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DESIGNING UNIVERSAL VISUOTACTILE PICTOGRAMS FOR ORIENTATION MAPS

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***Abstract*:** Pictograms are used in all domains of our daily life, in orientation maps in particular. They can be depicted visually or tactually for blind people. The problem is that these existing pictograms are not standardized. The aim of this study was to develop a range of visuotactile orientation pictograms, which would be understandable by adults, children, elderly, foreigners and people with visual disability. We conducted three studies: Study 1 aimed to make sighted users (adults and children) evaluate a set of visuotactile pictograms designed initially for blind users concerning their perceptual and cognitive processes. The results show that many of these pictograms proved to be too specific to be understandable by the general population. To complement the data, we analyzed the impact of colours on the understanding of pictograms by sighted users (Study 2). Finally, we conducted a series of creative workshops with sighted adults, blind adults and sighted children (Study 3) in order to generate a new set of universal visuotactile pictograms. This research contribution is twofold: from a methodological viewpoint, we experienced and observed the limitations of two approaches (top-down and bottom-up) to design universal pictograms.

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From a practical viewpoint, we created a set of universal visuotactile pictograms to make orientation maps more accessible.

Relevance to industry: Both the methodological insights and the design results can be useful to practitioners. Our proposal of the new set of universal visuotactile pictograms can be used by sign makers to design accessible orientation maps.

Keywords: Universal design; accessibility; visuotactile pictograms; orientation maps; people with visual disability

Introduction

Pictograms are usually used in daily life, in signage in particular, for example, to indicate toilets in a museum. “*They are used to replace written indications and instructions expressing regulatory, mandatory, warning and prohibitory information in order to process information quickly, to help foreigners or persons having limited linguistic ability, or having visual problems (e.g. older people)”* (Tijus et al., n.d.). Pictograms are 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”.* Pictograms are categorized according to their links with the object represented (Tijus et al., 2005):

- *Figurative pictogram*: the signified object or situation is reproduced more or less faithfully or schematized, supplying physical clues to facilitate comprehension (e.g., fork and knife to symbolize a restaurant).
- *Abstract pictogram*: the signified object or situation of reference is evoked through abstract graphic concepts which reproduce some of its features or functions, (e.g., the up and down arrows for the lift).

- *Arbitrary pictogram*: the signs used in the pictogram have a symbolic meaning possibly influenced by cultural factors (e.g., the dove symbolizing peace).

Pictograms are supposed to have a strong evocative potential with a significant metaphorical ability (Brangier & Gronier, 2000). It is generally accepted that pictograms are universal, recognizable and memorable by all people (Lodding, 1983; Wickens, 1992; Vaillant, 1997; Weidenbeck, 1999; Bordon, 2004). This explains why they are widely used in the medical field to improve medication information comprehension by adults, children, elderly or illiterate people (Houts et al., 2006; Thompson et al., 2010; Barros et al., 2014). Many studies in the field of illiteracy and dyslexia showed that pictures, graphics and pictograms facilitate access to information (Medhi, Sagar, & Toyama, 2005; Parikh, Ghosh & Chavan, 2003a, 2003b; Huenerfauth, 2002; Grisedale, Graves & Grünsteidl, 1997; British Dyslexia Association, 2009; Rainger, 2003; Gélinas-Chebat, Préfontaine, Lecavalier & Chebat, 1993) provided that they are culturally adapted (Chipchase, 2006; Medhi, Sagar, & Toyama, 2005), clear (Joshi, Welankar, Kanitkar & Sheikh, 2008), significant (Medhi, Menon, Cutrell & Toyama, 2010) and contextualized (Tijus et al., 2005).

Guastello et al. (1989) explain that pictograms with textual information are better understood, especially in complex situations; a strong concordance between the signifier and the signified is of utmost importance, the bigger the distance, the more difficult the understanding.

However, there are no standardized visual pictograms even if, since the 90's the International Standardization Organisation (ISO) has normalized existing pictograms and their creation. For example, the ISO norm 7001 gathers pictograms related to touristic information (e.g., "i" for information). It provides guidelines on the contents (e.g., background colour, size) to enable wayfinding designers to culturally adapt pictograms (Vaillant, 1997). This lack of standardization results in a great variability of pictograms. For example, we can find many graphical representations of toilets, not only the world as a whole but within the same country. This variability involves a learning process each time users are in front of a new graphical representation. This increases the time of visualisation, leading to cognitive load and therefore reducing the efficacy and efficiency (ISO 9241-11) of the pictogram.

Moreover, pictograms can be depicted not only visually but also tactually for blind people. Several combinations of the visual and tactile modalities can be designed: (1) the tactile signifier reproduces the graphical one, which results in a visuotactile pictogram, or, (2) two different signifiers are superimposed, a graphical one and a different tactile one. Currently, no standardized design guidelines exist for tactile and visuotactile pictograms.

In our opinion, this lack of standardization is the reason why in France, orientation maps are not universal and accessible. Each establishment receiving the public (such as museums, Town halls, and so on) has its own orientation maps with its own pictograms designed by differents sign makers. Sometimes, in the same establishment there is an orientation map for sighted people and another for the blind people. Therefore, our issue is to find a common representation for designing visuotactile pictograms, which requires that (1) the graphical representation must be comprehensible by all sighted people in the society (e.g. children, adults, the elderly, people with visual disability and foreigners) and, (2) the tactile representation must be comprehensible by people born blind and those who become blind later in life. Tactile designs involve respecting the criteria of transposability (Bris, n.d), which are:

- *Dimension*: pictograms must be adapted to the surface of the pad of the index finger,
- *No perspective*: perspective is a sighted concept and is not understood by blind people, particularly if they are born blind,

- *Simplicity*: to be comprehensible, pictograms must be simple and straight forward,
- *Discriminability*: each element composing a pictogram must be tactually discriminable, which means that tactile gaps of at least 2mm must be respected between two elements.

These criteria enable blind people to use their own experience, which may be different from accepted visual representations, to interpret pictograms. We intend to design visuotactile pictograms, i.e. to identify a single visual and tactile signifier which would be understandable by sighted and blind users. First, for the purpose of this research, it is assumed that such visuotactile pictograms will be more readable than the superimposition of different visual and tactile signs. Indeed, partially-sighted people may be unsettled in their reading when tactile is not equivalent to visual. Moreover, visuotactile pictograms may save space and reduce the informational load in comparison to juxtaposing two different signifiers on orientation maps. Finally, a single signifier may be more aesthetic than two different signifiers superimposed or juxtaposed.

Our research aims to develop a range of visuotactile orientation pictograms, which would be understandable by everyone(adults, children, elderly, foreigners and people with visual disability).

To achieve our goal, we studied the domain of Universal Design (Vanderheiden, 1997; Vanderheiden & Tobias, 2000) which is defined as follows "*the design of products and environments that can be used by all, to the maximum extent possible, without the need for adaptation or specific design*" (Story, Mueller, mace, 1998). The objective is to consider all audiences in design projects and particularly minimize the risk of stigmatization associated with specific products (Coleman, Lobben, Clarkson & Keates, 2003). To this definition are added seven principles with guidelines (Connel et al., 1997; Figure 1) considering needs of people with disabilities, but also children, elderly users, left-handers, etc. These principles are:

1. *Equitable use*: design a product that is useful and marketable to users with diverse abilities. Guidelines are :
    a. Provide the same means of use for all users: identical whenever possible; equivalent when not.
    b. Avoid segregating or stigmatizing any users.
    c. Provisions for privacy, security, and safety should be equally available to all users.
    d. Make the design appealing to all users.
2. *Flexibility in use*: design a product that takes into account the preferences and abilities of users.
    a. Provide choice in methods of use.
    b. Accommodate right- or left-handed access and use.
    c. Facilitate the user's accuracy and precision.
    d. Provide adaptability to the user's pace.
3. *Simple and intuitive use*: design a product that is easy to use and understandable regardless of prior experience, language skills or education level.
    a. Eliminate unnecessary complexity.
    b. Be consistent with user expectations and intuition.
    c. Accommodate a wide range of literacy and language skills.
    d. 3d. Arrange information consistent with its importance.
    e. Provide effective prompting and feedback during and after task completion.
4. *Perceptible information*: information about the use of the product must be effective.
    a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information.
    b. Provide adequate contrast between essential information and its surroundings.
    c. Maximize "legibility" of essential information.

   d. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions).

   e. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.

5. *Tolerance for error*: the product helps users avoid errors or accidents.

   a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded.

   b. Provide warnings of hazards and errors.

   c. Provide fail safe features.

   d. Discourage unconscious action in tasks that require vigilance.

6. *Low physical effort*: the product can be used with minimum effort and fatigue.

   a. Allow user to maintain a neutral body position.

   b. Use reasonable operating forces.

   c. Minimize repetitive actions.

   d. Minimize sustained physical effort.

7. *Size and space for approach and use*: dimensions of use are sufficient for any user.

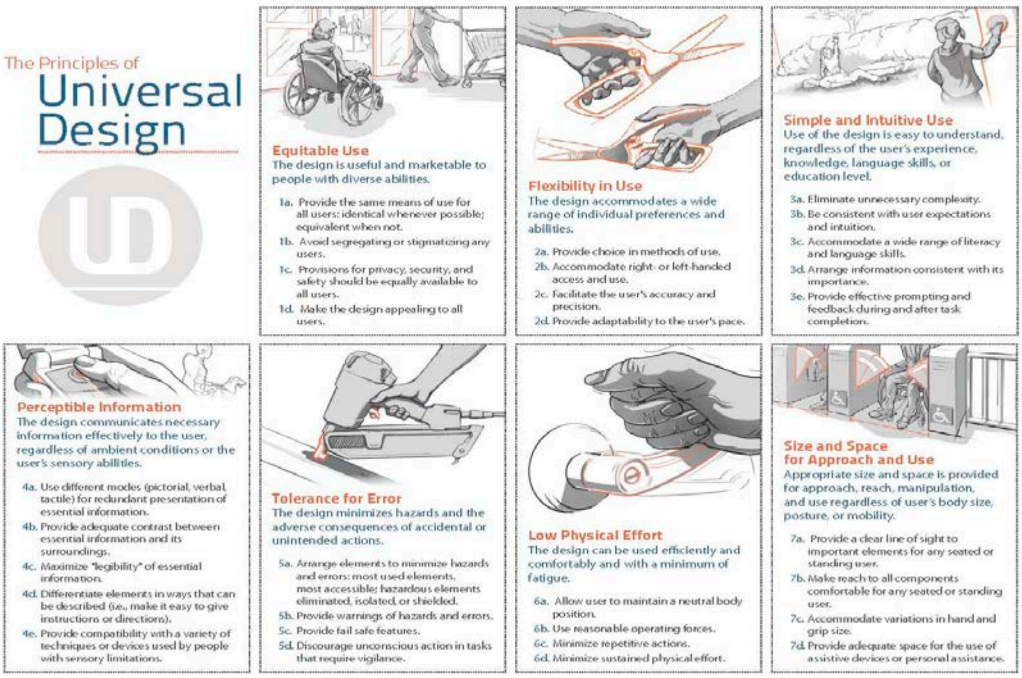
   a. Provide a clear line of sight to important elements for any seated or standing user.

   b. Make reach to all components comfortable for any seated or standing user.

   c. Accommodate variations in hand and grip size.

   d. Provide adequate space for the use of assistive devices or personal assistance.

Figure 1: the principles illustrates of Universal Design.



As part of this research, we focused on the first four principles. In respect of these four principles, we tested our proposal of pictograms with three profiles of users (sighted children, blind and sighted adults). We chose two modalities because of the first principle of the Universal Design for Learning is "Multiple means of representation", according to Rose (2006) "students differ in the ways that they perceive and comprehend information presented to them"(p.136), in this perspective we used two modalities (visual and tactile) to design pictograms. Tests will allow us to consider all capacities and to assure us that pictograms are effectively perceptible and comprehensible.

Two approaches support the design for all people (Stary, 1997; Plos et al., 2007):

- *Top-down (or adaptive) approach*: specialized products are designed to meet the special needs of specific target users, for example, disabled people, then these needs, or these solutions, are extended to other users.

- *Bottom-up (or proactive) approach*: products are designed for the greatest number of users (people who are disabled or not).

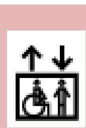
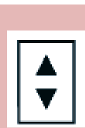
We initially chose to follow a top-down approach: a first set of visuotactile pictograms that were adapted to blind users was designed; then the visual form of these pictograms were evaluated by sighted users from the target population. However, as will be developed next section, it appeared necessary to redesign several pictograms in a bottom-up approach. Below we report on the evaluation process with sighted users (Study 1), a specific analysis of the impact of colours on the understanding of pictograms by sighted users (Study 2) and a series of creativity workshops that were conducted with sighted adults, blind adults and sighted children (Study 3). All studies were conducted in France; participants were French and lived in Paris. We did not include the cultural dimension of pictograms. It is one of the limitations of this research, as discussed in conclusion.

Study 1

An initial set of visuotactile pictograms were designed by several expert designers, including an expert in tactile transcription for orientation maps. These pictograms were intended to account for accessibility constraints, specific cognitive processes of blind users, transposability criteria as well as for existing visual conventions. Over the years and projects, these pictograms were evaluated by several associations (e.g. the National Federation of blind people in France, Valentin Haüy Association) (Boisadan et al., 2016) and proved to be readable and understandable by blind users. Ten concepts were identified (Table 1) by experts of this corporate partner because they are the most common in orientation maps and favour spatial structuring. Various signifiers exist for some of these.

Following this process, the aim of Study 1 was to validate the comprehension of the visual form of these pictograms with the general public (adults and children).

Table 1. Concepts and signifiers adapted to blind users' capacities and representations.

Concepts	Signifiers		
Reception			
Information point			
Stairs			
Access			
Lift			
Toilets			
Scale			
You are here			

Concepts	Signifiers	
Restaurant		
Wind rose		

Methodology

Participants

Three hundred and twenty seven volunteers participated, including 297 French-speaking adults (mean age = 33,5, Standard Deviation (SD) = 10,58) and 30 French-speaking children (mean age = 9,9; SD = 1,27). Adults were recruited through social networks, and children were recruited from a holiday centre located in Pantin, France.

Material

We created a questionnaire including two parts.

Part 1: The use of orientation maps

Adults participants used a 7-point Likert-type scale to rate their expertise level with regards to orientation maps. They were also invited to fill in two open-ended questions related to the information they expect to find in indoor and outdoor orientation maps. Children were asked if they knew what orientation maps were and if they had already used any.

Part 2: Pictogram identification

Each one of the 19 signifiers was linked to an open-ended question "For you, what does this pictogram represent?".

Procedure

Adults completed an online survey distributed on various networks (Linkedin, ErgoIHM list, ErgoList), whereas children completed a paper form during individual interviews. The facilitator helped them focus their attention on the pictograms and write their answer.

Data collection

Participants' answers for each pictogram were coded as correct or incorrect with regard to the intended meaning. For example, for the pictogram "cafeteria", the answers "cafe" or "bar" were considered as right and "hot drink" or "coffee machine" were judged as wrong.

Results

Part 1: The use of orientation maps

Adults obtained a mean score of 5 (SD = 2) regarding the use of orientation maps; this means that they are regular users of them. In indoor maps, they expect to find: you are here, toilets, service list, access, lift and stairs. Expected information in outdoor maps is: you are here, point(s) of interest, streets, transportation, wind rose and important buildings.

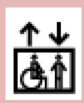
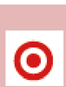
57% of the children had already seen orientation maps; 20% stated occasional use and 13% frequent use.

Part 2: Pictograms identification

In total, 19 signifiers were evaluated. They were classified in three categories (Table 2): 1) recognized by 80% or more participants, 2) intermediately recognized (60 to 79% recognition rate) and 3) not recognized (below 60%).

Table 2. Percentage of pictograms identification by children and adults (green: recognized, yellow: intermediately recognized, red: pictograms not recognized).

Pictograms	Concepts		% Adults (n=297)		% Children (n=30)	
			Yes	No	Yes	No
	Reception		2,71	97,29	3,33	96,67
	Information point		65,76	0,34	23,33	76,67
	Cafeteria	1	88,14	11,86	70	30
		2	63,39	36,61	40	60
		3	66,44	33,56	56,67	43,33
		4	73,90	26,10	30	70
	Stairs	1	4,75	95,25	3,33	96,67
		2	13,56	86,44	6,67	93,33
	Access	1	20,68	79,32	3,33	96,67
		2	2,37	97,63	3,33	96,67

Pictograms	Concepts		% Adults (n=297)		% Children (n=30)	
			Yes	No	Yes	No
		3	0,68	99,32	3,33	96,67
	Lift	1	0,68	99,32	0	100
	Lift	2	90,85	9,15	20	80
	Lift	3	54,92	45,08	63,33	36,67
	Toilets		91,53	8,47	83,33	16,67
	Scale		71,19	28,81	37	63
	You are here	1	36,95	63,05	16,67	83,33
	You are here	2	11,19	88,81	10	90
	You are here	3	36,95	63,05	10	90
	Restaurant	1	99,32	0,68	93,33	6,67
	Restaurant	2	90,17	9,83	63,33	36,67

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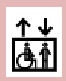
Pictograms	Concepts		% Adults (n=297)		% Children (n=30)	
			Yes	No	Yes	No
	Wind rose	1	94,92	5,08	83,33	16,67
		2	84,75	15,25	73,33	26,67

Ten pictograms were not recognized (reception, all signifiers of "stairs", "access" and "you are here"). Only three pictograms (toilets, restaurant 1 and wind rose 1) were well recognized by adults and children (Table 2). Below we provide an overview of the unexpected interpretations for the pictograms that were not recognized (Table 3).

Table 3. Adults and children interpretations of the pictograms that were not recognized.

Pictograms	Concepts	Interpretation of pictograms not recognized	
		Adults	Children
	Reception	wifi (38%), doesn't know (20%), panorama (16%)	eye (34%), doesn't know (16%), network (13%)
	Information point	/	doesn't know (40%)

Pictograms	Concepts		Interpretation of pictograms not recognized	
			Adults	Children
	Cafeteria	2	/	breakfast (30%), restaurant (21%), eat and drink (12%), bakery (12%)
		4	/	cup (20%), drink (20%), glass (17%)
	Stairs	1	doesn't know (36%), thermometer (17%)	temperature (23%), battery (20%), doesn't know (20%)
		2	doesn't know (55%)	doesn't know (43%), from the smallest to the biggest (10%)
	Access	1	doesn't know (27%)	triangle (40%), direction (15%), wrong way (12%)
		2	doesn't know (42%), distance (12%)	doesn't know (20%), right-left (17%), quotation marks (10%), big and small (10%)
		3	Up-going elevator (28%), going up (26%)	lift (33%), doesn't know (20%)
	Lift	1	doesn't know (63%)	doesn't know (23%), camera

Pictograms	Concepts		Interpretation of pictograms not recognized	
			Adults	Children
				(16%), car running (13%), mobile phone (13%)
		2	/	toilets (47%)
	Scale		/	doesn't know (17%), line (17%)
	You are here	1	doesn't know	doesn't know
	You are here	2	doesn't know (53%), point of interest (15%)	doesn't know (28%), circle (9%), roundabout (9%), target (9%), forbidden (9%)
	You are here	3	doesn't know (22%), target (16%)	target (30%), doesn't know (13%), point and circle (10%)

We only accepted precise answers. For example, the interpretation "eat and drink" is too general and can refer to similar concepts such as cafeteria and restaurant. There is a conceptual difference between these two notions. A cafeteria suggests a quick meal, whereas a restaurant implies a longer one. Adults' misinterpretations are often "doesn't know" contrary to children who tried to find an interpretation to all pictograms. In the latter case, interpretations are often descriptive and linked to children experience (school, environment).

Discussion

The majority of the pictograms initially intended for blind users were not understood by sighted users; in particular, pictograms that are blind-oriented (i.e., designed only for blind) and not figurative, for example, the "reception" or "stairs" pictograms (Table 2). In contrast, we know that these two pictograms are easily and quickly recognized by blind people when integrated into an orientation map. For sighted people, the pictogram "Reception" meant a low WIFI signal. These results suggest that, if we take into account the needs and the perceptions of blind users only, pictograms may not be comprehensible for sighted people.

Children understood the most figurative pictograms such as "restaurant" (knife, fork, spoon/knife and fork). Their low abstraction capacity may explain some of their answers; in fact, children's answers are descriptive. For example, for the signifier 2 of "cafeteria", children said "breakfast" or "eat and drink". Some misinterpretation can also be explained by the similarity between several signifiers, for example for the signifier "lift", many children answered "toilets" because of the two persons side by side on the pictogram.

Several methodological limitations appeared in this study. For example, presenting several alternative pictograms for a single signified concept proved inappropriate with children, who strived to provide a different answer to each design. Besides, pictograms were evaluated out of context and were only graphical. Results may have been different with pictograms inserted in an orientation map, and interpretation may be partly guided by contextual cues. However, our objective was to examine their meaning in absolute terms, without any context. Complementary evaluation *in situ* should be conducted, and the visuotactile (instead of purely graphical) form of pictograms may also influence the interpretation, even for adults.

Colour sometimes proved to influence participants' answers. For example, the concept "stairs", represented by a red gradient once triggered the answer “this pictogram indicates temperature” whereas stairs represented by a black gradient was once interpreted as “this pictogram is a barcode label”. To better inform the potential influence of colour on pictogram interpretation, we conducted Study 2 with a subset of pictograms.

Study 2

This study aimed to analyze the impact of colours on the understanding of pictograms by adult sighted users.

Methodology

Participants

Forty-five volunteers (age M = 30,1; min = 19; max = 61; SD = 17) participated in this study.

Material

We selected six pictograms (access, toilets, stairs, information point, you are here and lift) displayed all of them in four colours (black, red, blue and green (RGB colours); Figure 2).

Pictograms were:

- Access represented by a triangle pointing to the right
- Toilets represented by a person in a wheelchair, a man and a woman, one next to the other separated by a vertical line
- Stairs represented by four verticals lines next to each other, lines are less and less thick
- Information point reprenset by the letter “I” in a square
- You are here represented by a target

- Lift represented by a person in a wheelchair to the left of a person standing. They are in a rectagle with two arrows above (on the left: an arrow pointing upwards; on the right an arrow pointing downwards

This resulted in a set of 24 pictograms which were mixed and distributed into four questionnaires, each of which containing only one version of each pictogram.

Figure 2. Pictograms used for the study 2 (from left to right: access, lift, stairs, information point, you are here, toilets) and displayed in the four target colours (black, blue, green and red).

Procedure

During short interviews, the participants were shown the 6 pictograms in turn and asked to give a meaning to each one, in their own words.

Data collection

Spontaneous answers were coded 1 when the colour proved to have influenced the answer or 0 when there was no colour impact. For example, when participants answered "toilets not in use" when the "toilets" pictogram was represented in red, we considered that the colour had an influence.

Results

We observe a low colour impact on the percentage of the answers (Table 4).

Table 4. Percentage of colour impact on the interpretation of each pictogram.

Pictograms	Colours			
	Black	Red	Green	Blue
You are here	0%	0%	7%	0%
Toilets	0%	86%	0%	0%
Lift	0%	0%	2%	0%
Stairs	0%	57%	36%	0%
Access	0%	0%	0%	0%
Information point	0%	0%	29%	0%

Red and green colours added information to several pictogram's interpretation, in particular Toilets, Stairs and Information point. For example, when stairs were displayed in red, some participants said "banned stairs", when toilets were red some of them answered "busy toilets" or interpreted the colour as "interdiction". Conversely, green meant "open", "accessible" or "permission". However, it should be noted that displaying the "you are here" pictogram in red did not alter its meaning – this suggests that it remains possible to use red for this pictogram to attract users' attention at first sight.

In contrast, black and blue never influenced pictogram interpretation.

Discussion

For the set of new pictograms to be created, pictograms can be displayed in black or blue. When relevant, red can be used for interdiction or danger and green for permission. These results are in line with those of the literature on warning pictograms in which red, orange and yellow colours represent “danger” (Lin, Chang, Liu, 2015). This study was nonetheless useful to confirm that black and blue colours are equivalent and do not interfere with pictogram meaning. We also retain that displaying the “you are here” pictogram in red may be possible to direct sighted users’ attention without altering the meaning of the pictogram.

Study 3

Following Study 1 results, it appeared necessary to redesign several pictograms of our initial set. From a methodological viewpoint, we may mention that our initial top-down approach, drawing on blind users’ special needs to design universal pictograms, proved insufficient. We chose to complement the process with a series of creative workshops focusing on ideas and representations of 3 categories of users, namely sighted adults, adults with visual disability, and sighted children. Study 3, therefore, implements a bottom-up instead of a top-down approach, and relies on participatory methods instead of expert methods which had given rise to the first set of pictograms.

The participatory approach to pictogram design is original in itself, in particular with children and blind users. We chose this method as it seemed the most likely to produce the most cognitive activity of participants with no guidance from expert designers, and highlight similarities and differences between blind and sighted adults as well as sighted children. Involving blind participants in creative workshops remains rare and challenging (Brock et al., 2016; Hendricks et al., 2015).

Methodology

Participants

Four creative workshops were conducted in France: a first adult group (n = 6, mean age = 30 years, min = 26, max = 43, SD = 6,46), a second adult group (n = 16, mean age = 23 years, min = 21, max = 31, SD = 2,50), a children group (n = 6, mean age = 13 years, min =11, max = 15, SD = 2,06) and a group of people with visual impairments (n = 7, mean age = 58 years, min = 48, max = 66, SD = 6,52) in which 4 participants were visually impaired and 3 were blind.

Procedure

We asked participants to create as many drawings as possible for each target concept. The same material was used in all groups: paper sheets (1 blank sheet per participant and concept), small coloured round stickers (3 by participant and by concept), colour pens and big sheets for shared illustrations (1 per concept).

The creative process (inspired by Wallas, 1926 cited by Lubart et al., 2015) was identical for all groups. Our objective was to have a unique procedure that would be applicable to adults, children and iparticipants with visual disability in terms of comprehension, simplicity and duration. The overall structure of the session followed classical brainstorming steps (Osborn, 1953), namely a diverging step dedicated to a fluent generation of ideas and idea-sharing, and a convergent step to evaluate the creative productions.

Ideas generation started with the facilitator delivering the fundamental rules for idea production: (1) suspend your judgment (no critics, no approvals, no judgment, do not destroy the morale of the group, no evaluation), (2) the wildest imagination is welcome, (3) quantity over quality and (4) freely associate your ideas with each other. These rules remained on the wall throughout the session.

Afterwards, the facilitator presented each concept to be illustrated: the target concept was written on a shared screen (for adults and children groups) and read by the facilitator (for all groups). For each concept, the process was the following:

- **Individual phase** (4 minutes): participants were instructed to draw as many drawings of a concept as possible on a sheet of paper . They could use colours as they wanted. Blind people thought to the graphical representations without drawing, but some of them tried to draw.
- **Collective phase** (2 minutes): after the individual phase, sighted participants (adults and children) gathered around a big sheet to draw the most number of propositions together (Figure 4). They could reproduce their individual propositions but were encouraged to draw shared propositions and to enrich them. For blind participants, the facilitator drew based on the participants' descriptions and discussions.
- **Evaluation phase** (2 minutes): to finish, each participant had to evaluate which production(s) were the most typical for each concept. We used the dot-voting method as it is a common method in design sprint. Each participant was provided, for each concept, three coloured stickers' to distribute on 1 to 3 collective proposals. The criteria for votes was to choose the most typical graphical representations from the collective phase. For blind participants, facilitator attributed stickers to concepts based on the participants' instructions. This phase was rapid to get participants to do the vote as spontaneously as possible.

This process of individual and collective productions and evaluation was repeated for each concept.

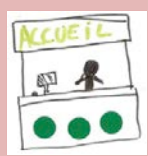
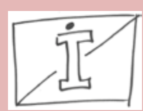
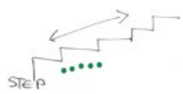
Data collection

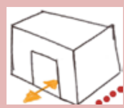
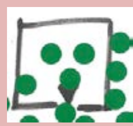
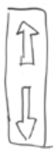
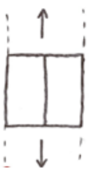
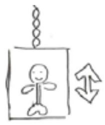
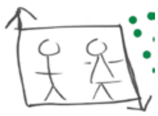
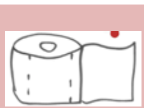
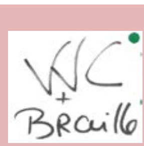
We first analyzed qualitatively collective productions. Then, for each concept, we identified the main idea, the percentage of votes assigned and a typical graphical representation. Our selection criteria were the originality of the idea and the possibility to transpose the drawing into a visuotactile pictogram, which requires considering details and dimension.

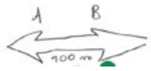
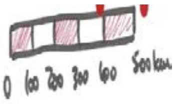
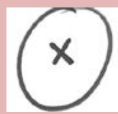
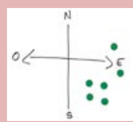
Results

In total, 2208 graphical representations were proposed, including 1758 individual and 450 collective ones. Table 5 shows the main ideas (pictograms for those which that the most votes), the percentage of coloured stickers assigned and a typically associated image. The concept “scale” was considered secondary and was not submitted to people with visual disability in order to make the session a bit shorter for them.

Table 5. Graphical propositions and percentage of votes for each group and concept.

Concepts	G1 Adults	G2 Adults	Children	Visually Impaired
Reception	 human 50%	 human + « i » 41,7%	 human 50%	 « i » 27,8%
Stairs	 profile stairs+			

Concepts	G1 Adults	G2 Adults	Children	Visually Impaired
	arrows 61,1%	profile stairs + human 58,3%	profile stairs 66,7%	profile stairs 61,1%
Access	 Arrow + door 38,9%	 Arrow + door 37,5%	 Arrow + door 50%	 Arrow + door 83,3%
Lift	 button+ arrow 33,3 %	 lift shaft+ arrows 75%	 lift shaft +arrow + human 100%	 lift shaft + arrow + human 50%
Toilets	 toilet paper 44,4%	 woman / man 41,7%	 WC 33,3%	 WC + Braille 61,1%

Concepts	G1 Adults	G2 Adults	Children	Visually Impaired
Scale	 ruler 44,4 %	 ruler 70,8	 Ruler 50%	/
You are here	 target 77,8%	 target 91,6%	 target 50%	 target 72,2%
Restaurant	 plate + culteries 22,2%	 culteries 12,5%	 burger 50%	 cutleries 61,1%
Wind rose	 wind rose 94,4%	 wind rose 37,5	 wind rose 33,3%	 wind rose 94,4%

Graphic representations proposed and retained are more figurative than those from our initial set of pictograms. Nevertheless, among the four groups, participants with visual disability' proposals are the least figurative and are coupled with text. These results are in line with those of Study 1, since the pictograms that had not been recognized by sighted participants were the least figurative ones (and the most effective tactilely).

For each concept, our observations are:

- *Reception/information point*: in adults and children representations, there was a human, whereas in people with visual disability representation the letter "i" for "information point" was used. We decided to keep the letter "i" because it is the only proposal compatible with transposability criteria and is one of the few pictograms to be standardized (ISO 7001, 2007). It was also well recognized by adults (study 1). The main limitation of this proposal is that the corresponding pictogram was not understood by children (study 1).
- *Stairs*: all participants represented profile stairs. This representation seems a perfect alternative to stairs seen from the above, which was not recognized in Study 1.
- *Access*: All groups proposed an arrow through a door. We retained this idea but removed the perspective used by Group 2 of adults and children. Arrows alone were not recognized in study 1, and study 3 shows the importance of the context: the door gives direction to the arrow.
- *Lift*: up and down arrows are present in all groups' representations. Children and people with visual disability added humans to the abstract arrows. We decided to keep arrows because, in study 1, children confused "lift" and "toilets" when lift included humans. Moreover, arrows are tactilely more compatible with transposability criteria.

- *Toilet*: adults proposed figurative representations, whereas children and people with visual disability proposed an arbitrary one (WC); we kept the latter representation.
- *Scale*: all groups proposed a graduated scale. We retained the idea to display a segment and add numbers in black and Braille above it.
- *You are here*: the notion of "target" arose in all 4 groups, therefore we decided to propose a target pictogram, assuming that adding volume would further help users understand that it means "you are here".
- *Restaurant*: adults and people with visual disability proposed cutleries (knife and fork) to illustrate this concept, which is similar to one of Study 1 pictogram that was well understood by both adults and children. We decided to keep the knife and the fork.
- *Wind rose*: all groups proposed a wind rose to illustrate the concept. This result confirms those of Study 1. We retained the wind rose with the indication of North.

Another observation is that participants mostly used the black colour to draw while markers of all colours were available to them. This result is also consistent with Study 2 results.

Design of new pictograms

In respect of the first four principles of Universal Design (i.e., equitable use, flexibility in use, simple and intuitive use and perceptible information) and based on the joint results of Studies 1 and 3, we selected for a new set of visuotactile pictograms the ideas that were likely to meet the following criteria: (1) be suitable for the maximum of users (sighted and visually-impaired adults, sighted children) and (2) comply with transposability criteria (dimension, perspective, simplicity and discriminability).

To facilitate the understanding of pictograms by users, we chose two manufacturing methods to display them. Indeed, following our experience, some pictograms are landmarks: to structure space, so they were manufactured by 3D printing (pictograms in volume), and pictograms judged as secondary were printed through UV injection (pictograms in 2D $^{1/2}$). 3D printing produces pictograms that measure up to 6 mm of height, and UV injection produces pictograms at a maximum height of 2 mm.

Pictograms for 3D printing

Pictograms manufactured in 3D printing (Figure 3) were:

- you are here represented by a target in red,
- reception (information point) represented by the letter "I" in black on white background surrounded by a black circle,
- stairs represented by three stair steps,
- access represented by an arrow pointing to the right,
- toilets represented by the letters "WC" in black on whithe background,
- lift represented by two arrows one below the other.One from the top point up and one from the bottom point down.

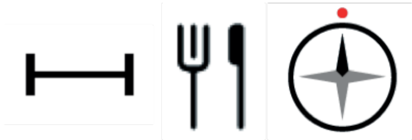
Figure 3. 3D printing's pictograms, left to right: you are here, reception (information point), stairs, access, toilets, and lift.

Pictograms for UV injection

Pictograms manufactured in UV injection (Figure 4) were:

- scale represented by a segment,
- restaurant representd by a fork and a knife,
- wind rose represented by a wind rose with the indication of North.

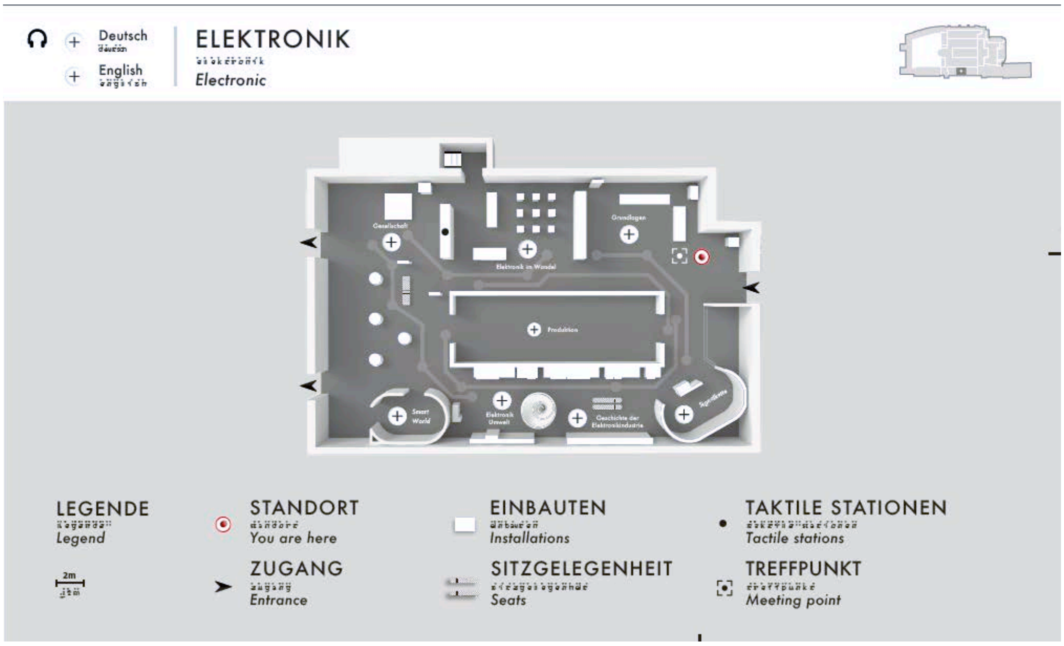
Figure 4. UV injection's pictograms, left to right: scale, restaurant and wind rose.



Integration into a test orientation map

Some of these new pictograms (you are here, stairs, scale, and access) were integrated into a project in Germany with the *Deutsches Museum* (Figure 5) to test their efficiency. The aim was to design orientation maps for each space of the Museum. These maps are visuotactile and include audio, to give information about the content of the exhibition rooms.

Figure 5. New pictograms tested at the Deutsches Museum (the orientation map is rectangle. The title is at the top left with the audio button; the room plan is at the center wit the legend below. The text is in black and Braille).



The orientation map was tested with both sighted and visually-impaired German adults in the Museum. Participants with visual disability (n=20) were mainly born blind, and they were between 50 and 60 years old. Researchers did an unstructured open observation to collect data. Each participant explored alone the orientation map for 15 minutes. Participants put the audio headset and listened to the instructions while they explored the orientation map with their fingers. Participants were guided by the audio information to explore the orientation map. Results of the user tests showed that all pictograms inserted in the map were recognized and understood by sighted and visually-impaired participants. We nonetheless observed several limitations related to the display of pictograms in volume. First of all, when pictograms are printed in high volume, there is no more hierarchy in the information. However, this process is fundamental to enable blind users to understand the most important information first (Boisadan et al., 2016). In particular, the "you are here" pictogram should be the first one to be identified by users because it enables them to structure their mental representation of space and locate themselves in the environment. Nevertheless, the new 3D pictograms representing stairs is higher than the "you are here" pictogram was identified in first. Therefore, new adjustments should be found to optimize the use of volume to foster spatial cognition for blind users.

Conclusion and perspectives

This research aimed to design universal visuotactile pictograms, which still represents a challenge faced by the society as a whole (to allow social participation of all, including people with disabilities) and by many companies and institutions (to provide accessible orientation maps to their customers and visitors). The first main challenge is the absence of standardization for graphical pictograms to be used in orientation maps. Secondly, should such standards exist, they may not be designed to comply with transposability criteria and be used as visuotactile pictograms. Guidelines for tactile information design remain very limited (ETSI, 2002). In this context, the present research provides two main contributions, namely a methodological one and a practical one (sets of pictograms).

The methodological contribution concerns the process of designing universal products. In the present research, we had the opportunity to test two approaches (Plos et al., 2012), a top-down adaptive one, and a bottom-up proactive one, and our results clearly support the latter. More specifically, the first set of visuotactile pictograms evaluated in Study 1 were designed by experts to meet the special needs of blind users, in order to test the possibility of extending their use to the general population. This top-down process appeared insufficient since most of these pictograms were not recognized by sighted users. Orientation maps with such pictograms cannot be universal. To redesign universal visuotactile pictograms, we conducted creativity workshops (study 3) with sighted adults, sighted children and adults with visual disability. Our objective was to find shared signifiers, also considering the mental representation of the three categories of users, which corresponds to a bottom-up approach. In our specific case, this process proved more effective. While the top-down approach had led to pictograms that were too specific, the bottom-up approach enabled us to consider cognitive abilities, needs and expectations of different target groups in pictogram design and meet their requirements.

The practical contribution corresponds to the series of pictograms used in our three studies. In this respect, both those which were validated and those which were not may be of interest to practitioners and sign makers. Pictograms that were not recognized in Study 1 may help practitioners question their choices and avoid some design mistakes. For example, it was particularly interesting to observe confusions between “lift” and “toilets” pictograms in children’s answers. Study 2 addressed the sub-question of the influence of colour on pictogram interpretation. The expected effects of red and green colours were confirmed by the results, but this study also highlighted subtler differential effects of colour as a function of the pictogram. For example, the red colour massively influenced some interpretations (e.g., the “Toilets” pictogram) but did not alter other ones (e.g., “You are here” or “Lift” pictograms). These results would need to be consolidated and replicated on larger and more diverse samples of populations, including various cultural backgrounds. However, they may nonetheless provide design insights to sign makers. Finally, the creativity workshops conducted with adults, children and participants with visual disability also highlighted original results, for example, that mental representations of orientation concepts are partly shared by these three categories of users. More research is still necessary to refine our pictograms, but Study 3 results tend to suggest that the general purpose of designing universal visuotactile pictograms may be achievable. Some challenges remain to be addressed, such as the sometimes antagonist specifications arising from children, who tend to prefer figurative pictograms, and blind users, who may prefer abstract or arbitrary representations.

We observed three methodological limitations of this research. The main limitation of this series of studies is the lack of cultural variability we were able to account for. The three studies were conducted in France, which surely may have influenced the results. Although the final test of the pictograms was conducted in Germany, we are aware of the magnitude of the task ahead to test and refine our pictograms based on feedback and ideas of people (both sighted and visually impaired) from all around the world.

The second limitation concerns study and the process to determine if interpretations of pictograms by participants are correct or incorrect. It was a subjective evaluation by ourselves. In future research, we will use three “judges” who will blindly assess the interpretations. Judges will come from various contexts (for example sign makers or researcher) and/or different culture.

Finally, the last limitation is about the dot voting process used in study 3. We asked participants to choose the most typical representations of each concept. We did not stop participants voting for their own-drawing or the most attractive drawing and not for the most common. In addition, various practitioners (for example see the article of Anderson, 2019) have raised some limits of this method such as familiarity bias, influence by others, or vote-splitting. Similar to the previous limitation, we could submit collective propositions to external judges (for example sighted and blind from France and others countries) and ask them to evaluate proposition through different criteria such as the most original, universal, or the most representative.

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