Tactile pictograms displayed on pin array tablets for blind children

Carolane Mascle[1], Christophe Jouffrais[2], Gwenaël Kaminski[1] and Florence Bara[1]

Abstract— **Illustrated books hold a special place in the development of children. However, few suitable books are available for children with visual impairments. New technologies such as retractable pin tablets make it possible to easily create dynamic illustrations for many books. The illustrations would be based on a set of raised points, representing a shape. In this study, we evaluated the recognition of stimuli achieved with raised dots by 28 sighted and blind children. We have observed that "high resolution" dotted pictograms can be well recognized by blind children and we highlight the importance of the size and proximity of the dots.**

I. Introduction

Illustrated books hold a special place in children's early literacy development. For sighted children, the number of books available at home predicts children's reading fluency [1] and the positive impact of illustration for text comprehension is well documented [2], [3]. Even though there is less literature for visually impaired children, books are as important as they are to sighted children for their engagement in and enjoyment of reading (e.g. [4], [5]). Furthermore, tactile books help young children to get used to tactile illustrations and provide them with an opportunity to develop skills for the exploration and interpretation of tactile content [6]. Thus, tactile books support both literacy development and the development of haptic skills.

However, for children with visual impairment, access to illustrated books is more difficult. Because making tactile pictures is time-consuming and requires specific expertise, these books are expensive and produced in low quantities. Moreover, they are fragile and deteriorate quite rapidly over time. Thus, children have access to a very limited number of stories. New technologies such as retractable pin array tablets could offer the possibility of creating and modifying pictures for several books with the same device. These tablets are based on arrays of pins that dynamically move up and down depending on the content to display. The tablet would update as the child turns the pages and the characters could appear, disappear or move as the pages and the story progress. In addition, children, teachers or parents could easily create their own pictures with dedicated software.

II. Related work

Different pin array tablets have been developed. However, due to technological constraints, these tablets have different resolutions (size and spacing of the pins). Recognition of simple geometric shapes has been evaluated on different pin array tablets with adults. Leo et al. [7] used a device consisting of 1 mm wide and 1.5 mm apart pins to display shapes on a 3x3 or 4x4 pin array. In this study, recognition rates were over 80% (blind: 92%, visually impaired: 85%, blindfolded sighted: 90%) and the array's size did not affect recognition rate. Bellik and Clavel [8] used a device with 1 mm wide and 1 mm apart pins to display shapes that filled a 2 cm, 3 cm or 4 cm square, approximately corresponding to 10x10, 15x15 or 20x20 arrays of pins. In this study, the recognition rate by blindfolded sighted subjects was 92%, and was not affected by the size of the array. Then, Velazquez et al. [9] used a device made of 1 mm wide and 2.5 mm apart pins to display shapes on a 5x5 array. They observed a 60% recognition rate with blindfolded sighted participants. Finally, Zarate et al. [10] used a device made of 4 mm wide and 4 mm apart pins on a 12x16 array. The authors provided several full usage scenarios to blindfolded sighted. For example, in the game "Pong" where players had to move a board represented by 3 raised pins to catch a ball represented by one raised pin. The authors also observed the use of the tablet to represent and navigate through the layout of a room. In this study, participants were able to use the tablet in all of the scenarios.

Altogether, these results show that simple geometrical shapes displayed on pin array tablets are recognized by blind and sighted adults but with important differences, which may depend on the spacing between the pins. Indeed, all the studies evaluating the recognition of simple geometric shapes used 1 mm wide pins, but the studies of Leo et al. [7] and Bellik and Clavel [8] relied on a tight spacing (1 and 1.5 mm) and showed high recognition rates in sighted participants (more than 90%), when the study by Velazquez et al. [9] relied on a larger spacing (2.5 mm) and showed a weaker recognition rate (60%).

III. The present study

While pin array tablets cannot be used to display complex pictures, they are suitable to display simplified representations such as pictograms. However, to our knowledge, this kind of device has never been tested with children. Moreover, as pictograms are more complex shapes than geometrical shapes (circle, square, triangle, ...) there is no guarantee that these more complex shapes could be easily recognized. First, the use of touch to compensate for vision imposes specific constraints inherent to the haptic system [11] that might make recognition of tactile pictures difficult (i.e. low identification rates from 9% to 52% with blind and sighted

*This work was not supported by any organization

[1]Carolane Mascle, Gwenaël Kaminski and Florence Bara is with Cognition, Langue Langage, Ergonomie (CLLE), University of Toulouse 2, France {firstname.lastname}@univ-tlse2.fr

[2]Christophe Jouffrais is with Institut de la Recherche en Informatique de Toulouse, France and IPAL, Singapore, Centre National de la Recherche Scientifique (CNRS), France christophe.jouffrais@irit.fr

children [6], [12]–[14]). Then, blind children are not used recognizing dotted line pictures and the spacing between the pins could impact recognition. In this study, we differentiated two categories of tablets: tablets with 1 mm pins spaced 1 mm apart that we called High-Resolution (HR) and tablets with 4 mm pins spaced 4 mm that we called Low-Resolution (LR).

In addition, pictograms are often designed after typical visual representations (e.g. a V shape to represent a bird). Hence, access to vision could improve recognition. It seems interesting to include blind and sighted children to discuss that effect.

Finally, we compared the recognition rates of dotted and line pictograms in sighted and blind children to answer the following research questions: (i) Can children recognize simplified representations as tactile pictograms? (ii) Can children easily recognize dotted pictograms that could be displayed on pin array tablets? (iii) Does the resolution of the tablet have an impact on the recognition of pictograms? (iv) Does visual status (blind or sighted) affect performance?

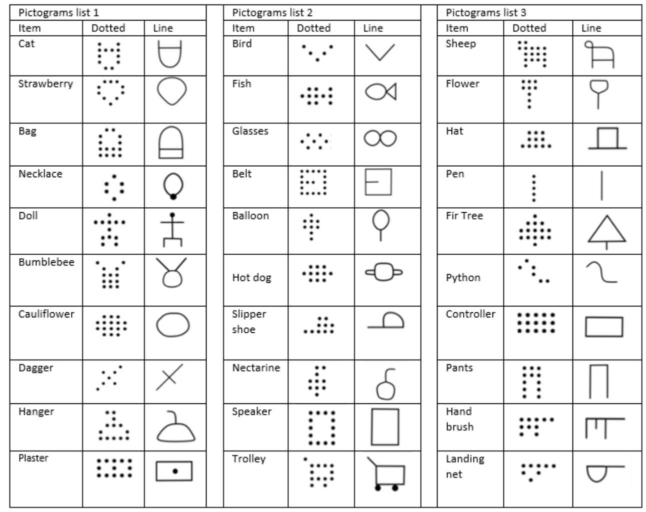

Fig. 1. Set of tactile pictograms used in the study dotted (LR and HR) and line

IV. Material and Methods

A. Participants

As these pictures are meant to illustrate tactile books that can help children to better understand the story [2], [3] it seemed relevant to evaluate the recognition of these pictures with young readers. This study included 20 blindfolded sighted children from 6 to 9 years old for a mean age of 8.1 (97 months, SD=6) and 8 blind children from 6 to 10 years old for a mean age of 7.5 (90 months, SD=9). The study was conducted with the understanding and the written consent of each participant's legal representative. It was approved by the local ethics committee of the Federal University Toulouse Midi-Pyrénées and conducted in accordance with the school district authorities and educational organizations for blind people.

B. Material

We created a set of three lists of ten French words using the Manulex database [15] according to their Standard Frequency Index (SFI): 5 high frequency (SFI ranging from 55.32 to 68.95) and 5 low frequency (SFI ranging from 35.32 to 44.88) words in each list. The average SFI were 50.99, 50.92, 51.01. We limited the types of items to three categories only: animals, graspable items and plants. We selected these categories because they correspond to items that can be touched by children in everyday life (at home, in museums, farms, etc.) The number of words in each category was the same in each list (2 animals, 6 graspable objects and 2 plants).

The set of 30 items (words) was subsequently illustrated as line pictograms that were designed after existing visual signage pictograms (e.g. the sheep on the road sign "animal crossing") or typical visual representations (e.g. a V shape to represent a bird). Line pictograms were from 1 cm to 4 cm wide and from 2 cm to 4 cm high with 1mm wide lines. Then, we reproduced the 30 items as dotted pictograms based on an array of 5x5 dots (Fig. 1). We based this design on three empirical criteria: (i) it is hard to create meaningful pictograms with less than 5x5 dots; (ii) it is possible to touch a 5x5 dots pictogram without moving the finger too much, and hence, avoiding large exploration movements that are cognitively demanding; and (iii) current pin-array tablets hold 12x16 pins (e.g. the Blindpad [10]), providing the possibility to display up to four 5x5 pictograms simultaneously; which allows representing a picture with one to four different items. Finally, the size and spacing of the dots were based on two existing pin-array tablets: The Blindpad [10] (4 mm wide and 4 mm apart dots) for designing Low-Resolution dotted pictograms (LR), and the Hyperbraille © (Metec AG, Germany; 1 mm wide and 1 mm apart dots for a 5x5 matrix of) for designing High-Resolution dotted pictograms (HR) (Fig. 1). LR pictograms were from 1 cm to 4 cm wide and from 2 cm to 4 cm high. HR pictograms were from 0.5 cm to 1.5 cm wide and from 1 cm to 1.5 cm high.

We pre-tested our LR dotted pictograms with twelve blindfolded sighted adults. The rate of recognition was 66%. At the end of the session, we asked the participants to indicate which pictograms they had struggled with. We selected ten items with a recognition rate below 60%. We asked the participants to represent those 10 items on a 5x5 array of dots. The final pictogram for those items was a mix of all the propositions. Then, we conducted a pretest with a blind adult participant. The result showed that he was able to recognize all the pictograms without any error. Finally, we pre-tested our entire protocol with two blindfolded sighted children to make sure they could easily understand the instructions.

C. Method

The study was done individually, at school for sighted children, and the special education center for children with visual impairments. Sighted children were blindfolded during the whole experiment with fully opacified safety glasses.

We used a paired-associate learning that relies on a two-step procedure. The first step was a learning phase in which the 10 words and their associated pictures were presented in random order. The children were told the name of the picture (e.g. "that's a cat") and were free to explore it for as long as they wanted. They were told to stop exploring as soon as they were confident that they could recognize the item in the following phase. The second step was a recall phase in which the pictures explored during the learning phase were randomly presented one by one. The children were told to explore the tactile picture and to identify it as quickly and accurately as possible. There was no time limit. If children were unable to identify a picture, they had to stop exploring and tell the experimenter. Feedback was always given regarding the correct answer.

To prevent guessing, the same picture could be randomly presented several times in a block until all the pictures had been presented; however, only the answer to the first presentation was considered in the results. For each block, two randomly chosen pictures of the list were presented a second time in a random order in the block. This procedure was repeated three times (three blocks), one for each illustration method (line pictograms, HR pictograms, LR pictograms). The set of items was balanced among illustration methods and the order of presentation of the illustration method was also balanced. The order of presentation of the 10 tactile pictures in each illustration condition was randomized.

To make sure that children fully understood the instructions we proposed a training task with two pictures (that were not part of the experiment) for each illustration condition.

D. Data Analysis

For each item and type of pictogram, we measured accuracy and response time for correct answers. The three illustration conditions (line pictograms, LR picograms, HR pictograms) and the two groups of children differing by their visual status (blind and blindfolded sighted) were compared. The accuracy for each tactile pictogram was scored 0 for incorrect and 1 for correct recall. For accuracy, we computed a logistic regression using a generalized linear mixed-effects model. Variables for the model included visual status, illustration condition, items and participants. Visual status and illustration conditions were considered as fixed effects. We included participants and items as random effects. Response times were recorded in milliseconds. A BoxCox estimation was first performed to determine the optimal transformation to normalize the distributions [16] and a log transformation was applied. We computed a linear regression using linear mixed-effects models. The model included the same variables (visual status and illustration conditions as fixed effects; items and participants as random effects). Mixed effect models were used to consider the sources of variability related to participants and items. For both regression we compared models with and without fixed effect, using Log-Likelihood Ratio (LLR) chi-square tests to test the significance of the fixed effects. Tukey-adjusted least-squares means comparisons were used to assess contrasts among the modalities of the fixed effects variables. Scripts for all analyses and anonymized data are available online[1].

V. Results

A. Response time

The effect of the visual status was significant χ^2 (1, N = 28) = 27.649, p < .001. There was no significant effect of the illustration condition χ^2 (2, N = 28) = 0.730, p = .694. and no significant interaction effect between the two variables χ^2 (2, N = 28) = 5.026, p = .082.

Blind children were faster than blindfolded children for all conditions (Fig. 2).

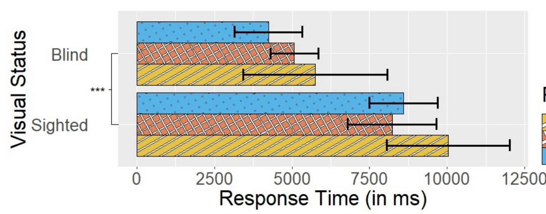

Fig. 2. Effect of illustration condition and visual status on response time: Mean response time and confidence interval (95%)

B. Accuracy

There were significant effects of the visual status χ^2 (1, N = 28) = 4.026, p = .044. and the illustration condition χ^2 (2, N = 28) = 57.591, p < .001. There was no significant interaction effect between the two variables χ^2 (2, N = 28) = 4.150, p = 0.126.

Blind children recognized pictograms better than sighted for all conditions. For both blind and sighted, line pictograms were better recognized than LR pictograms (β = 1.564 (SE = 0.206), t = 7.586, p < .001) and HR pictograms (β = 0.848 (SE = 0.199), t = 4.268, p < .001). HR pictograms were better recognized than LR pictograms (β = 0.715 (SE = 0.194), t = 3.680, p < .001) (Fig. 3).

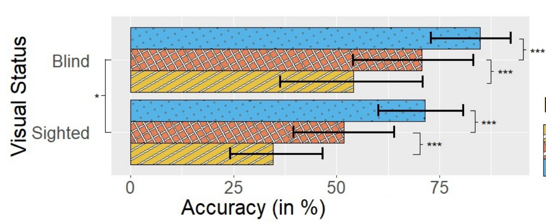

Fig. 3. Effect of illustration condition and visual status on rate of identification: Mean identification rate and confidence interval (95%)

VI. Discussion

A. Can blind and sighted children recognize simplified representations as tactile pictograms?

The recognition rate of line pictograms was particularly high among sighted (71.5%, CI[60.1, 80.7]) and blind

[1]https://osf.io/pwz2n/?view_only=3dbb58f5a3e74be9a912cbd0ef171ea9

children (84.9%, CI[72.8, 92.2]) both groups could also recognize them quickly (M = 5.3 s, CI[4.5, 6.7]). This result is interesting as it shows that a simplified picture as a pictogram can be well recognized by children whether sighted or blind. However, our experimental design also probably helped to identify and recognize the pictograms. Indeed, all the pictograms were explored in advance. Hence, it was possible to recognize pictograms even if they were not totally meaningful. For example, several blind participants asked why there was no hole for the head in the hat pictogram (Fig. 2). Therefore, it is possible that the participants would not reach the same recognition rate for the hat if it had not been presented before. Hence, the identification rates observed in this study cannot be directly related to the identification rates observed in other studies using recognition tasks. Nonetheless, these results are relevant in the context of a reading task where the characters are presented at the beginning or throughout the story or when a legend is available (e.g. on a building plan).

B. Can children easily recognize dotted pictograms that could be displayed on pin array tablets?

Even though blind children could recognize most of the dotted pictograms (recognition rate > 50%) it could be pretty low for sighted depending on the resolution. Moreover, the recognition rates of dotted pictograms (HR and LR) were lower than those of line pictograms for both groups. It is possible that the dot represents one unit of information to process in dotted pictograms whereas the line represents a single unit of information in line pictograms. Taking the example of the pictogram created for the pen (based on one line for line pictograms and four dots forming a line in dotted pictograms) the line would represent one unit of information for line pictograms and four units of information for dotted pictograms. Hence, there would be less information to process with the line pictogram (one unit of information) than with dotted pictograms (four units of information). Another hypothesis is that the use of continuous lines rather than dotted lines would increase the guidance of the finger and, as shown by Magee and Kennedy [17], a guidance of the finger during the exploration can improve the recognition of tactile pictures.

C. Does tablet's resolution have an impact on the recognition of pictograms?

The tablet's resolution had an impact on recognition for both blind and sighted children. They recognized HR pictograms better than LR pictograms. To recognize a shape drawn with dots, it is necessary to perceive the different dots as forming a continuous line. This principle of proximity has been described in the Gestalt perception theory [18]. Various studies have shown that the Gestalt proximity principle first observed in vision is applicable to touch [19], [20], although the haptic system is less sensitive to this principle [21]. However, these studies do not mention the threshold beyond which the gap between dots can make it difficult to perceive them as a line. It is probable that this threshold exists and that pins spaced too far apart would lead to perceptual issues. In this study, the 4 mm gap between dots in LR pictograms could have made it more difficult to perceive the dots as forming a shape than a 1mm gap for HR. In particular, with LR pictograms, two dots placed in diagonal to depict a curved shape are placed 7mm apart. Moreover, as mentioned earlier it is possible that, as lines guided the finger better, a small gap between dots (1 mm) would guide the finger better than a larger one (4 mm).

D. Does visual status (blind or sighted) affect the performances?

Blind children recognized line and dotted pictograms better and faster than sighted children. This result is consistent with previous studies showing that blind children outperformed blindfolded sighted children when identifying tactile pictures [12]–[14]. The familiarity of blind children with tactile content could have helped them to recognize the tactile pictures [6]. Shorter response time could be the result of better exploration strategies mastered by blind children.

Finally, it seems that access to vision is not necessary to learn and recognize pictograms designed by sighted and based on existing visual signage pictograms (e.g. the sheep on the road sign "animal crossing") or typical visual representations (e.g. a V shape for a bird).

VII. Conclusion

In this study, we evaluated the recognition of pictograms with three designs: line pictograms, pictograms based on high-resolution pin array tablets (HR) and pictograms based on low-resolution pin array tablets (LR). Dotted pictograms could be displayed on pin array tablets that offer the possibility of creating and editing pictures for several books with the same device. In addition, children, teachers or parents could easily create their own pictures with dedicated software.

We observed that line pictograms were easily recognized by blind and sighted children. This result is interesting as it suggests that teacher or family could create and use the same tactile pictograms as illustrations for blind and sighted children. As a matter of fact, tactile pictograms are already used in a few resource centers for the visually impaired to indicate classrooms. This study shows that this use could be widely expanded as tactile pictograms are easily and quickly recognized by children. Pictograms could also be used to illustrate books to help understand the story with easily and quickly accessible pictures.

However, the use of dotted pictograms does not seem to be as effective as the use of line pictures classically found in tactile books. The recognition rate of dotted pictograms was lower than those of line pictograms and the resolution of the tablet had an impact on the recognition of pictograms for both blind and sighted children. Nevertheless, the recognition rate can still be quite high (up to 70%) for blind children with pictograms based on "high resolution" tablets. Yet, the price of these devices is currently dissuasive because of the components used to produce them. For example, a HyperBraille© tablet (HyperBraille, GE) on a 76x48 pin matrix is currently sold for more than 10000€ when low-resolution tablets such as the Blindpad [10] (4 mm pins spaced 4 mm apart) cost between 400 and 3000€. However, dotted pictograms based on this tablet were less recognized by children (recognition rate: 54% for blind). It is therefore important to find a compromise between: (i) using line pictograms that are better recognized but are not dynamic, are used in expensive books that get damaged quickly and cannot be modified or created by the children or parents or (ii) using high-resolution tablets to display dynamic pictograms that can be used to propose a very large number of drawings that can be modified and created easily.

To improve the usability of pin array tablets, further studies should be conducted to better understand how dotted stimuli are perceived and explored. In particular, to determine the threshold beyond which the gap between dots can make it difficult to perceive them as a line. These studies could also focus on both the recognition rate and the exploration strategies implemented [22]–[24]. Indeed, the spacing between the dots could influence the implementation of exploratory procedures. Moreover, in this study, we were only interested in the ability to recognize pictograms. It would be interesting to observe the use of pictograms in a real context: to illustrate a book or on the map of a building. These studies could evaluate the impact of the use of pictograms on texts or maps comprehension.

References

[1] E. van Bergen, T. van Zuijen, D. Bishop, and P. F. de Jong, "Why Are Home Literacy Environment and Children's Reading Skills Associated? What Parental Skills Reveal," Read. Res. Q., vol. 52, no. 2, pp. 147–160, Apr. 2017, doi: 10.1002/rrq.160.

[2] J. Orrantia, D. Múñez, and J. Tarín, "Connecting goals and actions during reading: the role of illustrations," Read. Writ., vol. 27, no. 1, pp. 153–170, Jan. 2014, doi: 10.1007/s11145-013-9437-4.

[3] M. M. Pike, M. A. Barnes, and R. W. Barron, "The role of illustrations in children's inferential comprehension," J. Exp. Child Psychol., vol. 105, no. 3, pp. 243–255, Mar. 2010, doi: 10.1016/j.jecp.2009.10.006.

[4] F. Bara, E. Gentaz, and D. Valente, "The Effect of Tactile Illustrations on Comprehension of Storybooks by Three Children with Visual Impairments: An Exploratory Study," J. Vis. Impair. Blind., vol. 112, no. 6, pp. 759–765, Nov. 2018, doi: 10.1177/0145482X1811200610.

[5] J. Norman, "Tactile picture books: their importance for young blind children," Br. J. Vis. Impair., vol. 21, no. 3, pp. 111–114, Sep. 2003, doi: 10.1177/026461960302100305.

[6] A. Theurel, A. Witt, P. Claudet, Y. Hatwell, and E. Gentaz, "Tactile picture recognition by early blind children: The effect of illustration technique.," J. Exp. Psychol. Appl., vol. 19, no. 3, pp. 233–240, 2013, doi: 10.1037/a0034255.

[7] F. Leo et al., "Improving spatial working memory in blind and sighted youngsters using programmable tactile displays," SAGE Open Med., vol. 6, 2018, doi: 10.1177/2050312118820028.

[8] Y. Bellik and C. Clavel, "Geometrical shapes rendering on a dot-matrix display," in International Conference on Intelligent Human Computer Interaction, 2017, pp. 8–18.

[9] R. Velazquez, E. E. Pissaloux, M. Hafez, and J. Szewczyk, "Tactile Rendering With Shape-Memory-Alloy Pin-Matrix," IEEE Trans. Instrum. Meas., vol. 57, no. 5, pp. 1051–1057, 2008, doi: 10.1109/TIM.2007.913768.

[10] J. J. Zarate, O. Gudozhnik, A. S. Ruch, and H. Shea, "Keep in touch: portable haptic display with 192 high speed taxels," in Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems, 2017, pp. 349–352.

[11] D. T. V. Pawluk, R. J. Adams, and R. Kitada, "Designing Haptic Assistive Technology for Individuals Who Are Blind or Visually Impaired," IEEE Trans. Haptics, vol. 8, no. 3, pp. 258–278, Jul. 2015, doi: 10.1109/TOH.2015.2471300

[12] A. D'Angiulli, J. M. Kennedy, and M. A. Helle, "Blind children recognizing tactile pictures respond like sighted children given guidance in exploration," Scand. J. Psychol., vol. 39, no. 3, pp. 187x – 190, Sep. 1998, doi: 10.1111/1467-9450.393077.

[13] A. D'Angiulli and P. Waraich, "Enhanced tactile encoding and memory recognition in congenital blindness," Int. J. Rehabil. Res., vol. 25, no. 2, pp. 143–145, Jun. 2002, doi: 10.1097/00004356-200206000-00008.

[14] D. Picard, S. Lebaz, C. Jouffrais, and C. Monnier, "Haptic recognition of two-dimensional raised-line patterns by early-blind, late-blind, and blindfolded sighted adults," Perception, vol. 39, no. 2, pp. 224–235, 2010.

[15] B. Lété, L. Sprenger-Charolles, and P. Colé, "MANULEX: A grade-level lexical database from French elementary school readers," Behav. Res. Methods, Instruments, Comput., vol. 36, no. 1, pp. 156–166, 2004.

[16] J. W. Osborne. "Improving your data transformations: Applying the box-cox transformation." Practical Assessment, Research & Evaluation, 15(12), p 1–9, 2001. https://doi.org/10.7275/qbpc-gk17

[17] L. E. Magee and J. M. Kennedy, "Exploring pictures tactually," Nature, vol. 283, no. 5744, pp. 287–288, Jan. 1980, doi: 10.1038/283287a0.

[18] W. Köhler, "Gestalt psychology," Psychol. Forsch., vol. 31, no. 1, pp. XVIII–XXX, 1967, doi: 10.1007/BF00422382.

[19] D. Chang and K. V Nesbitt, "Developing Gestalt-Based Design Guidelines for Multi-Sensory Displays," in Proceedings of the 2005 NICTA-HCSNet Multimodal User Interaction Workshop - Volume 57, 2006, pp. 9–16.

[20] D. Chang, K. V Nesbitt, and K. Wilkins, "The Gestalt principle of continuation applies to both the haptic and visual grouping of elements," in Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (WHC'07), 2007, pp. 15–20.

[21] Y. Hatwell, Psychologie cognitive de la cécité précoce. Dunod, 2003.

[22] S. J. Lederman and R. L. Klatzky, "Hand movements: a window into haptic object recognition," Cogn. Psychol., vol. 19, no. 3, pp. 342–368, 1987.

[23] S. Bardot, M. Serrano, B. Oriola, and C. Jouffrais, "Identifying How Visually Impaired People Explore Raised-Line Diagrams to Improve the Design of Touch Interfaces," in Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, 2017, pp. 550–555, doi: 10.1145/3025453.3025582.

[24] K. Zhao, S. Bardot, M. Serrano, M. Simonnet, B. Oriola, and C. Jouffrais, "Tactile Fixations: A Behavioral Marker on How People with Visual Impairments Explore Raised-Line Graphics," in Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, New York, NY, USA: Association for Computing Machinery, 2021.