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ScienceDirect
Interacting with Computers 19 (2007) 121–132
Interacting with Computers
www.elsevier.com/locate/intcom

Haptic recognition of shapes at different scales: A comparison of two methods of interaction

Mounia Ziat *, Olivier Gapenne, John Stewart, Charles Lenay

Pierre Guillaumat Research Center – UTC, Dep. TSH – K102, 60203, Compiegne cedex, France

Received 21 February 2006; received in revised form 23 July 2006; accepted 23 July 2006
Available online 8 September 2006

Abstract

In order to design a ''haptic zoom'', in this fundamental study, we compare two scaling methods by focusing on the strategies adopted by subjects who are using a sensory substitution device. Method 1 consists of a reduction of the sensor size and of its displacement speed. Speed reduction is obtained by a ''human'' movement adjustment (hand speed reduction). Method 2 consists of a straightforward increase in the dimensions of the image. The experimental device used couples a pen on a graphics tablet with tactile sensory stimulators. These are activated when the sensor impinges on the outline of the figure on the computer screen. This virtual sensor (a square matrix composed of 16 elementary fields) moves when the pen, guided by human hand movements, moves on the graphics tablet. The results show that the recognition rate is closely dependent on the size of the figure, and that the strategies used by the subjects are more suitable for method 2 than for method 1. In fact, half of the subjects found that method 1 inhibited their movements, and the majority of them did not feel the scaling effect, whereas this was clearly felt in method 2.

Keywords: Sensory substitution; Zooming interfaces; Personal Digital Assistants (PDA); Haptic perception

1. Introduction

Today, mobile technologies and in particular cellular phones and PDAs (Personal Digital Assistants) occupy an important place in everyday life. Belonging to the category of ''handheld appliances'', PDAs are increasingly used for the multiple services that they offer. Note-taking, spreadsheets, agendas, address books, e-mail, web navigation, multimedia players and the consultation of geographical maps are all applications which one can find on a PDA and also in some cellular phones. However the main drawbacks of these systems include processor speed, storage capacity and the size and the resolution of the screen. These disadvantages limit the amount of information that can be stored and visualized on a PDA.

In addition to the limitations of the traditional WIMP (Windows, Icons, Menus, and Pointing) model, limitations which also afflict nomadic interfaces, the visualization of information on these devices is even more restricted because of their small displays. Visualization models that differ from this traditional model (Beaudouin-Lafon, 2000) would, however, appear to be a solution to this problem. New paradigms of interaction and visualization using a zoom function, such as zoomable user interfaces (ZUIs), have proved to be very relevant for navigation in sign spaces (semantic zoom) and graphical objects (geometrical zoom). Much theoretical, ergonomic and computer science programming research has been carried out regarding the possibility of multi-scale navigation (Bederson et al., 2000; Pook et al., 2000).

Several pieces of research (Bederson et al., 2002; Jern et al., 2003; Kwang and Grice, 2003) have already introduced ZUIs into PDAs, while trying to propose efficient solutions for interaction. People using a zoomable user interface were better at navigating than those using a

* Corresponding author. Tel.: +33 3 44 23 44 23/post: 5146.
E-mail address: mounia.ziat@utc.fr (M. Ziat).
URL: http://www3c.utc.fr/~ziatmoun (M. Ziat).

0953-5438/$ - see front matter
doi:10.1016/j.intcom.2006.07.004

traditional display, for example while shopping on-line or when using an "image browser" (Bederson, 2001). At different levels of zoom there is no need to use scrollbars, since the workspace is infinite in the ZUI and a large quantity of information can be displayed in a small space. The downside is that this multi-scale navigation increases the risk of disorientation, which Jul and Furnas (Jul and Furnas, 1998) called "desert fog". Users often lose track of where they are in the space, and on which level of scale.

One solution to these problems is to add a tactile feedback as an output modality. This has already been integrated successfully in mobile telephony, and several researchers have tried to combine it with various PDA applications (Poupyrev et al., 2002). As an alternative to vibrations, other researchers have chosen a haptic feedback (Lee and Hannaford, 2003). A mobile interface is used in a non-desktop setting. Users may be in locomotion when using their telephone or PDA. Thus a tactile feedback reduces the user's auditory and visual saturation and can transmit information when the user is unable look at the screen or listen to auditory output. For these reasons, and in order to reduce the constraints inherent in PDA use, we focused our research on what we call a haptic zoom. In interaction with a zooming interface (using a classical zoom), the system allows the recognition of digital objects via an interface implementing a tactile feedback. This zoom is directly inspired from devices known as sensory substitution devices. In these devices, the signals from an artificial sensor (for example a camera) are transformed into stimuli for a natural sensor (for example the skin). In other words, sensory substitution is a prosthetic transduction where signals normally interpreted by one of the five senses are made available for another sense (e.g., light for the blind).

One of these devices is TVSS (Tactile Visual Substitution System) (Bach-y-Rita, 1972) which converts an image acquired by a camera into a "tactile picture". This tactile image is produced by a matrix of vibrotactile stimulators (400 stimulators) placed on a subject's abdomen, back or forehead. Bach-y-Rita's work with TVSS showed that perception is active, and not simply a passive reception of information. To perceive the information appropriately it is necessary to interact with one's environment, in order to understand the laws which control one's actions and sensations (O'Regan and Noe, 2001) and which enable one to perceive things. With TVSS, the human subjects (sighted and blind) displayed a real recognition of shapes, but only if they were in full control of the camera. If the camera is fixed, the subject feels a prickling sensation on the skin but cannot describe the object depicted. On the other hand, when handling the camera oneself one comes to understand that a particular action corresponds to a particular sensation and vice versa, thus activating a circular process between actions and sensations, giving rise to perception via the device. An absolutely essential observation is that this shape recognition capacity is accompanied by perceptual externalization. Whilst moving, the user is able to recognize objects, forgetting the prickling sensation and perceiving objects in space.

From this observation the idea was born within our research team of creating an ultra-simplified device (1 sensor and 1 stimulator) to explain and understand how a human subject learns to perceive and recognize objects via sensory substitution devices (Lenay et al., 1997). Starting from a very basic prototype, we would then improve the interface, either by increasing the number of stimulations (points of sensation) or by enriching the points of action. Several results showed that subjects were able to deploy efficient strategies enabling them to perceive simple shapes and letters (Lenay et al., 2003; Sribunruangrit et al., 2004). In this context, the zoom appeared as an enrichment of the action which allowed us to study perceptual strategies developed by subjects to access shapes through the sensorimotor loop (O'Regan and Noe, 2001).

2. Objective

As we mentioned above, ZUIs were designed to facilitate interactive navigation within "large information sites". They are based on the space-scale diagrams (Furnas and Bederson, 1995) which allow a better understanding of navigation in this interface type. Except for one study (Guiard et al., 1999) devoted to the pointing and the checking of Fitts' law within these interfaces, very little fundamental and experimental research (Hightower et al., 1998) has been carried out into the use of these interactors. In our research, we will formally reconsider the zoom function in order to study the specific stakes for the development, appropriation and use of a portable haptic zoom. This zoom is associated with a sensory substitution device named Tactos (Gapenne et al., 2003). It is a platform which allows the exploration of digital 2D shapes on a computer screen using tactile stimulations of the index finger (Fig. 2). This perception is possible when causing the screen cursor (not seen by the subject) to move using the stylus on the graphics tablet. When the cursor impinges on the opaque outline of the figure on the screen, the pins are partially or totally activated (Braille cells). This partial or total activation depends on the definition of the virtual sensor, whose contacts with the figure are transformed into stimulations. Virtual sensors can have different shapes (circular, square, and rectangular), different sizes (the smallest sensor is a square of one pixel while the largest can cover the total area of the screen), and can comprise a variable number of elementary receptor fields (see Fig. 2).

This device is doubly relevant since, on the one hand, the stylus is one of the "input devices" associated with PDAs and, on the other hand, we are working with a tactile surface whose reduced dimensions make it suitable for integration in nomadic technology. The objective is not to use the tactile feedback to "describe" the explored figure, but rather to provide a basis for the development of exploratory strategies when navigating and recognizing shapes via a prosthetic device. In the first place, a tactile modality on a

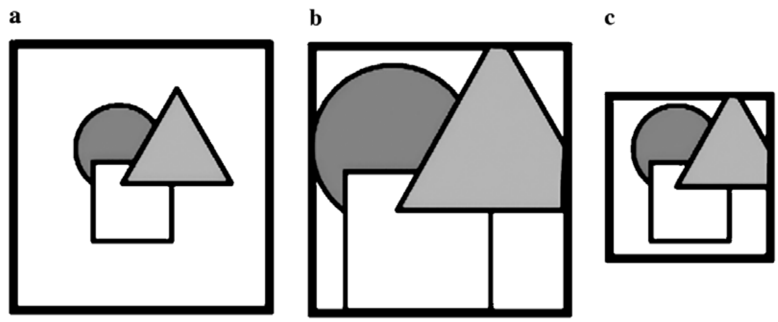

Fig. 1. (a) Initial image, (b) zoom on the image with a fixed sensor size, (c) zoom on the sensor size with a fixed image.

PDA will lighten the cognitive load (Munch and Dillmann, 1997) of the other modalities (vision and hearing); a tactile modality will also allow the user to have an access to the required information; whereas a visual system would not allow this. For this reason it is desirable to study the limits, advantages and disadvantages of a "tactile" zoom compared to a visual zoom. Second, zoomable user interfaces have clear advantages for navigation in huge information spaces. However, their principal drawback is the risk of getting lost and finding oneself in an empty space (Jul and Furnas, 1998). In this study we suggest an alternative to the zoom. In contrast with the traditional zoom, this zoom is not an expansion of the image but of the virtual sensor. Indeed, we can consider that the zoom function is an adjustable ratio between the image and the sensor dimensions. While zooming, one modifies this ratio either by increasing the image size inside the sensor window, or by decreasing the window size and keeping the image size fixed (see Fig. 1).

In order to study the zoom function and to understand and explain subjects' behavior when operating at a particular scale or level of detail, we did not let the subjects operate the zoom themselves. In this experiment the subject does not manipulate a zoom directly, but explores a level of detail (level of scale) that is unknown, and tries to adapt this level of detail in relation to the other sizes to be explored.

Therefore, the objective of the following experiment is to validate the theoretical equivalence of two scaling methods: (i) method 1 involves a reduction of the sensor size and its speed of movement, which is obtained by a "human" speed reduction (see Fig. 9); (ii) method 2 corresponds to the classical zoom and involves increasing the dimensions of the image. An increase in image size can be seen as a decrease in sensor size accompanied by a reduction in the speed of movement. This reduction can be obtained by a "human" reduction (subjects adjust their movements and decrease their speed at each successive level of scale, i.e. with each reduction of the sensor size). Moreover, according to our hypothesis, if the adjustment is made successfully (spontaneously or through learning), then it becomes clear that method 1 has the dual advantage of rendering image recalculation unnecessary and of keeping the whole object permanently accessible. In the case of a PDA the image could be held on a single screen, preventing subjects getting lost or finding themselves in an empty space (Jul and Furnas, 1998) when they use various zoom levels. Also, since storage capacity and processor speed are limited in a PDA, this constitutes a saving, inasmuch as the space required by the virtual sensor files is much smaller than that required by image files.

3. Experiment

3.1. Participants

Ten subjects, divided in two equal groups, took part in the experiment, which included two successive sessions. They were students at UTC and aged between 22 and 32. The subjects of the group 1 were first exposed to method 1 (session 1) and subsequently to method 2 (session 2), whereas the order of the two methods was reversed for the subjects of group 2 (session 1 was method 2 and session 2 was method 1).

3.2. Apparatus

The experimental device includes three parts: a computer, a graphics tablet with stylus, and tactile stimulators (see Fig. 2). The stimulators are two electronic Braille cells, each including eight tactile pins. They are connected virtually to a sensor able to distinguish figures on the screen from the background. In other words, when the sensor is on the outline of the figure a signal is transmitted to the stimulators and the corresponding pin is raised. The idea is to move the stylus on the graphical tablet so that a figure on the computer screen can be explored and recognized even though the user is blindfolded. The whole allows the recognition in blind mode of writing and/or drawing on the computer screen. Subjects used the stylus to sweep over the tablet while keeping the index finger of the left/right hand (according to the dominant hand) on the 16 tactile pins.[1] Each shape

[1] The 16 pins are two Braille cells of 16.7 mm × 6.4 mm which can be placed under one finger.

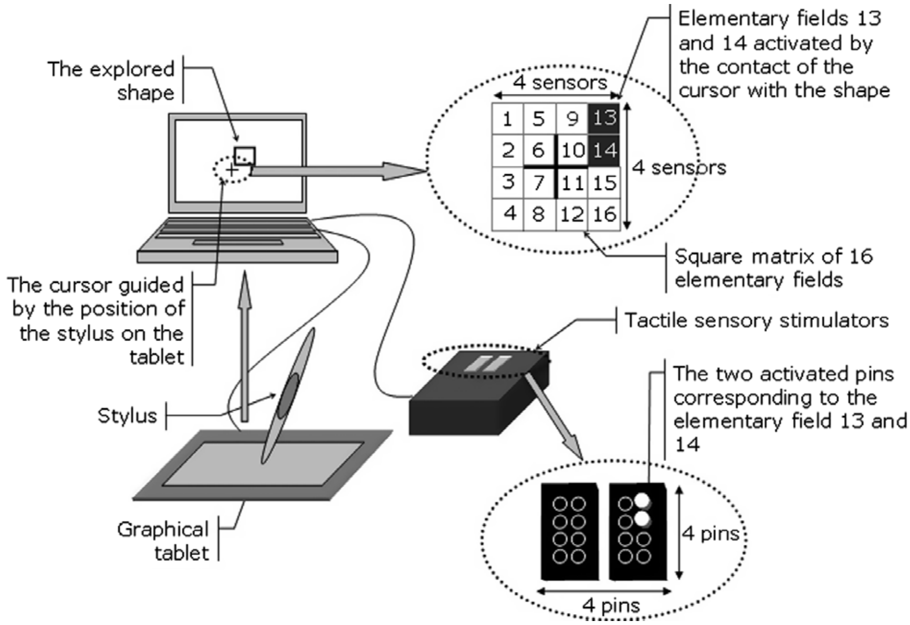

Fig. 2. The experimental device: Tactos.

or drawing displayed on the screen is haptically perceived according to the movements of the stylus on the tablet. The subject feels the stimulators being activated under the index finger each time the cursor (which corresponds to sensors) comes into contact with the outline of the shape on the screen.

For this experiment, the selected sensors are square matrices with 16 elementary fields. As Fig. 3 shows, with this type of matrix, each elementary field corresponds to a pin on the stimulators (two Braille cells). For example, fields 1, 2, 3 and 4 correspond to pins 1, 2, 3 and 4.

3.3. Experimental design

The experimental procedure comprised two phases: the first a training phase in which subjects learned how the device works, and the second the experiment proper.

3.3.1. Learning phase

This phase allowed subjects to become familiarized with the device and to better understand this new kind of perception. It was broken down into four steps.

3.3.1.1. Lines. After being told how the device works subjects were asked to put on a blindfold or dark glasses and to begin exploration. They were told to select the correct orientation of a line from among four possibilities (e.g., horizontal, vertical, obliques (see Fig. 4)). Three successive correct responses were required before subjects passed on to the next step. They gave their answers orally.

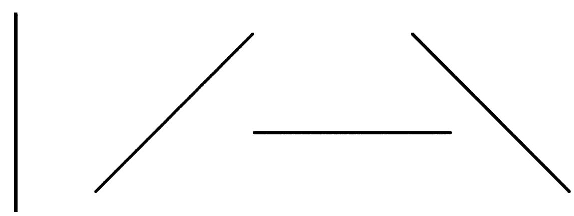

Fig. 4. Lines in different orientations.

3.3.1.2. Curves. In the second step subjects had to find the orientation of a curve (a quadrant (bottom left, bottom right, top left top right) or a semicircle (left and right) (see Fig. 5)). Again, three successive correct responses were required before subjects passed on to the next step.

3.3.1.3. Tumbling E. The "tumbling E" is a test of visual acuity that does not require a verbal response. In visual tests the subject has one eye covered and is asked to indi-

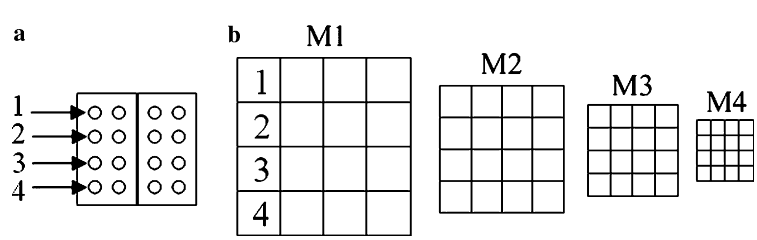

Fig. 3. (a) Tactile stimulators, (b) virtual square matrices used as sensors. From left to right: M1, M2, M3 and M4 (see sizes on Table 1).

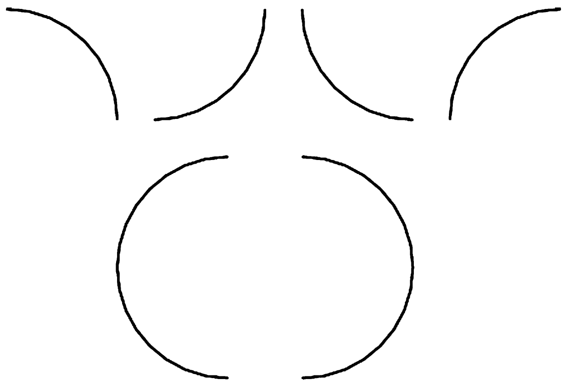

Fig. 5. Curves: quarter and half circles.

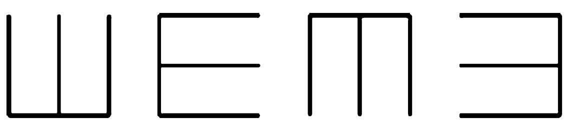

Fig. 6. Tumbling E.

cate one of the four the orientation of the E presented (see Fig. 6). In our case the exploration is not visual. Instead, the subject investigates the figure using the stylus. This test was chosen in the light of prior experiments undertaken with the device (Ziat et al., 2004), whose results indicated a good recognition of the letter E even at very small sizes (0.5 mm). Subjects had been able to produce relevant strategies to accomplish this recognition. In this third step in the training phase of the current experiment, subjects were asked to find the orientation of a letter E bounded by a 3×3 mm square (see Fig. 6). After obtaining two successive correct responses they passed on to the final step of training.

3.3.1.4. Letters. During this final step subjects had to recognize a letter (3 mm in height) from amongst a collection of five letters (see Fig. 7) which had been presented to them immediately beforehand. Two successive correct responses qualified the subjects to begin the experiment proper.

3.3.2. Experiment

3.3.2.1. Material. The task involved the recognition of simple geometrical shapes (square, circle or triangle) containing a letter (S, N or Z), nine combinations thus being possible (see Fig. 8).

The letters of the alphabet can be classified according to topological equivalence. There are three classes of letters: with a hole (e.g., a, b, d), without a hole (e.g., c, f, h)

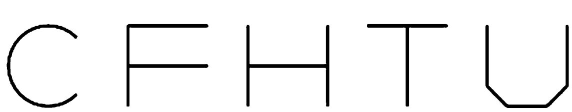

Fig. 7. Letters C, F, H, T and U.

and consisting of two pieces (i and j). We chose the letters S, N and Z because they are fairly similar, differing principally in orientation. This choice was motivated by prior studies involving letters with different orientations (for example: Tumbling E) (Ziat et al., 2002, 2004), where subjects were seen to deploy strategies adapted to particular letters' features.

3.3.2.2. Experimental conditions. In the first method, where the scaling affects the matrix, the size of the figure remained fixed throughout the experiment. In the second method the sensor size remained fixed and the size of the figure was increased after each series.

3.3.2.3. Experimental procedures. For each method, subjects performed four series of six trials. During a trial, the subject was asked first to recognize the outline in at most 90 s, and second the letter in at most 2 min. As stated previously, the subjects did not control the zoom, but merely explored one particular detail level. The scaling was controlled by the experimenter, who changed the size of the matrix or the figure at each trial.

After the training phase, the experimenter told subjects that they had to recognize figures whose sizes would decrease gradually. To determine whether subjects would reduce the size of their movements in order to perceive the scale changes, we did not tell them that the size of the figures would remain fixed with the first method. The first method will correspond theoretically to the second method only if subjects reduce the speed of their exploratory movements. Subjects were informed about the matrix's shape and the number of elementary fields, but not about its size. Likewise, they were given no information about the size of the figures and of the scaling steps. At the end of each session the experimenter asked subjects if they perceived the size change of the presented figures. Finally, at the end of the experiment, subjects were questioned about which methods they preferred, and why.

Before determining the minimum size of letters we undertook a survey to fix the comfort threshold, i.e. the smallest letter size which subjects would be able to read and trace with the stylus. Five subjects were asked to write the letters S, Z and N as small as possible using natural handwriting movements. They wrote these letters using the stylus on the tablet, trying to keep each letter approximately the same size as the other two; we recorded the traces and displayed them to subjects so that they might explore them haptically (blindfolded, using the device). Subjects were able to recognize their own writing only when letters were more than 3 mm high. In the light of this finding we fixed our threshold at 3 mm. The outline was eight times larger than the letter, that is to say with edges measuring 24 mm. From this initial situation other values were deduced with respect to a ratio R, using the same collection of figures for both methods, such that matrix size was increased for the first method, and figure size for the second.

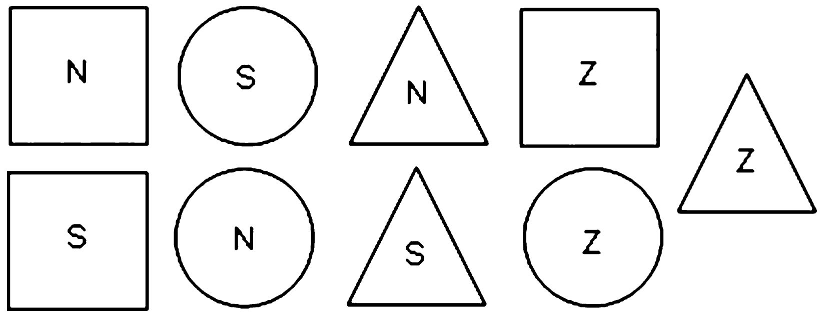

Fig. 8. Shapes: letters in outlines.

Table 1
Matrix size (first method)

Shape size	Matrix size (mm) (elementary field (mm))	R (ratio)
Letter (3 mm)	6 (1.5)	2
	4.5 (1.125)	1.5
	3 (0.75)	1
	1.5 (0.375)	0.5
Outline (24 mm)	6 (1.5)	0.25
	4.5 (1.125)	0.1875
	3 (0.75)	0.125
	1.5 (0.375)	0.0625

In the first method R corresponds to M/h (h: letter height; M: matrix size). Table 1 shows the different values. In the second method, and in order to keep the same scale ratio between the shape and the sensor for each series, R corresponds to h/M. For example, the exploration of an outline of 24 mm and of a letter of 3 mm with a matrix of 4.5 mm in method 1 is equivalent to the exploration of an outline of 32 mm and a letter of 4 mm with a sensor of 6 mm in method 2. The other values of the sizes are displayed in Table 2.

A summary of sizes is given in Fig. 9, where matrix size decreases for method 1 and remains fixed for method 2, while figure size decreases for method 2 and remains fixed for method 1.

Note that object perception was not direct, but the result of a technical mediation. Thus, tactile feedback did not result from a direct contact between the object and the finger, but from the contact between the virtual object and the virtual sensor. The recognition of the object cannot be based exclusively on tactile stimulations but must be associated with kinesthetic cues.

Table 2
Shape sizes (second method)

Matrix size (mm) (elementary field size (mm))	Shape size (mm)	R (ratio)
6 (1.5)	Letter: 3	2
	Letter: 4	1.5
	Letter: 6	1
	Letter: 12	0.5
	Outline: 24	0.25
	Outline: 32	0.1875
	Outline: 48	0.125
	Outline: 96	0.0625

In this experiment we measured subjects' performances for both methods. Our first hypothesis was that there would be no difference between correct identification of outline/letter. Our second hypothesis concerned the experience of scale. Similar performances do not necessarily imply a similar phenomenology. With method 2, subjects are likely to be aware of changes in the size of figures, since these changes occur in the real world. However, with method 1, the size changes are virtual and not part of the real world. In this case it is important to know whether subjects have the feeling of exploring different sizes even though it does not occur in the corporeal world of the subjects. We hypothesized that the subjects who were able to reduce their movements with method 1 would "experience" this change in virtual sizes. In order to validate this hypothesis, we asked the subjects if they had the feeling of exploring different or identical sizes (for both methods) and we compared their responses to the speed of their explorations. Our second hypothesis would be validated if the response corresponded to the speed: feeling of expansion = speed reduction in method 1; no feeling of expansion = no speed reduction in method 1.

An example is given to explain the necessity of reducing movements with method 1. Fig. 9a shows the matrix position on a portion of a triangle and the corresponding activation of pins. As can be seen in Fig. 9b, pin activation is similar with both scaling methods. However, after a movement X by the subject, pin activation is different for the two methods, as can be seen in Fig. 9c. Movements must be reduced so as to maintain the same relation between the subject's actions and the resulting sensations, i.e. in order for the subject to obtain the same sensations in method 1 as in method 2 when performing the same movements, speed must be reduced with method 1.

3.3.2.4. Measures. There are two dependant variables that we measured during the administration of the experiment. The first dependant variable was the correct identification of the shape (for outline and letter) based on the subject's answers. The second dependant variable was the mean of displacement speed, which was calculated for each subject. Finally the strategies were revealed by the recorded

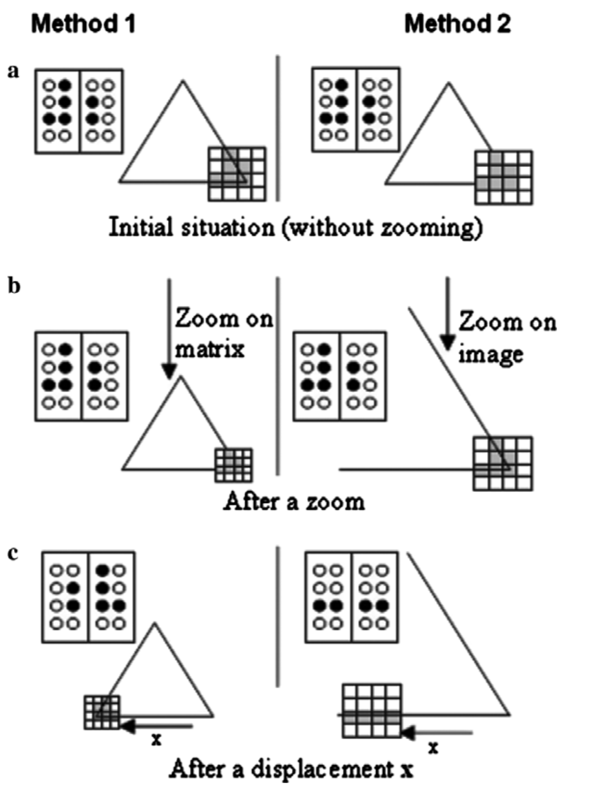

Fig. 9. Stimuli configuration according to the matrix position on the triangle (a) without zoom, (b) at the same place after a zoom, (c) after a displacement x.

trajectories and by subjects' verbal reports (we asked subjects to explain how they recognized the orientation and the size of the shapes).

We coded subjects' answers as 0 when they were incorrect and 1 when they were correct. And in order to pool and compare the subjects' performances in the two methods, we tested the effect of order (M1 followed by M2, or M2 followed by M1) and figure factors by using the Mann–Whitney test. Mean rank scores were calculated, test ranks compared and significance determined by the Wilcoxon rank test. To calculate the speed effect we used the Wilcoxon–Mann–Whitney test, comparing the speeds of two groups of subjects: the "no zoom" group, corresponding to subjects who did not feel the scale effect in method 1, and the "zoom" group, corresponding to subjects who experienced the scale change.

3.4. Results

The Mann–Whitney test tends to show that the difference between the two orders is not significant and suggests that the order factor has no discernible effect ($p = 0.59$). The same result holds for the figure factor ($p > 0.05$ for outline and letter). We were therefore able to pool the data from the two sessions. As seen in Fig. 10, mean performance on the outline was 70% for method 1 and 77% for method 2. The difference is not significant ($p = 0.30$) as regards a Wilcoxon rank test. For letters, the mean rate of correct responses was 40% for method 1 and 46% for method 2; a Wilcoxon rank test shows that the difference is not significant ($p = 0.1$). So the subjects attained similar levels of performance, which tends to suggest that method 1 is as good as method 2 for perceiving the outline and the letter.

The other main result is the difference relating to the size of figures (method 2) and matrices (method 1). Performances improve as matrix size is reduced in method 1, and as figure size is increased in method 2; Friedman test analysis shows that this size effect is significant both for method 1 [Fr $(7,63) = 7.69$; $p < 0.05$] and method 2 [Fr $(7,63) = 8.86$; $p < 0.05$]. As shown in Fig. 11, outlines are better recognized than letters, and if one compares the subjects' performances relative to chance (33%); they never exceed 53% (in both methods) for letters, whereas outline recognition is as high as 80%, without ever falling below 63%.

Fig. 10 shows in more detail that the performances for outlines are clearly better then those for letters, even though subjects required only half the time to recognize outlines (90 s) that they needed to recognize letters (180 s). This difference is due to the ratio R. We notice that performances do not increase significantly for values of R between 2 and 0.5 (letters), and for values of R between 0.25 and 0.0625 (for both methods). The letter recognition success rate remains less than or equal to 46.67%, whereas for outline the proportion of successful recognition never falls below 70%. The passage of R from 0.5 to 0.25 is statistically significant for both methods ($p < 0.01$) (using a Wilcoxon rank test).

The choice of R is thus crucial for outline recognition. Indeed, in previous studies (Ziat et al., 2002; Ziat et al., 2004), subjects were able to recognize letters of 3 mm with a rate of 80% ($R = 0.8$), and this rate did not fall below 53% for letters of 1.5 mm (for values of R between 0.56 and 0.4), whereas the success rate did not even reach 43% for small letters (3 mm) in the present study ($R \geqslant 0.5$). This decrease in performance for R equal to 0.5 is may be due

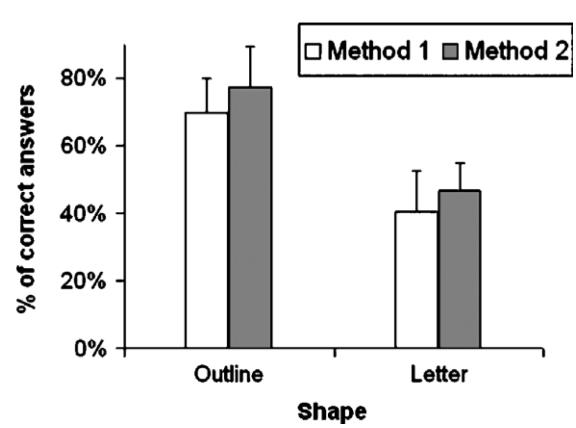

Fig. 10. Correct responses for outline and letter for the two methods.

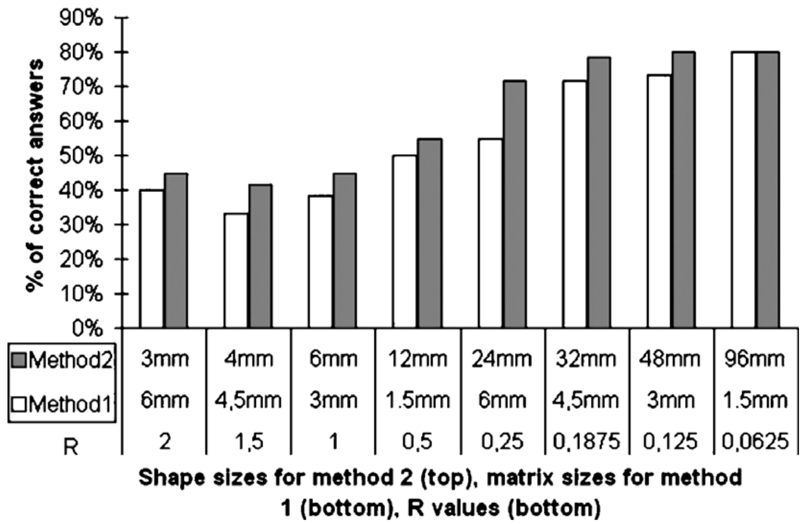

Fig. 11. Correct responses for both outlines and letters for the two methods; the dotted line corresponds to chance.

to: (i) the fact that, in this study, as part of the same task, subjects had to recognize two different objects (outline and letter) of large and small sizes, so performances with regard to small objects (letters) were less good, (ii) to the letters' features (Orientation of the letter E is more easier to identify than letters N, S or Z because there is no oblique lines in the letter E).

After the experiment we asked the subjects about the experience of scale and about their preference regarding the method used. Half of them felt no scale effect in method 1, whereas the other half did "experience" changes in scale. Fig. 12 shows the speeds for each matrix, according to whether or not the "experience" was present. We observe that for the subjects claiming not to feel the scale effect (the "no zoom" group), speed increased (or remained stable) as matrix size was reduced. However, for the other group (the "zoom" group) speed decreased in line with the reduction in matrix size. This difference between the two groups, compared using the Wilcoxon–Mann–Whitney test, is significant ($p = 0.0209$) and tends to support our hypothesis, because only the people who succeeded in reducing their movements said that the sizes were changing when they used method 1.

Finally, subjects' preferences between the two methods were evenly split, five preferring method 1 because they did not have to move the forearm during the exploration, and the other five subjects preferring method 2 because they disliked the small movements required for method 1.

3.4.1. Strategies

To recognize the outline the subjects used several strategies. Three strategies were observed:

(1) The majority of subjects made use of the topography of the figure to recognize it. Indeed, eight subjects started by locating the base of the outline in one of two ways:

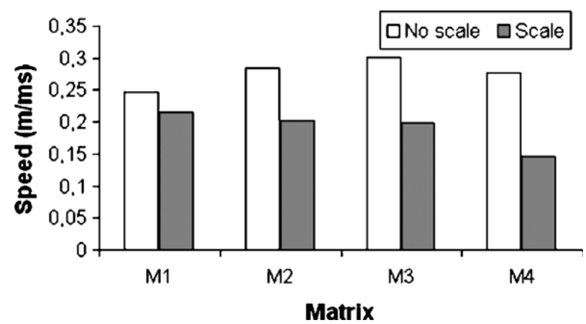

Fig. 12. Displacement speed for each matrix according to the feeling of scale.

(i) Horizontal lines: Three (3) subjects traced horizontal lines at the base of the outline to locate the point of contact with the figure, which subjects perceived either as a line or as a dot, depending on the particular sensations under the finger. If they felt a line, subjects would guess that the outline was either a square or a triangle. In this case, they would repeat the same approach at the uppermost edge of the outline, and if they still felt a line, they deduced that the outline was a square (Fig. 13). Table 3 summarizes the possible answers.

A potential problem with this type of strategy is when the subject believes he/she is sweeping in horizontal lines, but is actually sweeping diagonally. Fig. 14 illustrates some possible errors when using this strategy:

In Fig. 14 the subject is making diagonal sweeps over a square while believing the sweeps are horizontal. At the top of the square, the possible error is to feel a dot instead of a line; if, at the bottom of the square, the line is then perceived as such, the answer will be a triangle; if, however, there is a similar mistake at the other extremity, and the line is erroneously perceived as a dot, then the answer will be a circle.

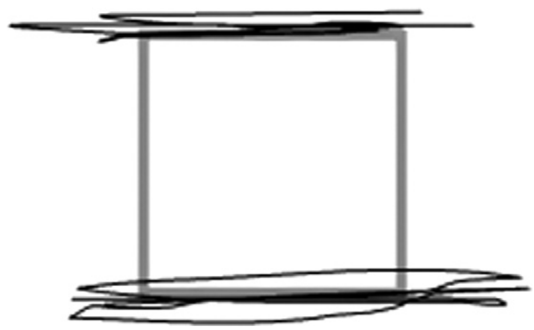

Fig. 13. Horizontal lines strategy on a square.

Table 3
Subjects' possible answer for the outline according to the sensation under the finger

Sensation on the outline base	Sensation on the outline top	Possible answer
.	.	Circle
–	.	Triangle
–	–	Square

Likewise, when exploring a circle, if there is a shift from the extremities inside the circle, the dot sensation will be lost and the subject will have the feeling of crossing a line.

(ii) Horizontal lines with a technique: In the same way, five (5) subjects located a dot or a line at both outline extremities by choosing a constant contact or a micro-sweeping movement (see below). The risk of a biased horizontal is less than in the first case.

(2) Constant contact: A subject keeps constant contact with the outline: With this strategy the subject tries to follow the outline without deviating from it, i.e. by ensuring that a stimulation is present practically all the time. Fig. 15 shows subject O's path on a square using this strategy. Black line represents the moments when the stylus was in contact with the shape and shows that the subject hardly ever left the shape.

(3) Border and micro-sweeping: One subject chose a border technique for method 1, then changed to a micro-sweeping technique for method 2:
- The border strategy consists of tracking the circumference of the shape by "tapping" it
- With the micro-sweeping strategy, the subject makes rhythmical sweeping movements over the shape, voluntarily leaving and re-entering while trying to maintain a regular interval between departure and re-entry

  The difference between the two strategies is that a subject adopting the border technique does not cross the shape, but "taps" the outline from the outside (a sensation is sought at the edge of the sensor); whereas with the micro-sweeping strategy, the sensor crosses the line and is alternately inside and outside the outline.

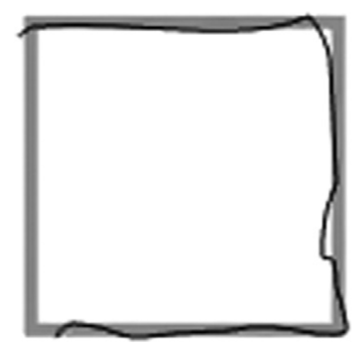

Fig. 15. Constant contact strategy on a square.

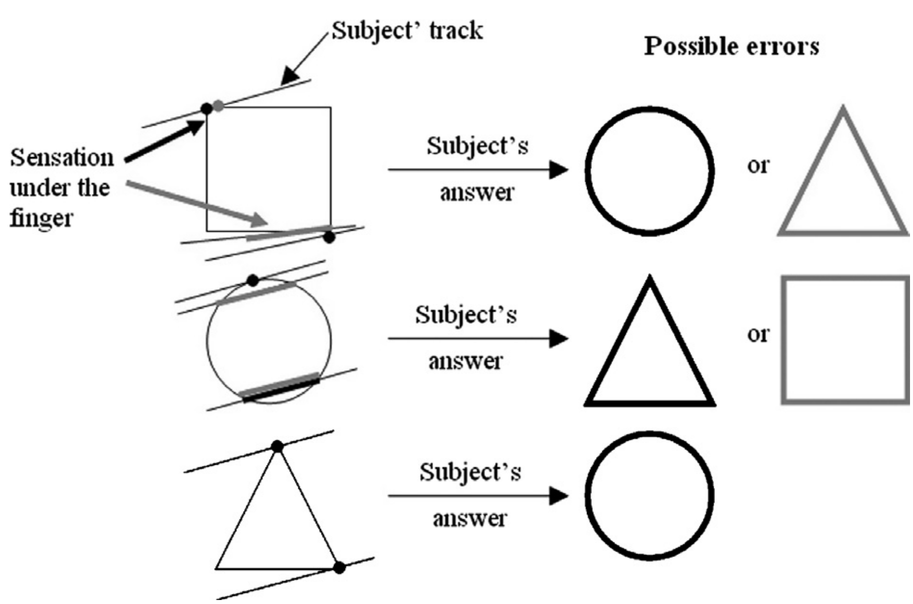

Fig. 14. Tracking of outlines by subjects (gray lines/points correspond to gray outlines and black lines/points correspond to black outlines).

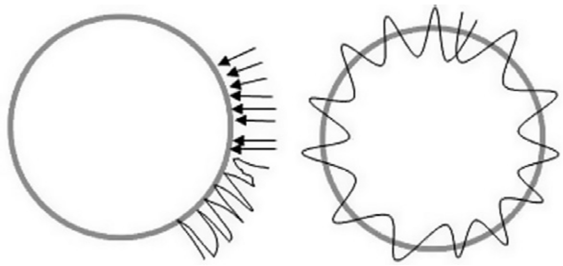

Fig. 16. Border strategy (left) and micro-sweeping strategy (right) on a circle.

In Fig. 16, the subject O covers a circle of 96 mm using a micro-sweeping technique. The subject visibly "hugs" the shape, making micro-sweeping movements that follow the circle.

Table 4 summarizes the mean percentage of correct responses according to strategy for the two methods. Apart from the constant contact strategy, the performances are in general slightly better for method 2 than for method 1. We also notice that the subject's performances are better than 72% for both methods, except when using the border and horizontal lines strategies with method 1 (63% and 61%, respectively). Indeed, the percentage of correct responses reaches 83% for the micro-sweeping strategy (method 2), 79% for constant contact (for both methods), 75% (method 1) and 79% (method 2) for horizontal lines with a technique, and finally 72% (method 2) for the horizontal lines strategy. The considerable difference between the border technique and the micro-sweeping is due to the strategy change. As the subject did not have enough control using the border technique, this strategy was replaced by the micro-sweeping technique strategy for the second session (method 2).

In the case of the letters, four strategies were observed:

(1) Horizontal and vertical lines: Five (5) subjects performed horizontal and/or vertical sweeps over the letter: they tried to locate the vertical lines, horizontal lines or dots. The same principle is used as with outlines (see Fig. 14). Table 5 summarizes the different sensations felt under the finger.
(2) H and V lines with angles: Three (3) subjects combined the former strategy with one which attempted to locate angles by trying to place the matrix at the extremities of letters. Angle location is based on stimulation intensity. Subjects found that the maximum stimulation was obtained when crossing the angles of the letter.
(3) Border: Only one subject tried to track the outline of the letter by "tapping" its edges (see Fig. 16).
(4) Constant contact: The last strategy used was to follow the letter as closely as possible.

Table 4
Subjects' performances for the outline by strategy (for the two methods)

Strategies	Method 1 (%)	Method 2 (%)	Number of subjects
H lines with a technique	75	79	5
H lines	61	72	3
Constant contact	79	79	1
Border/micro-sweeping	63	83	1

Table 5
Subjects' responses for the letter according to the sensation under the finger

Bottom	Top	Right	Left	Letter
..	..	|	|	N
.	.	:	:	S
–	–	:	:	Z

Table 6
Subjects' performances for the letter by strategy (for the two methods)

Strategies	Method 1 (%)	Method 2 (%)	Number of subjects
H lines	43	44	5
H and V lines + angles	46	49	3
Constant contact	33	42	1
Border	31	58	1

Table 6 summarizes the subjects' performances according to strategy for the two methods. When they did not use the border strategy, subjects were slightly more successful with method 2 than with method 1, but this difference is negligible. When the border strategy was used, there was a noticeable difference between the two methods. This is due to the fact that letter "tapping" is much less regular for the small sizes (method 1) than for the larger ones. Subject frequently believed they were tapping the edge of the letter, but in fact they were crossing the edge without realizing it, the letter size being relatively small (3 mm).

4. Discussion

The aim of the experiment is to compare two methods of scale by using a haptic feedback in order to design, in a future study, a continuous haptic zoom. First, the non-parametric tests showed that the recognition rate between the two methods is not significant, but subjects reported that method 1 felt different from method 2 when exploring outlines. In the case of the outline test, when one refers to the comments of the subjects, one remarks that the progressive change of the outline size, from a proprioceptive point of view, is strongly felt by subjects using method 2, while the size change remains undetected using method 1. Subjects' strategies (see below) would appear to be better suited to a real scale change than to a virtual change. Indeed, the seven subjects using a micro-sweeping technique or tracking outlines attempted to locate horizontal and/or vertical lines. This location seems to be more palpable for the subjects over a long distance than over a short one. In method 2, the subjects perceived the scale increase since their wrist moved over the tablet. In addition, with method 1, half of the subjects (5) didn't feel the scaling effect because they were not able to reduce their speed movements. This scaling remained virtual because they traversed the same distance on the tablet relative to the speed. This relatively short distance (24 mm) did not allow them to perceive the orientation of their movements if they were not able to slow these movements down. Finally, one of the subjects changed strategy between method 1 and method 2. The strategy used for method 1 reduced performance because it was not well controlled by the subject, who subsequently adopted a different strategy for method 2 during the second session. Likewise, for letters, using the border strategy led to a drop in performances for method 1, because it seems not to be appropriate for this category of sizes and tasks. As regards letters, people did not report feeling any scaling with either method, even when letter size went from 3 to 12 mm with method 2. For the subjects there is no real difference between method 1 and method 2 because they have the impression of exploring the same distance on the tablet whatever the method used, and making the same micromovements. This is indeed the case for method 1, but it is not true for method 2. In this second case, even if subjects are aware that the letter size is varying, the situation isn't experienced as such. Finally, according to the task, strategies make use of the topography of the figure. The strategies used for both outline and letter recognition can be described as either trying to draw the figure (constant contact, border, and micro-sweeping) or trying to find intersection points (horizontal and vertical lines).

The results showed that the chosen ratio R is important for the recognition of shapes. Outline performances (consistently greater than or equal to 70%) are better than letter performances (consistently less than 46%). The larger figures (more than 12 mm) helped subjects clearly distinguish size changes and estimate the size of the object they were exploring. The smaller the value of R, the better the performances. Indirectly, this means that the size chosen for a figure increases performances if it is sufficiently large. This level of scale, which is highly dependent on the ratio selected between the dimensions of the figure and the dimensions of the matrix, is perceived by the subject only when size is sufficient to allows larger movements of the stylus. These movements seem to depend on the threshold of proprioceptive perception, but it will be interesting in future work to situate our result with reference to psychophysical studies on haptic sensation (Biggs et al., 1999; Clark et al., 1986; Louw et al., 2000).

5. Conclusion

Although the subjects' performances for the two methods did not differ, and the majority of them claimed to feel the scaling effect with method 2 and not with method 1, in particular for the outline, their preferences for method 1 or method 2 were divided. Half the subjects preferred method 1 because they could traverse the same distance without having to move their wrists. The other half preferred method 2, since they found slowing down and reducing their movements extremely bothersome. They had the impression that they had less freedom of movement and that in the end these micromovements were a strain.

When using method 1 subjects need to reduce their movements while zooming on the capture window. It is only in this case that they have the impression of exploring figures of different sizes and experience a scaling "feeling". We plan to test this hypothesis using a much larger sample. If this zoom is really effective, we will try:

(1) To define, thereafter, a comfort threshold for producing gestures in order to avoid subject boredom and tiredness, as was the case when subjects were trying to identify letters using method 1, since they were faced with very small sizes. It would thus be necessary to define a minimal threshold which would allow recognition of shapes and be comfortable for the subjects.
(2) To define suitable zoom steps for the recognition of objects. This choice is essential in order to know the smallest difference required between two sizes for a feeling of scaling to be created. We noticed with the letters while using method 2 that a progressive change of size from 3 mm to 12 mm with the chosen step (3 mm, 4 mm, 6 mm, and 12 mm) was not felt as such. It is however possible that choosing other steps would have given the impression of size increasing.
(3) To validate the zoom function supplied in tasks of shape localization and recognition. We are implementing, in collaboration with another team of research (Lecolinet and Mouret, 2005), the application on a PDA in order to validate the contribution of a haptic zoom function in a PDA. We intend to put subjects through a visual pointing task where objects are not visible on a screen, but are detectable only via a haptic zoom.

Acknowledgement

This research was funded by the CNRS.

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Mounia Ziat was born in 1974. In 2002, she obtained a Master degree in Technology and Human Sciences from the University of Technology of Compiegne. Since 2002, she is preparing a doctoral thesis in Human Computer Interaction which is expected in October 2006. The author's major field of study should be lower-cased. Her research interests are in the area of multi-scale navigation. She is particularly interested in zoomable user interfaces (ZUI), haptic perception and mobile devices. She combines these three areas in order to identify and solve practical design problems related to a haptic zoomable mobile interface.