DigitalWorld 2012

January 30 - February 4, 2012 - Valencia, Spain

ISBN: 978-1-61208-015-4

ICDS 2012
The Sixth International Conference on Digital Society

ACHI 2012
The Fifth International Conference on Advances in Computer-Human Interactions

GEOProcessing 2012
The Fourth International Conference on Advanced Geographic Information Systems, Applications, and Services

eTELEMED 2012
The Fourth International Conference on eHealth, Telemedicine, and Social Medicine

eL&mL 2012
The Fourth International Conference on Mobile, Hybrid, and On-line Learning

eKNOW 2012
The Fourth International Conference on Information, Process, and Knowledge Management

CYBERLAWS 2012
The Third International Conference on Technical and Legal Aspects of the e-Society

ACHI 2012

The Fifth International Conference on Advances in Computer-Human Interactions

ISBN: 978-1-61208-177-9

January 30- February 4, 2012

Valencia, Spain

ACHI 2012 Editors

Leslie Miller, Iowa State University - Ames, USA

Silvana Roncagliolo, Pontificia Universidad Católica de Valparaíso, Chile

ACHI 3: Usability and Universal Accessibility II

Building Bridges Between Elderly and TV Application Developers

José Coelho, LaSIGE, Univeristy of Lisbon, Portugal
Carlos Duarte, LaSIGE, Univeristy of Lisbon, Portugal
Pedro Feiteira, LaSIGE, Univeristy of Lisbon, Portugal
Daniel Costa, LaSIGE, Univeristy of Lisbon, Portugal
David Costa, LaSIGE, Univeristy of Lisbon, Portugal

Analysis of Volumetric Tactile Symbols Produced with 3D Printing

Jaume Gual, Universitat Jaume I, España
Marina Puyuelo, Universitat Politecnica de Valencia, España
Joaquim Lloveras, Universitat Politecnica de Catalunya, España

Ethnographic Examination for Studying Information Sharing Practices in Rural South Africa

Amandeep Dhir, Aalto University, Finland
Imad Moukadem, Gulf University for Science and Technology, Kuwait
Nobert Jere, University of Fort Hare, South Africa
Puneet Kaur, Aalto University, Finland
Sari Kujala, Aalto University, Finland
Antti Ylä-Jääski, Aalto University, Finland

Accessibility Study of Rich Web Interface Components

Juliana Braga, Federal University of ABC, Brazil
Rafael Damaceno, Federal University of ABC, Brazil
Rodrigo Leme, Federal University of ABC, Brasil
Silvia Dotta, Federal University of ABC, Brazil

Virtualization Technology for Multi-display Systems

Igor Petukhov, Mari State Technical University, Russian Federation
Lyudmila Steshina, Mari State Technical University, Russian Federation
Ilya Tanryverdiev, Mari State Technical University, Russian Federation

Analysis of Volumetric Tactile Symbols Produced with 3D Printing

Jaume Gual
Dept. of Industrial Systems Engineering and Design
Universitat Jaume I, UJI
Castellón, Spain
jgual@esid.uji.es

Marina Puyuelo
Dept. of Graphic Expression in Architecture
Universitat Politècnica de Valencia
Valencia, Spain
mapuca@ega.upv.es

Joaquim LLoveras
Dept. of Engineering Design
Universitat Politècnica de Catalunya
Barcelona, Spain
j.lloveras@upc.edu

***Abstract*— The morphological elements of design used for designing tactile maps and symbols for visually impaired users are points, linear, and areal elements. One of the main characteristics of these elements is their two-dimensional and graphic nature. However, since three-dimensional design came to be a fourth group of elements, volumetric elements, has come into use. The key questions of this study are: Is it possible to extend the range of a discriminatable set of symbols by using volumetric elements with height contrast extended in the Z axis? Can some formal variations of these volumetric symbols be distinguished using the sense of touch? The results of this study show that some tactile symbols with simple volumetric forms are easily recognizable using the sense of touch. In the absence of further studies, this could suggest an affirmative answer to the first research question posed.**

Keywords-tactile symbols; tactile maps; inclusive design; visual impairment

I. INTRODUCTION

This study presents the first results of a doctoral thesis carried out on tactile maps and symbols for the guidance of the visually impaired. The work reported here has been included in a research project from the Universitat Politècnica de València (project DPI2008-03981/DPI), Spain).

Tactile maps, as tangible graphic resources, are a group of devices showing graphic information using relief. Tactile symbols are contextualized within this type of device and are normally used with their corresponding keys. These products help blind people understand the features of the environment around them through the sense of touch.

The use of these devices is almost always combined with audio descriptions to facilitate a correct understanding of the tactile exploration. This means that these resources are not used independently. Thus, the challenge is focused on designing more user-friendly and efficient tactile maps. To achieve this goal it is vital to improve two aspects of the information on these devices, on one hand, user-friendliness [1], and on the other, the interaction with sound outputs. This study focuses on improving the former.

All graphic information can be expressed using different elements in relief. Thus, tangible graphics can represent all kinds of graphs, maps, plans, etc, which are difficult to express through text. As will be shown, there are three elements used to compose the tangible graphics: points, lines, and areas. However, a fourth category of design elements, volumetric elements, are barely used in the design and production of this type of devices, due partly to the conditions of traditional production systems: microencapsulation and thermoforming [2]. The novelty of this work is the study of some possible applications of volumetric elements, basic prisms, specifically in their application as tactile symbols, to improve the usability of tactile maps. The manufacturing technique used in this case to make these symbols is 3D printing which can produce more complex geometries than traditional methods [3].

In contrast, one of the fields of knowledge which has focused most on the issue of tactile devices is that of Cartography and Geography. The integration of other areas, such as Psychology and Education Science, has also paid serious attention to this issue.

From the perspective of product design, it is possible to observe how these products have barely been addressed in depth, despite the fact that the philosophy of Inclusive Design [4] seems an ideal framework to study these objects.

This paper has the following structure:

- Section I. Introduction;
- Section II. Tactile Perception, Typology and Particularities of Relief Maps;
- Section III. Study Description;
- Section IV. Results, and
- Section V. Conclusions and Further Work.

II. TACTILE PERCEPTION, TYPOLOGY AND PARTICULARITIES OF RELIEF MAPS

On the other hand, tactile perception is a relatively new field of study. David Katz was a pioneer and in 1925 published a classic monograph on the subject, Der Aufbau der Tastwelt (The world of touch), which laid the foundation for later studies [5]. These early studies give us a better understanding of the attributes and characteristics of the sense of touch and enable us to design more efficient tangible graphics.

There are different types of tactile maps used for communicating and teaching geography, and also orientation skills, to facilitate movement through certain environments. According to Edman [6], these products can be classified as:

- Mobility Maps;

 ISBN: 978-1-61208-177-9

- Topological Maps;
- Orientation Maps;
- General Reference Maps, and
- Thematic Maps.

It should be noted that the usefulness of these types of devices in facilitating mobility, spatial orientation, and the autonomy of visually impaired people has been clearly demonstrated in previous studies [7][8][9].

However, reading a tactile map also depends on the skills, strategies of exploration, experience, and training of the people using it [10]. These factors allow blind users to recognize the information offered in a tactile product more accurately and effectively, even in real contexts [11]. Another important aspect in blind users is haptic memory, since a blind person explores tactile graphics in a sequential way. In contrast, the phenomenon of visual perception is simultaneous and less time is required to assimilate the same amount of information [12]. This means that the design of tactile devices should be simple, with less information than in the visual version.

Finally, the contexts for the use of tactile maps can be varied, depending on map format and user preferences. These can be previously used at home or at a specific location with the support of a Mobility Instructor. There are even some formats that are portable and can be used in situ. Some studies show that blind users prefer to use them at home, in their own time [13].

A. Inclusive Design and Usability

Generally, in order to make this type of product easy to use, and taking into account that tactile perception is not as sharp as visual perception, any tactile-graphic device must contain synthesized information in order to ensure it is easily legible using the sense of touch. If the tactile device includes corresponding visual information, such as colour contrasts or large type, adapted to the specific requirements of other groups, the number of users that may benefit from it may grow to include, for example, the elderly or partially sighted, in keeping with the philosophy of Inclusive Design [4].

There are general requirements that must be mentioned now in order to acknowledge the specific nature of the design process for these products for the sense of touch. However, there are no set criteria and the general requirements greatly depend on the specific experience of each designer.

The maximum size of any tangible graphic must be designed taking into account the space needed using both hands together. A comfortable hand position would include an area approximately the size of an A3 sheet, although maps may be bigger or smaller based on the different formats and types of information to be represented. On the other hand, the scale is conditioned by the constant dimensions of Braille code and the purpose and type of information to be represented. The minimum distance between the elements represented, such as the symbols of a map, must be carefully designed. A minimum separation of 3 mm is needed between elements so they can be recognized using the sense of touch. In any case, these data only represent a small part of all the requirements studied for the design of a correct tactile map. Extended and more detailed information can be found in reference publications [6] [14] [15].

However, most of the design guidelines published for relief maps are focused on the traditional methods of production, rather than on the techniques used in this study: 3D printing from Rapid Prototyping (RP).

B. Manufacturing systems of tactile maps. Rapid Prototyping

There is extensive literature on the manufacture of tactile maps in the field of geography. The usual methods of production are thermoforming of plastic sheets (Fig. 1) and microencapsulation (Fig. 2) [2] [16].

It is important to mention the possibilities opened up by RP for blind people, producing pieces from virtual Computer Aided Design (CAD) models. According to some studies, three-dimensional configurations can improve visually impaired people's understanding of these products [17].

In any case, these techniques enable the production of single pieces or small series in a relatively short time compared to traditional systems of production. Hence their name of 'rapid'. At the same time, they can be used in the early stages of production as master models, that is to say, as preliminary prototypes for long series.

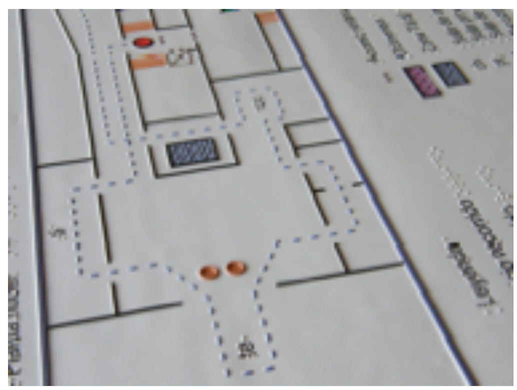

Figure 1. Thermoform copy.

Figure 2. Microencapsulated copy.

But, the main novelty of techniques, such as 3D printing, for the production of tactile maps is the possibility of introducing complex geometries and polychromed pieces. In contrast, the usual techniques employed in the production of tactile maps, thermoforming and microencapsulation, are somewhat limited in this respect. One of the main disadvantages is their poor surface quality, which makes the model rough to the touch, although this can be corrected with subsequent surface treatments, although so far this implies high costs when producing long series. There have been several previous experiences in the field of haptic devices, especially for the field of tactile scale models [18] [19] [20], but also with tactile maps [21].

C. *Morphological elements for designing tactile maps*

According to the literature, there are three morphological elements for designing tactile maps, tactual symbols, or any tangible graphic for the visually impaired [6] [22] [23]:

- Points
- Lines
- Areas

But, if we concentrate on the fundamentals of design, it is apparent that these three types of elements are also called visual or conceptual design elements [24] [25]. Specifically, they are employed in the world of graphic design. The common denominator of these elements is their two-dimensional nature, that is to say, the fact that they are expressed in visual formats within the two dimensions of a flat framework.

However, it is also known that when product designers work in a three-dimensional space, i.e., when objects are represented in relief or in three dimensions, light and volume play a special role. Light models dark bodies and allows a clear perception of volumes in space. Thus, volume is commonly known as the fourth element of conceptual design and can be perceived using the sense of touch.

D. *Symbology in relief maps*

The symbology of tactile maps has been widely studied in the above mentioned disciplines, particularly Cartography [26]. Recognition, legibility, and discrimination of symbols are the factors that various studies have taken into account to verify the usability of these sorts of products and their efficient use in maps [15] [27] [28].

Standardization of tactile symbols is an issue demanded by those involved but at the same time, it is proving controversial, given the difficulty in reaching efficient agreements. On the one hand, there have been efforts as proposed in the International Conference on Mobility Maps in Nottingham in 1972 [29] and, on the other, some countries such as Australia [30], Brazil [31], and Japan [32] among others, have adopted or are in the process of adopting specific standards.

Beyond the difficulties in the standardization of tactile symbols, in this case, some design considerations in its use should be noted. In his manual, Edman talks about point, linear, and superficial symbols. Each of these types is used to present specific information. In mobility plans, point symbols represent specific locations, lines can express direction and guidance, and superficial symbols cover certain areas. All these symbols are informative and can be categorized as ‘flat symbols’, which are in fact those used most regularly at present.

In summary, and from the point of view of design and usability, the difficulty of identifying symbols in a map increases with the amount included. Therefore, the use of symbols in a map is always the minimum possible: if more than 6 symbols are included a blind person could have trouble memorizing them. The space between symbols should be no less than 3 mm to ensure proper differentiation in relief. It is best not to use similar symbols together as they may be confused, for example, two circles of similar sizes, one outlined, and the other filled in. The minimum size for a symbol to be recognized is around 5 mm. These are just some of the considerations cited by Edman [6].

However, the representation of symbols on conventional tactile maps follows the guidelines of using the three design elements mentioned above, which are part of an essentially two-dimensional nature and are exposed to the sense of touch by the slight elevation.

However, other areas of knowledge such as ergonomics [33], also focused on the study of displays adapted to human use, show that it is possible to use volumetric elements in tasks where one of the requirements is a high degree of tactile discrimination. This is the case with the controls of an airplane which should be distinct and discriminatable to touch in order for pilots to avoid fatal errors. These controls use keypads which the discipline of ergonomics studies from the standpoint of efficiency of use [34].

III. STUDY DESCRIPTION

A. *Objective and contextualization*

The research team planned a series of tests to select a range of easily identifiable and legible volumetric symbols using the sense of touch.

Thus, the main objective of these tests was the selection of a series of three-dimensional symbols easily identifiable using the sense of touch. As a starting point, basic solid figures were chosen by the authors, taking into account that the literature barely deals with these shapes used as tactile symbols. This also followed some earlier studies carried out by the authors suggesting the possibility of this line of research [35] [36]. This is the main innovation in this study.

This selection of symbols will be used in further works in order to determine if this type of symbol can be useful in the configuration of tactile maps.

In contrast, this work focuses only on the study of shape and size factors and does not examine texture and surface quality, resistance, production, cost, or other possible factors that could be of interest in future studies or research.

B. *Methodology*

The methodology used for data collection is fundamentally based on the use of tasks with users and prototypes (mock-ups) [37]. In addition, qualitative research techniques and direct observation [38] are used.

C. *Material used in the study*

The material used in this study has been produced using 3D printing. In order to improve the surface quality of this system, a thin transparent acrylic layer was applied to the

 ISBN: 978-1-61208-177-9

surface of the tactile symbols. However, it must be emphasized that the study does not attempt to tackle the differences in surface texture, but the differences in shape and size.

Fifteen categories of tactile symbols have been designed and analysed, with eleven of these categories belonging to volumetric elements while the rest are flat elements.

Elementary forms like spheres, cubes, rectangular prisms, cylinders, pyramids, inverted pyramids, cones, inverted cones, and rings (hollow cylinders) have been used in the design of the category of volumetric symbols. As regards the category of flat symbols, the ‘U’, ‘L’, ‘V’ and ‘O’ shapes, some of these are shown in Fig. 3. The proportion of some simple shapes (cylinder, pyramid, rectangular prism, etc.) used in this study were chosen using direct ratios (1, 1/2, or 1/4, or their respective multiples), as for example, in the case of the rectangular prism, 1 × 2 × 1.

In addition, a select group of symbols has been generated using some formal variations, adding complexity to the initial form: angled cut, angled concave cut… in order to assess the users’ ability to identify added features using the sense of touch (Figs. 4 and 7).

In addition, to determine the minimum sizes recognizable, each category of symbols has also been represented in a reduction scale of three different dimensions at the base (0.25; 0.5, and 0.75 cm) (Fig. 5). Following Edman’s recommendations a standard size of 5 mm was considered [6] (Figs. 5 and 6).

All symbols were coded according to their geometry, size, and additional features, and presented on a white 20x20 mm square base.

Figure 3. Sample of symbols used in the study.

Figure 4. Sample of formal variations to add complexity to some symbols. The picture shows simple shapes on the left (sphere and rectangular prism), incline cut operations in the centre and concave cut transformations on the right.

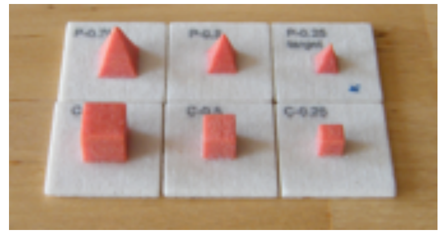

Figure 5. Sample of reduction scale of pyramid and cube.

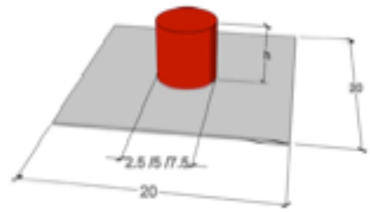

Figure 6. Sample of symbol dimensions on square base (millimeters).

D. Test content

Tests consisted of verbal descriptions of the symbols while participants touched the 80 symbols one by one. This assumed that if a symbol is verbally describable, then it will be perceptible and recognizable under other conditions using the sense of touch. The correct answer rates for the 80 symbols were measured.

E. Sample and user profile

A sample of 23 participants, 22 blindfolded and one blind user, performed the test. The age range of participants (12 male and 11 female) was from 25 to 55 years old.

F. Test procedure

The research team showed participants the symbols one by one, asking them to provide verbal descriptions. The symbols were shown in no particular order until all 80 had been completed. Each symbol was shown on its base. Participants were seated in a comfortable and relaxed position. Users could rotate and manipulate them freely, but not pick them up off the surface of the table.

The description had to be as precise and short as possible. The research team ensured, when beginning the test, that users knew the nomenclature of the geometric shapes in order to refine the description and avoid misunderstandings. In addition, the research team provided participants with a brief introduction to the kind of forms and shapes that they were likely to find, also warning them that some symbols had additional features which participants were to describe if they perceived them.

Participants could use analogies to describe the perceived forms. There was no time limitation, although participants were invited to get the task over with quickly. The research team only intervened with encouraging comments, without providing clues. All the descriptions of symbols which did not adjust to the features were considered errors. Moreover, if participants did not perceive and describe the formal variations of some symbols with additional features, the research team also considered this an error. The average time spent on the test was around 50 minutes per participant.

G. Record

The test was recorded in summary reports and Excel spreadsheets. Summary reports included some interesting comments for the study. Some details were collected using direct observation, including gestures and individual exploration strategies.

IV. RESULTS

After carrying out the process with all 23 users, the highest percentage of correct answers occurred in single symbols, i.e., those not including special features (more complex and with additional information). Symbols with angled and concave cutting operations generally produced a greater number of errors, while the angled cutting operation had a greater average of correct answers than the angled concave cutting (Fig. 7). In three cases with symbols with formal variations, the cylinder, the 'U', and the 'L', these reached equal or better results than their corresponding simple versions (Table 1). The concave cut tended to be confused with the angled cut, especially in small-scale symbols. As the graphs for symbols measuring 0.75 cm per side (Fig. 8) and 0.5 cm (Fig. 9) show, it is possible to appreciate a pattern in which the symbols with no formal variation have a greater amount of hits.

Moreover, in the second graph of 0.5 cm, compared with the first graph, it is possible to appreciate a slight decrease in hits due to the loss of tactile acuity resulting from the reduced scale of the symbols. The figures show discontinuities as formal variants were applied only in some cases, as explained above, in order to reduce the number of symbols in the tests or prolonging these excessively.

Thus, as regards the size of the tactile symbols, the general pattern was that a larger size of symbol produced fewer errors of perception (Fig. 10). Some of the symbols tested – the rectangular prism, the cube and the 'V' – obtained better results in the small versions than in the larger ones, although the differences were minimal.

The best described volumetric symbols were the pyramid, the ring (100% of correct answers in all sizes), and the thin cylinder, although the cube and the rectangular prism also produced a high index of correct answers. Generally, all of the symbols mentioned were described quickly and spontaneously. Cylinders tended to be confused with cones due to their similar rounded shape, but the reverse was not the case. Pyramids were distinguished from cylinders and cones thanks to the tactile reading strategy of detecting the edges of the pyramid. Symbols ending in a point were spontaneously distinguished when fingertips touched a pointed form. Spheres had a relatively high error rate, and were often described as a cylinder with a rounded head, errors increasing with the reduction in size. Cubes produced some perceptual illusions as when describing them some participants thought they had unequal sides. Inverted shapes, as is the case of inverted cones or pyramids, produced relatively greater numbers of errors than their corresponding forms in their usual positions, although the larger sizes (0.5 and 0.75 cm side) did produce a higher index of hits: 91.30 %. Using the fingertips to access the lower part of these forms with smaller bases, was a key factor in recognizing them.

As regards the flat symbols, all had an optimum success rate. The least number of errors occurred with the circles ('O') and the 'V' shapes. There was a tendency for 'U' to be confused with 'V', as one of the lines could not be perceived, or alternatively, in the case of small-scale symbols, with two parallel lines. 'L's with equal sides caused perceptual illusions, as some users perceived one side higher than the other.

Finally, through direct observation, some significant hand gestures have been detected while participants were exploring using the sense of touch. An example of this is the strategy of pinching with several fingers to feel the height in order to distinguish the symbol. This occurred when users explored volumetric symbols such as the thin cylinder, pyramid, or cone. This strategy allows greater precision when distinguishing some tactile forms [33]. On the other hand, some forms were even detected spontaneously through feeling the point with their fingertips, as is the case, for example, of pyramids and cones with pointed tops.

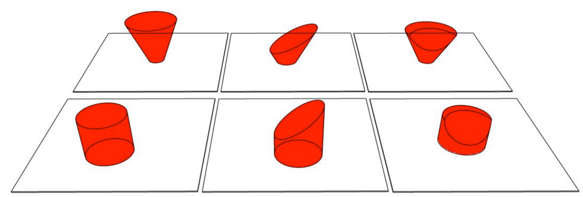

Figure 7. Sample of shape variations of tactile symbols. On the left, simple cylinder or inverted cone shapes; in the centre, shapes with an angled cut; on the right, shapes with an angled concave cut. The last ones obtained the worst rates.

TABLE I. DIFFERENCES OF AVERAGE BETWEEN SIMPLE AND COMPLEX SHAPES FOR SET OF 0.5 CM SYMBOLS

Sample of Tactile Symbols	**Correct answer rates (%)**		
	Simple shape	***Inclined cut***	***Concave cut***
Sphere	91.30	56.52	*
Rectangular prism	91.30	82.61	68.18
Cylinder	91.30	91.30	*
Inverted cone	91.00	*	65.22
L	73.91	82.61	17.39
U	82.61	82.61	26.09
V	95.65	56.52	52.17
Total	**88.20**	**75.36**	**50.49**

* Not all the variations were tested for all the sizes in order to reduce the duration of the user test to 50 minutes.

 ISBN: 978-1-61208-177-9

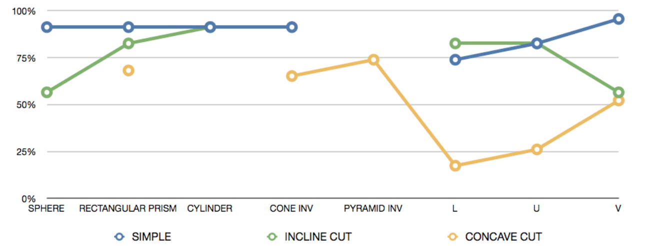

Figure 8. Percentage of correct answers for symbols with formal variations: simple, angled cut, and concave. It shows how simple symbols produced better results.

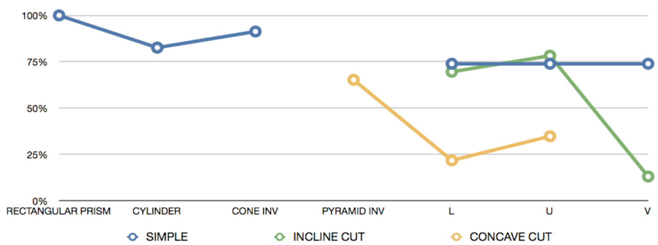

Figure 9. Percentage of correct answers for symbols on different scales. The graph shows a decrease of correct answers compared to figure 8.

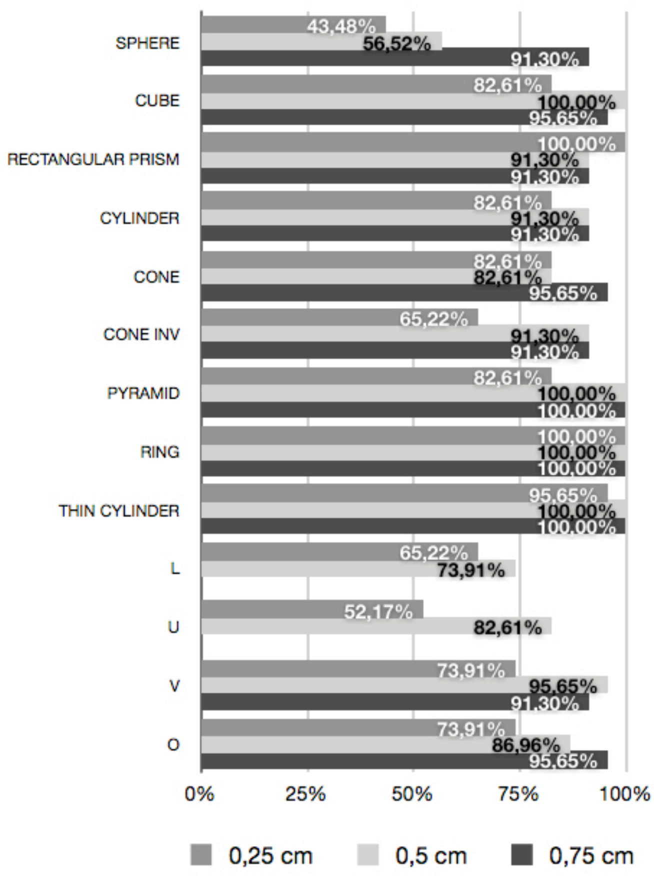

Figure 10. Percentage of correct answers comparing tactile symbols of different sizes.

V. CONCLUSIONS AND FURTHER WORK

A first conclusion is drawn from the results obtained: given the amount of errors in identifying tactile symbols with formal variations, simple volumetric symbols are more easily perceptible to the sense of touch than complex symbols, thus answering the second research question proposed at the start. This could indicate that, in this case of tactile perception, it seems to fulfil the visual gestalt principle of simplicity.

Furthermore, as expected, larger symbols were more easily identifiable than small symbols. There were no significant variations between the symbols measuring 0.5 cm and 0.75 cm square. Although three of the symbols – the rectangular prism, the cube and the 'V' – seem to have an optimum size of less than 0.75 cm, it would be interesting to study this phenomenon in depth in later studies, as certain larger shapes may produce unexpected results outside the general pattern.

However, in the 0.25 cm square symbols, the number of errors increased significantly. This leads us to the conclusion that a size of 0.5 cm square or larger may be appropriate for the design and implementation of three-dimensional symbols in future tactile maps. After analysing the data collected, the best volumetric symbols have been: pyramid, thin cylinder, cube, and rectangular prisms. These presented 100% correct answers in at least one of three sizes.

Regarding two-dimensional symbols, the circle 'O' and the 'V' achieved optimal hit rates. The flat symbols could be placed on a second level of volumetric accuracy after those mentioned above, but with no significant differences.

Some of the gestures observed during the tests with users, for example, the way in which fingers are used to pinch and explore some volumetric symbols, could be an interesting subject of study.

The fact that some forms have been detected, even spontaneously, thanks to certain formal attributes could open future paths of experimentation in terms of strategies for the exploration of tactile maps. One such example is the effect of pinching fingertips when examining volumetric forms such as pyramids, cylinders, or thin cones. This fact suggests that these sorts of symbols could be used as point symbols. Also, the process for scanning relief maps with volumetric features requires specific strategies that have no place in flat formats.

In addition, certain perceptual illusions detected during the experiment suggest that some curious phenomena, known in detail in the field of visual perception, also play a part in the sense of touch. In future work it would be interesting to study the differences in the proportion of the different solid shapes, for example, the ratios for correctly distinguishing a rectangular prism from a cube.

Regarding the first research question posed, the results of this study suggest that it would be possible to extend the range of discriminatable symbols to include the category of volumetric symbols within the current set of symbols, specifically some basic prisms, which are apparently easily identifiable. Although we must add that it is still early to assert this claim rigorously, and it is necessary to test these symbols in future volumetric tests, for example, in context in real tactile maps with different symbols close to each other, and not just isolated like those in this study. The optimal distance for correctly distinguishing the set of symbols when these are employed together should also be taken into account.

Thus, the authors assume that these two categories of symbols, 'flat symbols' and 'solid shapes', are difficult to confuse with each other, and would therefore be easy for the users to memorize when used together. Therefore, it would be possible to use more than 6 symbols per key or, at least, to use 6 symbols per key with formal differences that would allow us to avoid discrimination mistakes when using a tactile map. Further studies should deal with the maximum amount of tactile symbols that can be used in a map key to be memorized by users, including those discussed here and those proposed by the authors.

Thus, following the completion of this first trial, further works are pending to clarify the initial. Some of these works have already started in pilot mode using an improved sample of visually impaired persons, showing some initial positive results (Fig. 11).

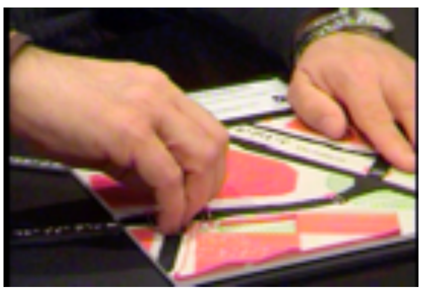

Figure 11. Pilot study of 3D symbols on relief maps.

ACKNOWLEDGEMENTS

The work reported here has been a part of the research project *'Estudio y diseño de elementos de orientación, soportes de comunicación y otros accesorios para la mejora de la accesibilidad en distintos ámbitos de interpretación del patrimonio natural y/o construidos'* supported by the Spanish Ministry of Science and Innovation (project DPI2008-03981/DPI). The authors wish to thank the *Centre de Recursos Educatius* (ONCE) and the *Associació Discapacitat Visual Cataluña B1+B2+B3*, Barcelona, for supporting this research. Finally, this work has been supported by the *Programa de Mobilitat del Personal Investigador de la Universitat Jaume I* (E-2010-32) and the *Fundació Caixa Castelló-Bancaixa.*

REFERENCES

[1] AENOR, "UNE-EN ISO 13407, Procesos de Diseño para Sistemas Interactivos Centrados en el Operador Humano", 2000.

[2] J. Rowell and S. Ungar, "The World of Touch: an International Survey of Tactile Maps. Part 1: production", British Journal of Visual Impairment, vol. 21, 2003, pp. 98-104.

[3] C. K. Chua, K. F. Leong, and C. S. Lim, Rapid Prototyping: Principles and Applications, New Jersey: World Scientific, 2003.

[4] J. L. Clarkson, R. Coleman, S. Keates, and, C. Lebbon, Inclusive Design: Design for the Whole Population, Berlín, Germany: Springer-Verlag, 2003.

[5] D. Katz, "Der Aufbau der Tastwelt (The World of Touch). Translated by L. Krueger (1989)", Der Aufbau der Tastwelt (The World of Touch). Translated by L. Krueger (1989), 1925.

[6] P. Edman, Tactile Graphics, New York American Foundation for the Blind, 1992.

[7] J. Lillo-Jover, "Gráficos Tangibles y Orientación en el Invidente", Psicothema, vol. 4, 1992, pp. 429-444.

[8] M. Blades, S. Ungar, and C. Spencer, "Map Use by Adults with Visual Impairments", The Professional Geographer, vol. 51, 2010, pp. 539-553.

[9] C. Spencer and J. Travis, "Learning a New Area with and without the Use of Tactile Maps: a Comparative Study", British Journal of Visual Impairment, vol. 3, 1985, pp. 5-7.

[10] J. Lillo-Jover, "Tacto inteligente: El papel de las Estrategias de Exploración Manual en el Reconocimiento de Objetos Reales", Anales de Psicología, vol. 8, 1992, pp. 91-102.

[11] C. Perkins and A. Gardiner, "Real World Map Reading Strategies", The Cartographic Journal, vol. 40, 2003, pp. 265-268.

[12] S. Ballesteros, "Percepción Háptica de Objetos y Patrones Realzados: una Revisión", Psicothema, vol. 5, 1993, pp. 311-321.

[13] J. Rowell and S. Ungar, "Feeling Our Way: Tactile Map User Requirements- A Survey." Proc. International Cartographic Conference, La Coruña. 2005.

[14] J. Rowell and S. Ungar, "The World of Touch: an International Survey of Tactile Maps. Part 2: Design", British Journal of Visual Impairment, vol. 21, 2003, pp. 105-110.

[15] E. P. Berlá, "Haptic Perception of Tangible Graphic Displays", Tactual Perception: a Sourcebook, 1982, pp. 364-386.

[16] D. McCallum, K. Ahmed, S. Jehoel, S. Dinar, and D. Sheldon, "The Design and Manufacture of Tactile Maps Using an Inkjet Process", Journal of Engineering Design, vol. 16, 2005, pp. 525-544.

[17] L. Thompson and E. Chronicle, "Beyond Visual Conventions: Rethinking the Design of Tactile Diagrams", British Journal of Visual Impairment, vol. 24, 2006, pp. 76-82.

[18] A. Voigt and B. Martens. "Development of 3D Tactile Models for the Partially Sighted to Facilitate Spatial Orientation." Proc. 24th eCAADe Conference (Education and Research in Computer Aided Architectural Design in Europe), Bruselas, 2006.

[19] L. F. Milan and M. G. C. Celani, "Maquetes Táteis: Infográficos Tridimensionais para Orientação Espacial de Deficientes Visuais", 2008.

[20] G. C. Celani and L. F. M. Milan, "Tactile Scale Models: Three-Dimensional Info Graphics for Space Orientation of the Blind and Visually Impaired", Virtual and Rapid Manufacturing: Advanced Research in Virtual and Rapid Prototyping, London, UK: Taylor & Francis Group, 2007, pp. 801-805.

[21] V- Vovzenílek, M. Kozáková, Z. vSt'ávová, L. Ludíková, V. Ruuvzivcková, and D. Finková. "3D Printing Technology in Tactile Maps Compiling." Proc. 24th International Cartographic Conference. 2009.

[22] M. P. Corre-Silva, "Imagen Táctil: una Representación el Mundo", Universitat de Barcelona, 2004 (Thesis).

[23] R. L. Welsh and B. B. Blasch, Foundations of orientation and mobility, American Foundation for the Blind, 1980.

[24] Wong, Wucius, Fundamentos Del Diseño Bi y Tri Dimensional. Barcelona: G. Gili, 1986.

[25] D. A. Lauer and S. Pentak, Design Basics, Wadsworth Pub. Co., 2007.

[26] R. Rener, "Tactile Cartography: Another View of Tactile Cartographic Symbols", The Cartographic Journal, vol. 30, 1993, pp. 195-198.

[27] L. L. Lambert and S. L. Lederman, "An Evaluation of the Legibility and Meaningfulness of Potential Map Symbols", Journal of Visual Impairment & Blindness, vol. 83(8), 1989, pp. 397-403.

[28] D. McCallum, S. Ungar, and S. Jehoel, "An Evaluation of Tactile Directional Symbols", British Journal of Visual Impairment, vol. 24, 2006, p. 83.

[29] G. A. James, "Mobility Maps", Tactual Perception: A Source-Book, 1982, pp. 334-363.

[30] A. D .O. N. Mapping, Symbols for Tactual and Low Vision Town Maps, [Canberra]: The Division, 1986.

[31] R.E. Nogueira and B. Florianópolis-Santa Catarina, "Standarization of Tactile Maps in Brazil".

[32] H. Fujimoto, "Standardization of Display Methods for Tactile Guide Maps for Buildings, Stations and Other Public Facilities." Proc. Tactile Graphics 2005, 2005

[33] S. Pheasant and C. M. Haslegrave, Bodyspace: Anthropometry, Ergonomics, and the Design of Work, Boca Raton: Taylor & Francis, 2006.

[34] M. S. Sanders, Human Factors in Engineering and Design, New York: McGraw-Hill, 1993.

[35] J. Gual, M. Puyuelo,, J. Lloveras, “Universal Design and Visual Impairment: Tactile Products for the Heritage Access”. In 18th International Conference on Engineering Design (ICED 2011), vol. 5, 2011, pp 155-164.

[36] J. Gual, M. Puyuelo,, J. Lloveras, “Three-dimensional Tactile Symbols. Relief Maps for the Visually Impaired”. Proc. 4th World Conference on Design research, Doctoral Coloquium, 2011.

[37] H. Aldersey-Williams, J. Bound, and R Coleman. The Methods Lab: User Research for Design. UK: Design for Ageing Network (DAN), 1999.

[38] B. Laurel, Design Research: Methods and Perspectives, Cambridge, Mass.: MIT Press, 2003.