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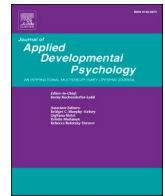
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Displaying easily recognizable tactile pictures: A comparison of three illustration techniques with blind and sighted children

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ABSTRACT

Illustrated books hold a special place in children's early literacy development. However, blind children have little access to them and there is no guarantee that they can easily understand tactile pictures. There are several designs of tactile illustrations, each leading to different identification performances. Our study aimed to compare three designs of tactile illustration in two populations (36 blindfolded sighted children and 18 blind children) in order to better understand the factors that influence haptic recognition of tactile pictures. On the one hand, we assessed the advisability of using new technology such as pin array tablets which showed encouraging results. On the other hand, we questioned the need for a figurative shape in tactile pictures when information about texture was already provided. The main result of our study is that when given texture information, blind children do not seem to need additional information to associate a picture with a word.

Introduction

Illustrated books hold a special place in children's early literacy development. The number of books available at home predicts children's reading fluency (van Bergen, van Zuijen, Bishop, & de Jong, 2017). In addition, the positive impact of illustration for text comprehension in children is well documented (Orrantia, Múñez, & Tarín, 2014; Pike, Barnes, & Barron, 2010). Pictures are readily used as cues to build an accurate mental representation of the story, in particular for young readers (Cain, Oakhill, Barnes, & Bryant, 2001; van der Schoot, Reijntjes, & van Lieshout, 2012).

Access to books and understanding of their content is a determining factor of literacy development for all children. In the case of children with visual impairment, this access may be lacking. While there are books with tactile pictures intended to facilitate blind children's interactions with books, making tactile pictures is time-consuming and requires specific expertise, and tactile books are expensive. Hence only a few tactile books are available and blind children have little access to them (Claudet, 2014). Even when available, there is no guarantee that children will understand tactile pictures easily since the use of touch to compensate for vision imposes specific constraints inherent to the haptic system that might make recognition difficult. Yet these books are as

important to visually impaired children as they are to sighted children use for their engagement in and enjoyment of reading (e.g. Bara, Valente, & Gentaz, 2018; Norman, 2003). Research shows, for instance, that in the initial stages of reading, visually impaired readers will use tactile illustrations to pretend to read (Wright, 2008). 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. Theurel, Witt, Claudet, Hatwell, and Gentaz (2013) found that blind children who have extensive experience with tactile pictures perform, for example, better in tactile picture identification as compared with children with no or little experience. Thus, tactile books support both literacy development and the development of skills for the exploration and interpretation of tactile content which are important skills for academic achievement.

The design of tactile books is largely a small-scale endeavor in the specialized structures for these children without clear scientific recommendations. Some technological devices might also be available, such as pin array tablets that can display simplified pictures but are not widespread to illustrate books. As illustrations not only have an aesthetic value but also support the understanding of the story, it is of importance to determine what kind of illustration can be easily recognized by blind children. The recognition of tactile illustrations depends on individual

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haptic abilities and exploration strategies as well as on the kind of material used to design these illustrations. The present study compared three illustration techniques. Our motivation was to help design tactile pictures that are easily recognizable by children and that can be used to illustrate storybooks in a meaningful way. We also would like to take advantage of innovative devices using digital technologies such as pin array tablets to display illustrations.

Functioning of the haptic system

Tactile perception is associated with passive contact by a static subject. The information accessible by tactile perception is quite poor and partial: it is only extracted from the mechanical deformation of the skin available in a reduced perceptual field (Hatwell, Streri, & Gentaz, 2003). To gather more information, movements of exploration are necessary. In addition to the mechanical deformation of the skin, these movements make it possible to recover proprioceptive information. Proprioception refers to the perception of the position of different parts of the body. This information comes from muscles, joints and tendons. We then speak of active touch or haptic perception. The haptic system combines tactile information from skin sensors and proprioceptive information from movements to process tactile information.

Haptic exploratory movements were classified by Lederman and Klatzky (1987) who asked blindfolded adults to match objects on a particular dimension (texture, shape, weight). Texture discrimination relies on simple movements (lateral motion and pressing) that are mastered very early in childhood. Sighted infants can discriminate textures by touch (smooth or granular) before six months old (Molina & Jouen, 1998). Shape identification relies on more complex exploratory movements, such as contour following, which requires hand and finger coordination (Lederman & Klatzky, 1987). Because the haptic perceptual field is limited to the fingertips, contour following is sequential and requires slow exploration. Consequently, it is the most taxing use in terms of working memory resources.

The texture seems to be a predominant feature in haptic identification. Lederman and Klatzky (1997) observed that blindfolded adults can discriminate an object faster if it differs by texture rather than by shape. Berger and Hatwell (1993, 1995, 1996) used a haptic classification task and observed that blindfolded children (aged 5 to 9) mainly concentrated on a single dimension of the object. Notably, children tended to use exploratory procedures mainly related to texture recognition, which led them to classify objects according to texture rather than size.

Identification of tactile pictures

There are several designs of tactile illustrations, each leading to a different identification performance. Raised line pictures are produced using paper impregnated with microcapsules of alcohol. When exposed to heat, the microcapsules burst under the black spaces on the page, thus increasing the volume of the page in these areas only. Hence only the contour of the pictures is embossed. Studies with raised-line pictures showed low identification rates in blindfolded sighted adults and blind adults. The rate of recognition of a raised line picture depicting a familiar object varied from 25 to 30% in blindfolded adults (Heller, Calcaterra, Burson, & Tyler, 1996; Klatzky, Loomis, Lederman, Wake, & Fujita, 1993; Lederman, Klatzky, Chataway, & Summers, 1990). In early blind adults, the percentage of correct identification did not exceed 10% (Lederman et al., 1990). Low identification rates of raised line pictures are also observed in children. D'Angiulli, Kennedy, and Heller (1998) used pictures of daily life objects (bottle, umbrella, key) and faces and observed a 9% identification rate in blindfolded children and 45% in blind children from 8 to 14 years old.

Another way to design tactile pictures is to produce textured shape pictures, obtained by assembling several textures (fabrics, foams, paper, etc.). This method provides information about the shape but also about the texture of the depicted object, which is more related to haptic than to

visual experience. Theurel et al. (2013) assessed the effect of three different illustration techniques on picture recognition (texture, raised line and thermoform). The study included blind children aged from 6 to 16 years. They selected eight tactile pictures that children are likely to encounter in books and that depicted graspable and non-graspable natural objects (fruits and animals) and artifacts (kitchen utensils and vehicles). Categorical information about the pictures was given before the exploration. The authors observed that textured shape pictures were better recognized than raised line pictures (rate of identification 36% vs. 27%). Textured pictures have the advantage of providing information about material properties and also convey 3D information as the different textures are placed on top of one another. In this study, the identification rates were lower than in the study by D'Angiulli et al. (1998). However, in Theurel et al. (2013) most of the pictures were not everyday life objects that children could grasp (helicopter, kangaroo, lion, motorbike).

When exploring real objects with many material properties, it is possible to use a large range of exploratory movements (e.g. pressure, lateral motion, static contact) which are easy to master (Lederman et al., 1990). Textured pictures allow easier shape and texture processing because both lateral motion and contour following exploratory procedures are relevant. On the contrary, raised line pictures only allow shape information, limiting the exploratory movement to the contour following procedure, which is highly sequential. The use of raised line drawings makes it difficult to access the global shape. These kinds of pictures have been shown to provoke confusion between figure and background (Thompson, Chronicle, & Collins, 2003), leading the individual to believe that some parts of the background are parts of the figure. As the different parts that make up the picture are explored sequentially, it is often difficult to succeed in associating the different pieces of information to access the overall shape. This is illustrated by Kalia and Sinha (2011) who asked blindfolded sighted participants with drawing skills to identify raised line pictures and then draw the perceived shape. When participants tried to reproduce a tactile picture that they had not recognized, in 46% of the cases they produced drawings that did not represent anything, thus showing that they were unsuccessful at representing the shape mentally and at associating meaning to it. Textured shapes can help overcome this difficulty. As they provide additional information about texture, the individual can easily access the meaning of the picture and mentally represent its shape even if some information about the precise shape is missing.

Visual status and tactile picture recognition

Comparative studies using raised-line pictures showed that identification rates were better for late blind and blindfolded sighted compared to early blind adults (Heller, 1989; Lederman et al., 1990; Thompson, Chronicle, & Collins, 2006). When no indication about the meaning of the picture was given, early blind adults rarely exceeded 10% of correct identification. These differences in performance depending on the visual status could be related to a lack of visual imagery in the early blind. According to the visual mediation model, haptic information must be translated into a visual representation before identification. In this model, haptic identification requires four steps: (i) haptic exploration, (ii) transfer or translation of haptic information into a visual image, (iii) identification of the concept, (iv) recovery of the object name. Visual imagery may therefore be essential for tactile image recognition.

Differences in tactile identification rates depending on the visual status (early or late blind) may also be explained by a lack of familiarity with visual 2D conventions (Heller, McCarthy, & Clark, 2005; Millar, 1975). For instance, perspectives and occultation are typical visual conventions learned by sighted people and that may be misinterpreted by people with visual impairments. To support this hypothesis, Thompson et al. (2006) created a specific design of raised-line pictures without visual conventions. They showed that in blind people, the identification rate of these pictures was indeed better than that of

standard pictures. When using 2D raised line patterns (instead of familiar drawings of objects), no significant effect of the visual status was observed (Picard, Lebaz, Jouffrais, & Monnier, 2010).

The results with children are quite different and children with visual impairment tend to perform better than sighted children (D'Angiulli et al., 1998). D'Angiulli and Waraich (2002) using raised line drawings observed a 10% identification rate in blindfolded children and 57% in blind children aged from 9 to 12. When categorical information was given to the children the task was made easier but visually impaired children still outperformed blindfolded sighted children (respective rates of identification: 52% vs 37%; Picard, Albaret, & Mazella, 2014). Orlandi (2015) used textured pictures based on a children's book and showed a significant difference between blindfolded sighted children (rate of identification 40%) and visually impaired children (rate of identification 50%) aged from 3 to 12.

The contrasting results in children and adults support the claim that experience with tactile exploration and tactile pictures can compensate for the lack of visual experience at some moment. Kennedy (1993) claimed that visual experience is not mandatory to interpret tactile pictures and that experience could make it possible for blind people to draw and interpret tactile pictures. Indeed, blind and visually impaired people are used to exploring raised line material (in particular children who attend resource centers for the visually impaired) and could then benefit from better expertise in picture exploration and identification (Behrmann & Ewell, 2003; Berla & Butterfield Jr, 1977). Sighted children do not have such experience and do not demonstrate expertise in haptic exploration.

Changes and variabilities in mental representation could also explain some disparities in studies assessing the identification of raised line pictures. Studies suggest that the mental representations of blind people are mainly based on haptic experiences (Vanlierde & Wanet-Defalque, 2005). Hollins (1985) showed that the mental imagery skills change after loss of sight: mental representations based on haptic experience may gradually replace or enhance the representations based on visual experience. Mental representations are then not purely visual and can emerge from multimodal information (haptic, kinesthetic, auditory, olfactory) (Eardley & Pring, 2006; Hubbard, 2010; Levy, Henkin, Lin, Hutter, & Schellinger, 1999). Converging studies confirm that early blind people rely on mental representations using haptic, auditory or verbal information whereas sighted people rely mainly on visual representations (e.g. Ogden & Barker, 2001; Vinter, Fernandes, Orlandi, & Morgan, 2013). In summary, the results of past work show that the haptic system is more appropriate to process texture than shape and that mental representations in blind people are based on haptic cues more than on visual cues.

Pin array tablets and raised dot pictograms

Even though textured pictures seem to be the best way to depict objects, the use of textures makes tactile books cumbersome and fragile, and results in a limited lifespan of books that are expensive. New technologies in the market such as pin array tablets may provide editors with the possibility to create several illustrations and even several books with the same device (Maucher, Meier, & Schemmel, 2001; Prescher, Bornschein, & Weber, 2017; Velazquez, Pissaloux, Hafez, & Szweczyk, 2008; Zarate, Gudozhnik, Ruch, & Shea, 2017). Children would only have to carry a braille textbook and plug it into the tablet to get the companion illustrations. Moreover, children and teachers or parents could easily create their own pictures.

Different pin array tablets have been evaluated for their ability to display simple geometric shapes. These studies showed high recognition rates. Depending on the size of the matrix and the space between the pins the recognition rates varied from 60% to 90% in blind and sighted adults (Bellik & Clavel, 2017; Leo, Baccelliere, Waszkielewicz, Cocchi, & Brayda, 2018; Velazquez et al., 2008). Moreover, Zarate et al. (2017) showed that several usage scenarios for people with visual impairments

can be implemented with their Blindpad device (12 × 16 matrix of 4 mm pins spaced 4 mm apart). To our knowledge, this kind of device has never been tested with children.

While pin array tablets cannot be used to display complex images they are suitable to display simplified representations such as pictograms. A pictogram is defined as “a stylized figurative drawing that is used to convey information of an analogical or figurative nature directly to indicate an object or to express an idea” (Tijus, Barcenilla, De Lavalette, & Meunier, 2007, p. 2). These simplified pictures represent selected features of the depicted objects in order to discriminate them from others.

As mentioned earlier, the identification of raised line pictures can be difficult especially for children. One way to facilitate exploratory procedures and hence identification could be to use simplified pictures. Deák and Toney (2013) showed that young children (3 to 4 years) can learn pictograms as well as or even better than words. Preschoolers' experience with pictograms (Horner, 2005), however limited, could allow them to interpret novel pictures as abstract symbols. Pictograms are used in many contexts to replace written indications and instructions expressing regulatory, mandatory, warning and prohibitory information, or when the information needs to be processed quickly (e.g., road traffic signs), when users speak different languages (i.e. Japanese and Korean children; Takasaki & Mori, 2007), or as a communication tool for people with special needs (Paolieri & Marful, 2018). We expect pictograms to be useful for visually impaired people too. Pictograms could be an interesting way of conveying information for people with visual impairments who do not know braille and may struggle with tactile pictures. They could also be used as simplified illustrations in storybooks.

The present study

There are several ways of designing tactile pictures; each of them presents advantages and limitations. Raised-line pictures are easy to produce but can be difficult to identify as they only provide information about the shape of the object, which requires complex exploration movements to extract. Moreover, raised-line pictures representations are based essentially on visual features which could be difficult to understand for blind people who rely more on haptic experiences. Textured pictures seem better adapted to the haptic system and are easier to explore. However, they are more expensive and challenging to create, and make tactile books cumbersome and fragile. To overcome these difficulties, we wondered whether the use of circular patches of texture as illustrations could be a solution. In this case, only information about texture (but not about shape) is provided. In recent years pin array tablet technology emerged, making it possible to easily create and edit pictures. Nevertheless, these devices do not display texture and imply the use of raised dot stimuli. Like raised line pictures, these stimuli only provide information about the shape, which could be difficult to identify. In this regard, the use of simplified pictograms could facilitate the identification and attenuate the need for complex exploratory movements to extract the simplified shape.

This study aimed to assess the impact of three designs of tactile pictures on their recognition in blindfolded sighted children and blind children. Using a learning association task between an image and the name of the object it depicts, we compared circular patches of texture, textured shapes and raised dot pictograms. If the shape is not mandatory to identify a picture, pictures based on circles of texture could be identified as well as or better than pictures with shape and texture since such illustrations would only require the extraction of texture information. Such pictures could also reduce the exploratory movement to the easiest procedures (lateral motion and pressure; Lederman & Klatzky, 1987). The removal of a figurative shape would avoid the use of visual conventions and thus would reduce the difference between blind and sighted individuals.

We assumed that blind children would recognize circles of texture as

well as textured shape pictures. Moreover, because there is less information to process, they should be able to learn and recognize patches of textures at least as fast as textured shape pictures. Regarding pictograms, our study was exploratory only. Because there is no information about texture, we predicted that children would perform less well with pictograms than textured pictures. However, the use of simplified pictograms could still facilitate the identification and attenuate the need for complex exploratory movements to extract the simplified shape. Then children could still perform well with pictograms. Moreover, because of the many advantages of pin array technology, we assessed the question of whether pictograms based on raised dots were identifiable.

Method

Participants

The study included 54 participants in two groups: thirty-six sighted children (19 girls and 17 boys) with a mean age of 7.5 years (91 months, ranging from 84 to 98 months) and eighteen blind (visual acuity <1/20; considered as legally blind) children (9 girls and 9 boys) without associated disorders and a mean age of 8.1 years (98 months, ranging from 72 to 120 months). Among the blind children, 72% were born blind or lost sight before one year of age.

Stimuli

We created a set of three lists of ten French words using the Manulex database (Lété & Sprenger-Charolles, 2004) 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 was 50.99, 50.92, 51.01 for each of the three lists. 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) were subsequently illustrated with the three different methods. 90 tactile pictures were created; 30 correspond to pictures with shape and texture (textured shape), 30 to pictures with only circular patches of texture (circles of texture), and 30 to pictograms made of tactile dots (see Fig. 1).

The materials used for textures were selected based on their similarity with the textures of the original items (e.g. cloth, leather, wool, wood; for more details see “Textured pictures material” in the Open Science Framework1). We created two types of textured pictures: textured shapes and circles of texture. For textured shapes, we glued textures onto cardboard to create the shape of the depicted object. For textures only we used a circle of texture to depict the object (e.g. a circle of wool for a sheep).

We also designed dotted pictograms to assess the use of pin array technology to illustrate books. The pictograms were created based on the design of an existing tablet, the Blindpad (Zarate et al., 2017). We chose this tablet because it is portable, easy to set up, inexpensive and has been used in several usage scenarios. As the device consists of 4 mm pins spaced 4 mm apart we created pictograms with 4 mm dots spaced 4 mm apart. We chose to create pictograms having a 5 × 5 pin size

List 1				List 2				List 3			
Words	Textured Shapes	Circles of Texture	Pictos	Words	Textured Shapes	Circles of Texture	Pictos	Words	Textured Shapes	Circles of Texture	Pictos
Bag				Bird				Flower			
Doll				Fish				Hat			
Necklace				Balloon				Sheep			
Strawberry				Glasses				Pine			
Dagger				Belt				Pen			
Cauliflower				Speaker				Landing Net			
Cat				Trolley				Sweatpants			
Python				Hot Dog				Bumblebee			
Plaster				Rope-soled Sandals				Hand Brush			
Hanger				Nectarine				Controller			

Fig. 1. The set of tactile pictures.

Note. The set of pictures included ten items each, illustrated with three methods: textured shapes, circles of texture, and pictograms.

because: (i) it seems to be the minimum size to create figurative pictograms, and (ii) as the Blindpad (Zarate et al., 2017) is a 12×16 matrix of pins it makes it possible to display four pictograms on the tablet at the same time (enabling a scene with two or more items to be displayed).

We created 30 pictograms on a 5×5 dots matrix. The pictograms were modeled on already existing visual signage pictograms (e.g. the sheep shown in profile based on the road sign “animal crossing”) or typical visual representations (e.g. a V shape to represent a bird). Thus, pictograms included visual conventions such as occultation (e.g. the sheep with two legs).

All the tactile pictures (textured shapes, circles of texture and pictograms) were pre-tested with twelve blindfolded sighted adults. The rate of recognition for textured shapes and circles of texture was 98%. The rate of recognition for pictograms 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 5×5 array of dots. The final pictogram for those items was a mix of all the propositions. Lastly, we conducted a final pretest with a blind participant who was able to recognize all the pictures.

Procedure

The study was done individually, at school for sighted children, and at the special education center for children with visual impairments. Sighted children were blindfolded during the whole experiment with painted safety glasses. Paired-associate learning 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. Each picture was presented at the center of a cardboard measuring 10×8 cm. The participants were told the name of the picture and were free to explore it. During this phase, the exploration time for each picture was measured to obtain data on the difficulty of associating words and pictures, depending on the illustration method. The children 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 the 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 whole procedure was repeated three times (three blocks), one for each illustration method. Finally, each participant had to learn and identify 30 pictures (10 textured shapes, 10 textures only, and 10 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.

Data analysis

For each item and illustration method, we measured the exploration time during learning, and both accuracy and response time in the recall phase. The three learning conditions (textured shape, circle of texture, and pictogram) and the two groups of children differing by their visual status (blind and blindfolded sighted) were compared. The accuracy for each tactile picture was scored 0 for incorrect and 1 for correct recall. The accuracy was analyzed using a generalized linear mixed-effects model. Variables for the model included visual status, learning condition, item, participant and schools. The visual status and learning condition were considered as fixed effects. We included participants, items

and schools as random effects. This model was used to consider the sources of variability related to participants and items. We used a binomial test to assess the hypothesis that children's performance was above chance level. Exploration and response times learning were recorded in milliseconds and analyzed using linear mixed-effects models. A BoxCox estimation was first performed to determine the optimal transformation to normalize the distributions (Osborne, 2010). A log transformation was applied to the exploration and response times. The model for the exploration and response times analysis included the same variables (visual status and learning condition as fixed effects; items, participants and schools as random effects). To test the significance of the fixed effects, we compared models with and without them, using Log-Likelihood Ratio (LLR) chi-square tests. Tukey-adjusted pairwise comparisons were used to assess contrasts among the modalities of the fixed effects variables. Size effects were reported using Cohen's d (Cumming, 2012) for the linear mixed effect model and odds ratio for generalized linear mixed-effects.

Statistical analysis was performed using the computing environment R. Scripts for all analyses and anonymized data are available at the Open Science Framework.¹

Results

Exploration time during learning

The best model for the exploration time included both fixed effects variables and their interaction. The effect of the interaction between visual status and learning condition was significant $\chi^2(1, N = 54) = 6.09, p = .013$. The results showed that the blind children ($M = 9738, SD = 5460$) took significantly longer than the blindfolded sighted children ($M = 6836, SD = 3677$) to explore textured shapes, $\beta = -0.32, p < .001, d = 0.596$. The blind children ($M = 7945, SD = 4610$) also took significantly longer than the blindfolded sighted group ($M = 5917, SD = 3462$) for circles of texture, $\beta = -0.305, p = .002, d = 0.522$. No significant difference was observed between the blind ($M = 8724, SD = 4940$) and blindfolded sighted groups for pictograms, $\beta = -0.089, p = .365, d = 0.171$. The results showed a significant difference for the exploration time, which was longer for textured shapes than textures only both with the blindfolded sighted children, $\beta = 0.174, p < .001, d = 0.331$, and the blind children, $\beta = 0.195, p < .001, d = 0.352$. With the blindfolded sighted children, the pictograms showed the longest exploration times, which were significantly longer than for textured shapes, $\beta = -0.325, p < .001, d = 0.602$, and textures only, $\beta = -0.500, p < .001, d = 0.881$. With the blind children, no significant differences were found between the pictograms and the other two conditions: textured shapes, $\beta = -0.089, p = .199, d = 0.176$, and textures only, $\beta = -0.106, p = .104, d = 0.185$ (see Fig. 2).

Response time

The best model for the response time included visual status and learning condition as fixed effects. The effect of the visual status was significant; the blind children ($M = 3889, SD = 3903$) were faster than the blindfolded sighted ones ($M = 5725, SD = 5044$) for all conditions, $\chi^2(7, N = 54) = 14.31, p < .001$. The effect of the condition was significant, $\chi^2(7, N = 54) = 34.90, p < .001$. The pictograms showed the longest response times, which were significantly longer than for textured shapes, $\beta = -0.447, p < .001, d = 0.557$, and textures only, $\beta = -0.533, p < .001, d = 0.713$. No significant difference was observed between the textured shapes and textures only modalities, $\beta = -0.085, p = 557, d = 0.156$. (see Fig. 3).

¹ https://osf.io/7vx9m/?view_only=a395bb4dd62e4cedac78d212f4dff11c.

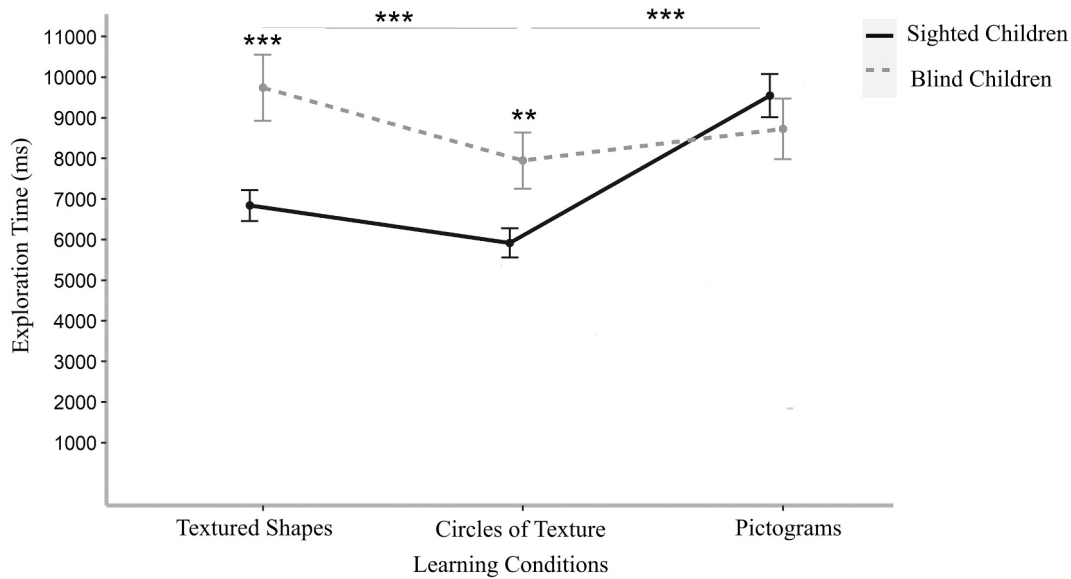


Fig. 2. Effect of learning condition on exploration time.
 Note. Mean exploration time in each learning condition for sighted and blind participants. Error bars show 95% CI.
 ** $p < .01$; *** $p < .001$.

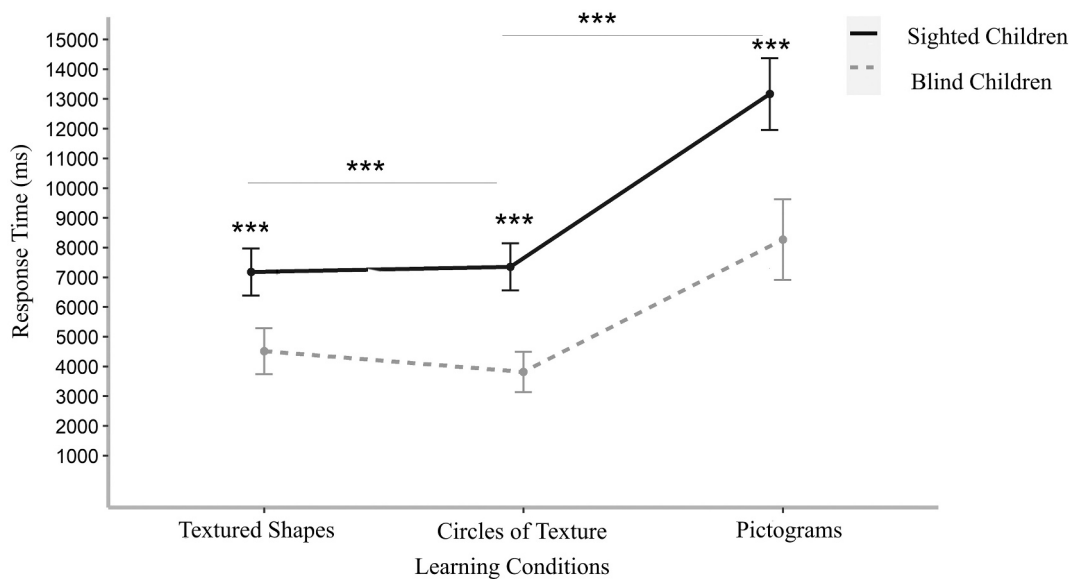


Fig. 3. Effect of learning condition on response time.
 Note. Mean response time in each learning condition for sighted and blind participants. Error bars show 95% CI.
 *** $p < .001$.

Accuracy

The best model for accuracy included both the fixed effects variables and their interaction. The effect of the interaction between the visual status and the learning condition was significant $\chi^2 (2, N = 54) = 7.4629, p = .023$. The results showed a significant difference between the blind (mean identification rate = 0.875, 95% Confidence Interval [CI] [0.782, 0.932]) and the blindfolded sighted children (mean identification rate = 0.692, 95% CI [0.585, 0.781]) for textures only, $\beta = 1.136, p = .002, t = 3.03, OR = 3.11$ (95% CI [1.49, 6.49]). There were no significant differences between the blind (mean identification rate = 0.909, 95% CI [0.832, 0.952]) and the blindfolded sighted groups (mean identification rate = 0.878, 95% CI [0.813, 0.922]) for textured shapes, $\beta = 0.326, p = .410, t = 3.11, OR = 1.38$ (95% CI [0.63, 3.01]) and no

significant differences between the blind (mean identification rate = 0.554, 95% CI [0.404, 0.695]) and the blindfolded sighted groups (mean identification rate = 0.469, 95% CI [0.359, 0.583]) for pictograms, $\beta = -0.341, p = .326; t = 0.98, OR = 1.40$ (95% CI [0.71, 2.77]). Among the blindfolded sighted children, the recognition rate for textured shapes was significantly higher than for textures only, $\beta = 1.165, p < .001, t = 4.36, OR = 3.14$ (95% CI [1.88, 5.25]). No significant difference was found between these modalities in the blind children, $\beta = 0.355, p = .585, t = -0.92, OR = 0.69$ (95% CI [0.3, 1.46]). In both groups the lowest recognition rate was obtained with pictograms, significantly lower than with textured shapes (blindfolded-sighted: $\beta = 2.096, p < .001; t = -7.79, OR = 0.13$ (95% CI [0.07, 0.21]); blind: $\beta = 2.082, p < .001; t = -5.71, OR = 0.11$ (95% CI [0.05, 0.23]) and textures only (blindfolded-sighted: $\beta = 0.931, p < .001; t = -3.75, OR = 0.39$ (95% CI

[0.24, 0.64]); blind: $\beta = 1.727, p < .001; t = -5.14, OR = 0.15$ (95% CI [0.07, 0.32])). Binomial tests indicated that the proportion of recognition for pictograms was above the level of chance (0.1) for the blind children ($M = 0.54, 95\% CI [0.463, 613], p < .001$) and the blindfolded-sighted children ($M = 0.469, 95\% CI [0.359, 0.583], p < .001$) (see Fig. 4).

Discussion

The present study aimed at comparing tactile exploration and recognition of different tactile pictures in two populations (sighted and blind children). We compared two existing types of tactile pictures: textured shapes (pictures obtained by shaping different textured materials, the most widely used type of picture in tactile books for children with visual impairments) and textures only (a simple circular patch of different textured materials), and proposed a new one based on innovative raised-pin tablets: pictograms (pictorial pictures made of raised dots).

Our results showed that performance with pictograms was worse than expected even if significantly above random. Also, raised dot pictograms led to the lowest recognition rates and the longest response times in both groups of children, even if performance was significantly above random. For textured pictures, we showed that in blind children, circles of texture were recognized as well as and as fast as pictures that combined shape and texture and were also learned faster. However, for sighted children, the rate of recognition was lower for circles of texture than for textured shape pictures.

We will first discuss the results for raised dot pictograms. It is possible that pictograms may not be relevant for children. Pictograms only show certain specific characteristics of the object represented (e.g. the wings for the bird, which has neither beak nor legs). According to [Overvliet and Krampe \(2018\)](#), children tend to implement “guessing” strategies while exploring tactile pictures: they recognize the pictures due to one of the picture's specific characteristics (e.g. the horns of the giraffe). Hence, pictograms may not be detailed enough to allow children to use local characteristics of the object to recognize pictures. In other words, if the child does not understand that these are the wings of the bird, he does not have other local clues to recognize the picture.

Another difficulty stems from the perception of these dot-based pictograms by touch. To grasp the shape of the pictograms, it is

mandatory to perceive the distinct dots as a whole. This principle of proximity has been described in Gestalt perception theory ([Köhler, 1967](#)). Studies have shown that the Gestalt proximity principle is applicable to touch ([Chang & Nesbitt, 2005; Chang, Nesbitt, & Wilkins, 2007](#)), although the haptic system is believed to be less sensitive than vision to this principle ([Hatwell, 2003](#)). The gap between the dots in our pictograms could make it difficult for children to perceive them as a whole. Further studies should be conducted to better understand how dot-based stimuli are perceived. As mentioned previously, several pin array tablets have been developed and marketed with different designs. It would be interesting to determine if the recognition of pictograms depends on the tablet design (size and spacing of the pins). Future studies should be conducted to better understand the perception of raised-dot illustrations and how to design them. Indeed, those raised-dot illustrations can be displayed on raised-pin tablets that make it possible for children to create their own illustrations and store many illustrations in a single device.

We will now discuss the results for the circle of texture pictures compared to textured shape pictures. We assumed that shape was not mandatory to associate a textured picture to an object. Our main results show that, in blind children, circles of texture were recognized as well as and as fast as pictures that combined shape and texture and were also learned faster. However, for sighted children, the rate of recognition was lower for pictures made with circles of texture than for textured shape pictures. These results can be explained by two complementary hypotheses.

First, mental representation and memorization strategies have been shown to be different in blind and sighted children. Sighted people mainly rely on visual imagery to process tactile pictures ([Picard et al., 2010](#)). Because of this visual imagery process, picture recognition in sighted children relies strongly on shape information gathered through touch. Blind people rely less on visual imagery ([Picard et al., 2010](#)) and different studies suggested that mental representations are mainly based on haptic experience ([Hollins, 1985; Vanlierde & Wanet-Defalque, 2005](#)). The texture may therefore be a key feature in tactile picture recognition for blind children. As the extraction of shape (structural information) is a complex exploratory procedure that is cognitively costly ([Hatwell et al., 2003; Loomis, Klatzky, & Lederman, 1991](#)), blind children may primarily focus on texture discrimination even though the shape is available. Our results (accuracy and response times) seem to

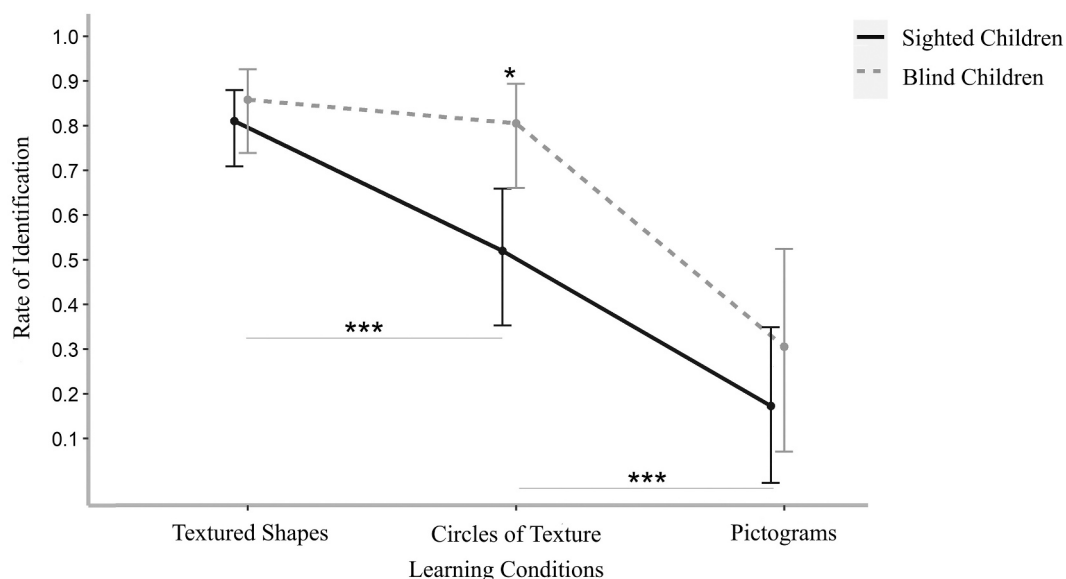


Fig. 4. Effect of learning condition on rate of identification.

Note. Mean identification rate in each learning condition for sighted and blind participants. Error bars show 95% CI.

* $p < .05$; *** $p < .001$.

indicate that the presence of a figurative shape did not provide them with additional information necessary to identify a picture.

In this study, we selected object categories that could be touched by children in everyday life. Among these items, some of them were graspable and others not (e.g. animals). Although the texture is easy to perceive for graspable and ungraspable objects, shape information is easier to perceive (by touch) for graspable objects than for ungraspable. Then, in future work, it will be important to check if there is a difference regarding shape information between graspable and ungraspable objects.

Our second hypothesis is that blind children are more familiar with tactile pictures, and thus can better discriminate textures than sighted children. The circles of texture in our task required the discrimination of ten different textures. For instance, among the 12 sighted and 6 blind children who used list #3 in the circles of texture condition, we noticed that “pine” was mistaken for “hand brush” in 6 sighted children whereas none of the blind children made that mistake. Both textures were made of similar vertical lines (pine needles for the pine and brush bristles for the hand brush, see Fig. 5). The sighted children may have focused on this feature only and did not perceive the slight differences in thickness and orientation. The blind children may have outperformed the blindfolded-sighted children because they used better exploratory strategies that made it possible to discriminate most of the textures when the blindfolded sighted cannot. To separate our two hypotheses about the lower performance of sighted children with circles of texture (i.e. representations based on tactile cues rather than on visual cues or better exploration strategies for texture), it would be possible to train sighted children with the textures used for the study until they can recognize as many textures as blind children and then use our paired-associate learning task to assess their capacity to associate the textures to a picture. If sighted children still show poorer performance, that would mean that texture discrimination is not the problem but rather that it is harder for sighted individuals to associate a texture to a picture (i.e. a circle of fur is not a cat).

Whatever the tactile picture design, the response times of the blind children were shorter than those of the sighted children. This result is consistent with previous studies (Bardot, Serrano, Oriola, & Jouffrais, 2017; Thompson et al., 2006; Withagen, Kappers, Vervloed, Knoors, & Verhoeven, 2013), and suggests that blind children have better expertise and familiarity with tactile pictures. The blind children spent more time exploring pictures in the learning phase but were then able to recognize them faster than the sighted children did. As we did not analyze the exploratory procedure during the learning phase it is difficult to draw any definitive conclusion from this difference in exploration. It is however possible to assume that blind children who are used to exploring tactile pictures tried to implement precise exploratory procedures and to gain as much information as possible about the picture.

Using a circle of texture helps to simplify the pictures because the texture is the only feature to extract. However, texture then becomes the

only clue to discriminate one object from another. The choice of textures is therefore decisive for the recognition of this type of image.

The main limitation of the study is that it did not assess the ability to identify tactile pictures but rather to recognize them from memory. Indeed the task we have chosen, a paired-associate learning task is not frequently used in studies about the haptic perception of tactile content. Hence, the results only apply in a context where pictures are presented in advance. and cannot be directly compared to the results of other studies using textured pictures. For example, Theurel et al. (2013) observed a 35.87 ($SD = 23.63$) identification rate when we observed a 90.9% (95% CI [83.2, 95.2]) recognition rate with blind children. However, in tactile books, the story provides children with a context that helps the recognition of pictures, which finally is similar to the task used in this study. Thus we assume that our results can have direct pedagogical applications and be used for the design of tactile pictures in children's books.

Another limitation concerns the matching between the two groups of children (sighted and blind) which was done solely on age. To have a sufficient number of participants, the inclusion criterion on age was broader for blind children (6 to 10 years) than for sighted children (7 to 9 years). In addition, a one- to a two-year delay in schooling is common among children with visual impairments even when they have no mental retardation (Hatwell, 2003). Hence, the abilities of a six years old blind child could not be the same as those of a 6 years old sighted child.

Conclusion

Our results showed that circles of texture were learned faster and identified as accurately and as fast as textured shapes. Hence, it seems that pieces of textures could be an appropriate way of illustrating books for children with visual impairments. They are very easy to make and would therefore decrease the cost of illustrated tactile books, which is an interesting result for publishing houses. Currently, a few publishing houses already sell books using pieces of textures as illustrations (see e.g. “C'est moi le plus fort”, Les Doigts Qui Rêvent, Talant, FR). These books are cheaper than regular tactile books using textured shapes and are, in this respect, more accessible for parents, libraries and schools. It is possible to use simple geometric textured shapes (e.g. circles, squares, rectangles, triangles) to represent the characters in the story, associating each of them with a simple geometric shape and texture. This type of image could compensate for possible texture discrimination difficulties: if two textures are too close or even the same, the simple geometric shape makes it possible to distinguish the two characters from each other (e.g. Little, Small, Wee Bear, Middle-sized Bear and a Great, Huge Bear from “The story of the three Bears”). It could also make it possible to represent objects whose texture is not the central cue of the concept to figure by representing them with a simplified shape (e.g. two circles for a bike).

In this study, we only assessed the ability of children to associate a word with a picture. Future work should evaluate the use of circles of texture in reading activities by using pictures to illustrate a story. Reading activities could be observed with visually impaired and sighted children. Reading activities with circles of texture illustrated books could make it easier for children to explore the pictures and identify the characters. If so, it could make children more self-sufficient in their reading activities and so more motivated to read books.

New technologies such as pin array tablets are a promising method for creating illustrations for visually impaired children. Our study showed that raised-dot pictograms can be learned by blind and blindfolded children. However, it is still not clear if difficulties with raised-dot pictograms stem from the use of symbolic pictures as pictograms or the use of dotted shapes. Subsequent studies should compare the use of line pictograms and dotted pictograms to separate these two hypotheses. Moreover, it seems that the design of the tablet could also influence recognition and should be assessed in further studies. We chose Blindpad (Zarate et al., 2017) as the baseline to create our pictograms as it was

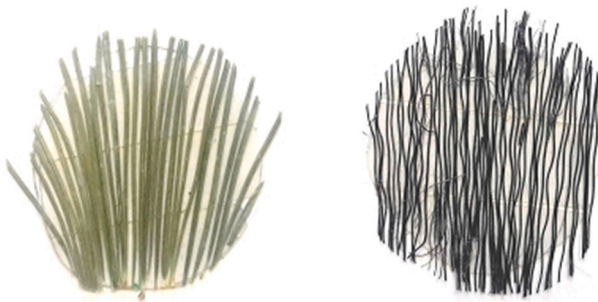


Fig. 5. Circle of texture pictures for pine and hand brush.
Note. Circle of texture picture for pine (left) was made of pine needles. Circle of texture for hand brush (right) was made of brush bristles.

cheaper. However, other more expensive tablets with a better resolution (smaller spacing) could make it easier to recognize the pictograms.

Declaration of Competing Interest

None.

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