports the participant's experiences and insights that emerged during the exploratory session.

5 Findings

The participant regularly uses charts for work purposes and described them as a useful starting point for gaining a quick overview of a dataset, provided the data is not too complex. While they felt generally comfortable accessing the Happiness Index chart using a screen magnifier, the cognitive effort required was substantial: they needed to zoom in repeatedly to read each bar value, memorise it, zoom out, and then zoom in again to read the next one. If more detailed operations are needed, such as identifying minimum or maximum values or calculating averages, they said he would turn to data analysis software. As they put it: "Sometimes [a graph] is enough, sometimes it is not. Being a computer science student is an advantage because I know coding, and I can also analyse datasets using software."

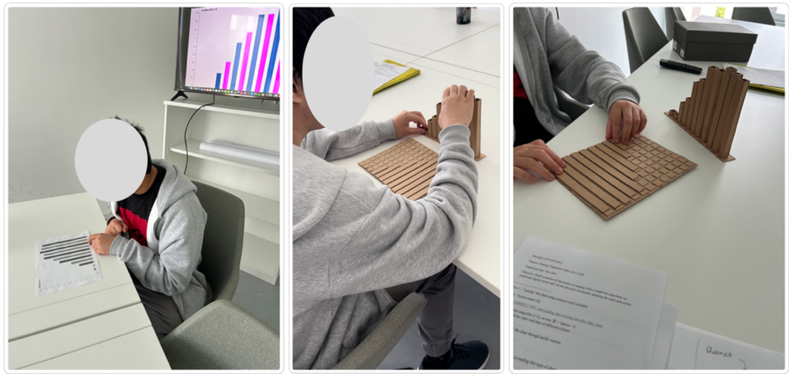

Figure 1: Story/Test/Story method with low vision participant: (a) reading a visual printed version of the chart; (b) reading the chart through a 3D representation; (c) reading the chart through a unit-based tactile representation

When interacting with the tactile cardboard probes, however, the participant reported several advantages over the digital visualisation. The tactile bar chart made from discrete units (Figure 1c) was perceived as *"more precise than the visualization on screen, because here I can tell more precisely how data change one bar after the other. With the digital version I could just make an estimation."* The discrete-unit construction enabled what the participant described as a "calculator logic": by counting and comparing units, they could determine value differences, recognise minima and maxima, and approximate average values. This suggests that tactile segmentation supports a stepwise, cognitively manageable interpretation strategy, contrasting with the high cognitive load of visually scanning magnified values. In contrast, the three-dimensional model (Figure 1b), despite initially attracting interest, ultimately hindered interpretation. The participant reported difficulty perceiving the overall trend, distinguishing subtle height variations, and understanding how values changed across the timeline. This indicates that three-dimensional, height-based encoding introduces ambiguity when fine-grained comparisons are required, particularly for BLV users who rely on precise tactile cues rather than visual inference.

Together, these reactions highlight a clear preference for tactile encodings that afford discrete comparison, low cognitive load, and unambiguous value differentiation, while indicating limitations of volumetric or continuous 3D forms for representing temporal data. These insights pointed us toward the need for a representation strategy that moves beyond conventional bar-chart metaphors while retaining their core logic, namely, volumes that expand or contract over time, paired with new interaction modalities that better support trend recognition, comparison, and embodied engagement. In summary, the tactile representations encouraged forms of numerical reasoning that differed from screen-based approaches. Three key practices emerged:

- reading values through discrete, countable units
- comparing adjacent bars to calculate differences rather than relying on absolute values
- aiming to identify overall trends across the dataset

During the final reflective prompts, the participant emphasised adaptability as a major limitation of the probes. They imagined a dynamic, reconfigurable system capable of adjusting to different charts and datasets, noting:

"If it would be dynamic, it could be used in schools so the teacher could send the prompt to the tactile map. It will take the shape of the current graph, and when someone touches it, a sensor will send the info to the software which will communicate the data value by text-to-speech".

This highlights a need for responsive physicalizations that can change form according to data and provide multimodal feedback, particularly auditory support, to complement tactile exploration.

Finally, an unexpected insight is the choice of dataset itself. We initially assumed that the dataset choice would be less relevant in this kind of protocol. However, the "Happiness Index of Hungary (2013–2024)" proved to be engaging as the participant was motivated not only to explore the data but also to connect personal experiences to it. For instance, lower values in 2020 were immediately linked to the Covid-19 pandemic. While this aspect does not inform the Data Fidget design, it highlights the importance of meaningful datasets when conducting similar sessions on data physicalization.

6 Data Fidget

The semi-structured interviews and the Story/Test/Story protocol were analysed and synthetised into key insights, translated into design requirements and concretely implemented in the design of the Data Fidget (Table 2).

We designed a compact device that dynamically translates bar chart values into mechanical elongation along one axis (Figure 2). The concept draws on the embodied gesture of indicating size with the gap between thumb and index finger: as the fidget expands, it increases the distance between the two fingers to represent a higher value; when it contracts, the distance shrinks, indicating a lower value. In designing the prototype, we prioritised ergonomics and data readability.

Table 2: From user insights to design implementations

User insight	*Design requirement*	*Design implementation*
Accessing visual data demands high cognitive effort and memory load, despite widespread use of digital tools	Reduce cognitive strain through embodied metaphor and intuitive comparison	Mechanical expansion and contraction represent value change physically (*near-far*)
Benefitting from strong contrast and multimodal cues (visual, tactile, auditory)	Facilitate comprehension through multimodal feedback	High-contrast colours, subtle vibration and mechanical sound from the servomotor paired with movement
Counting discrete elements aids understanding of relative differences	Encode values in perceivable increments rather than continuous scales	Device moves in discrete, countable steps corresponding to data units enabled by an internal threaded mechanism
Envisioning dynamic, adaptable tactile tools for data exploration	Design for modularity and future integration with digital input	Modular structure allows Bluetooth connection with PC or smartphone for future updates

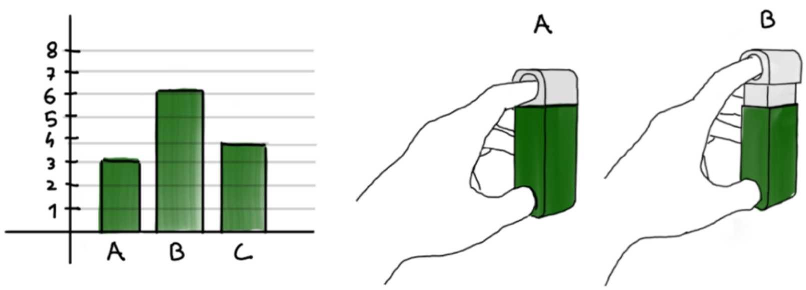

Figure 2: Sketches of Data Fidget function and interaction

Regarding ergonomics, the device had to remain hand-held while accommodating anthropometric constraints. Growth could not exceed the maximum pinch aperture of approximately 140 mm for an average European adult, while the embedded electronics limited the minimum to 80 mm, resulting in a usable range of 60 mm. Grip holes were sized to at least 20 mm in diameter to ensure finger fit (Figure 3a), and the overall bar-like proportions of the fidget communicated its intended function of translating bar charts. For people with residual vision, the use of high-contrast colours ensures easier tracking of the motion.

Next, we focused on the interaction identifying three key features: periodic movement, multisensory feedback, and pinch distance.

- The fidget translates differences between bars into discrete steps. For example, if bar B is three units larger than bar A, the device performs three successive growth actions. This periodicity allows users to count movements, making relative differences easier to perceive and reducing the need for estimation (Figure 2)
- Next to its periodical motion, each step was paired with sound and faint vibration. These sensory cues reinforce the interaction, ensuring that changes were noticed even if touch or hearing was less effective in each moment.
- As the fidget expands or contracts, it alters the pinch distance, meaning the distance between thumb and index finger. This variation engages muscle memory, providing a bodily sense of value magnitude. The physical experience supports recall of earlier values, enabling comparison and recognition of trends in the dataset.

Together, these features transform the device into a multimodal interface that conveys both quantitative differences and qualitative trends in data through touch, hearing, and proprioception (Figure 3). These design assumptions will be the key topic of investigation in the next phase of in-depth evaluation with a larger group of BLV participants. At this stage, the prototype illustrates how abstract data can be embodied into an accessible and memorable interaction.

7 Discussion and Further Development

This work contributes to research in data physicalization and tangible interaction for BLV users by extending prior studies on tactile charts, manipulatives, and multimodal interfaces toward dynamic and temporally shaped forms of physicalization. while previous

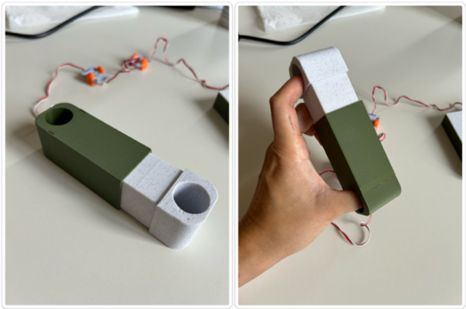

Figure 3: Prototype of the Data Fidget: (a) expanded of 3 data units; (b) held by a 25th percentile hand

work has shown how static tactile encodings and task-specific systems can support data access in educational or expert context [6, 7, 16, 29], our findings highlight the importance of movement and temporal change in enabling everyday data exploration through touch.

The results show that tactile, unit-based encodings support forms of numerical reasoning that differ from both screen-based magnification and three-dimensional representations. By enabling counting and comparison of discrete units, tactile charts reduced memory demands and supported incremental interpretation, extending earlier work on tangible manipulatives [16, 29]. At the same time, the difficulty encountered with the static three-dimensional model aligns with prior concerns around volumetric encodings, suggesting that form alone is not sufficient without perceivable change to support trend recognition.

From this we derive two contributions relevant to physicalization for BLV needs. First, movement-based feedback such as expansion and contraction proved more effective for communicating data variation than static tactile charts. This finding supports theoretical perspectives that position interaction as a temporal composition [26], showing their relevance for data representation. Second, new tools might be designed to complement rather than replace existing assistive technologies like screen readers and magnifiers, building on practices that BLV people already find effective. This distinguishes our approach from systems designed as standalone alternatives and suggests new directions for inclusive data interaction.

We acknowledge the limitations of this early work: it involved a single participant, a simple univariate dataset, and low-fidelity tangible probes. Further testing with diversified participants and richer datasets is crucial to assess how these findings generalise and to refine the design of Data Fidget. Ultimately, future work will evaluate the Data Fidget as a research prototype through semi-structured interviews with a larger group of BLV participants, focusing on perceived usefulness, the effectiveness of movement as metaphor, and compatibility with existing data practices. The study will combine task-oriented questions (e.g., identify number, trends changes) with think-aloud protocols. Based on the interview results, we will explore possible improvements to the Fidget, iterating on its functionality, interaction modes, and form factor to better align with practices and needs of BLV people.

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ETHICAL APPROVAL

This study was conducted in accordance with institutional ethical standards and approved by the Politecnico di Milano Ethics Committee (Protocol n.: 31/2025) Participants were informed about the purpose of the study and provided informed consent prior to participation.

References

[1] Bakker, S., Antle, A. N., & Van Den Hoven, E. (2012). Embodied metaphors in tangible interaction design. *Personal and Ubiquitous Computing*, *16*(4), 433-449.
[2] 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.
[3] Butler, M., Holloway, L. M., Reinders, S., Goncu, C., & Marriott, K. (2021, May). Technology developments in touch-based accessible graphics: A systematic review of research 2010-2020. In *Proceedings of the 2021 Chi conference on human factors in computing systems* (pp. 1-15).
[4] Chen, M., Pedraza Pineros, I., Satyanarayan, A., & Zong, J. (2025, April). Tactile Vega-Lite: Rapidly Prototyping Tactile Charts with Smart Defaults. In *Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems* (pp. 1-23).
[5] Darrah, M. A. (2013). Computer haptics: A new way of increasing access and understanding of math and science for students who are blind and visually impaired. *Journal of Blindness Innovation and Research*, *3*(2), 3-47.
[6] Ebermann, J., & Keck, M. (2024, October). From Sight to Touch: Designing Tactile Data Physicalizations for Non-sighted Users. In *2024 1st Workshop on Accessible Data Visualization (AccessViz)* (pp. 9-13). IEEE.
[7] Fan, D., Kim, G. S., Tomassetti, O., Patel, S. N., O'Modhrain, S., Lee, V. R., & Follmer, S. (2024, May). Tangible stats: an embodied and multimodal platform for teaching data and statistics to blind and low vision students. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems*(pp. 1-9).
[8] Getto, G. (2020). The story/test/story method: A combined approach to usability testing and contextual inquiry. *Computers and Composition*, *55*, 102548.
[9] Hamraie, A. (2017). *Building access: Universal design and the politics of disability*. U of Minnesota Press.
[10] Jansen, Y., Dragicevic, P., Isenberg, P., Alexander, J., Karnik, A., Kildal, J., ... & Hornbæk, K. (2015, April). Opportunities and challenges for data physicalization. In *proceedings of the 33rd annual acm conference on human factors in computing systems*(pp. 3227-3236).
[11] Jiménez, T. R., & Orozco, M. (2021). Prompts, not questions: Four techniques for crafting better interview protocols. *Qualitative sociology*, *44*(4), 507-528.
[12] Keilers, C., Tigwell, G. W., & Peiris, R. L. (2023, July). Data visualization accessibility for blind and low vision audiences. In *International Conference on Human-Computer Interaction* (pp. 399-413). Cham: Springer Nature Switzerland.
[13] Kim, N. W., Joyner, S. C., Riegelhuth, A., & Kim, Y. (2021, June). Accessible visualization: Design space, opportunities, and challenges. In *Computer graphics forum* (Vol. 40, No. 3, pp. 173-188).
[14] Koeser, R. S., Doroudian, G., Budak, N., & Li, X. (2020). Data Beyond Vision. Startwords, 1. https://doi.org/10.5281/zenodo.4139781
[15] Museo Nacional del Prado. 2015. *Touching the Prado* (Exhibition). Museo Nacional del Prado, Madrid. Retrieved from https://www.museodelprado.es/en/whats-on/exhibition/touching-the-prado/29c8c453-ac66-4102-88bd-e6e1d5036ffa
[16] Pittarello, F., & Semenzato, M. (2024, January). Towards a data physicalization toolkit for non-sighted users. In *2024 IEEE 21st Consumer Communications & Networking Conference (CCNC)*(pp. 1-6). IEEE.
[17] Ranasinghe, C., & Degbelo, A. (2023). Encoding variables, evaluation criteria, and evaluation methods for data physicalisations: A review. *Multimodal Technologies and Interaction*, *7*(7), 73.
[18] Reinders, S., Zaib, M., Butler, M., Lee, B., Zukerman, I., Qu, L., & Marriott, K. (2025). Accessible Data Access and Analysis by People who are Blind or Have Low Vision. *arXiv preprint arXiv:2506.23443*.

[19] Romeo, K., Pissaloux, E., Gay, S. L., Truong, N. T., & Djoussouf, L. (2022). The MAPS: Toward a novel mobility assistance system for visually impaired people. *Sensors*, *22*(9), 3316.
[20] Sanders, E. B. N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. *Co-design*, *4*(1), 5-18.
[21] Stangl, A., Morris, M. R., & Gurari, D. (2020, April). " Person, Shoes, Tree. Is the Person Naked?" What People with Vision Impairments Want in Image Descriptions. In *Proceedings of the 2020 chi conference on human factors in computing systems*(pp. 1-13).
[22] Stusak, S., Butz, A., & Tabard, A. (2018). Variables for data physicalization units. *Toward a Design Language for Data Physicalization, IEEE VIS.*
[23] Sutton Koeser, R., Doroudian, G., Budak, N., & Li, X. (2020, October). *Transformations: Data beyond vision* (Issue 1). Zenodo. https://doi.org/10.5281/zenodo.3713670
[24] Taher, F., Hardy, J., Karnik, A., Weichel, C., Jansen, Y., Hornbæk, K., & Alexander, J. (2015, April). Exploring interactions with physically dynamic bar charts. In *Proceedings of the 33rd annual acm conference on human factors in computing systems*(pp. 3237-3246).
[25] Tooteko. (n.d.). *Tooteko Talking Tactile*, from https://www.tooteko.com
[26] Vallgårda, A., Winther, M. T., Mørch, N., & Vizer, E. E. (2015). Temporal form in interaction design. *International Journal of Design*, *9*(3), 1-15.
[27] Vermeulen, J., Luyten, K., Van Den Hoven, E., & Coninx, K. (2013, April). Crossing the bridge over Norman's Gulf of Execution: revealing feedforward's true identity. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1931-1940).
[28] Weninger, M., Ortner, G., Hahn, T., Drümmer, O., & Miesenberger, K. (2015). ASVG− Accessible Scalable Vector Graphics: intention trees to make charts more accessible and usable. *Journal of assistive technologies*, *9*(4), 239-246.
[29] Wijers, J., Brombacher, H., & Houben, S. (2024, February). DataChest: a Constructive Data Physicalization Toolkit. In *Proceedings of the Eighteenth International Conference on Tangible, Embedded, and Embodied Interaction* (pp. 1-7).