Perception in numerical and corporeal spaces in a 2D haptic virtual world

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Abstract

Two kinds of space can coexist in the virtual world: the corporeal and the numerical ones. The manner in which a human being apprehends and perceives his virtual environment is often confused: Is the space of perception focused on virtual or real subject's movements when he is exploring numerical objects[*]? In this fundamental and experimental study, we try to give a beginning of answer at this question in connection with the perception of virtual space. Results show that the numerical perception can calibrate the corporeal perception in the apprehension of objects through a sensory substitution device only if subjects are immersed in the virtual world. Efficient strategies which are of domain of the corporeal perception (which corresponds at body movements in the real world) are used differently at profit of the numerical perception (which is felt in the virtual world). This immersion in the virtual world gives the illusion of exploring a longer distances than those really explored in a haptic 2D space. This illusion is more precise if the ratio between the chosen sizes of shapes (h) and the sensor size (M) is included between C = 0.2 and C = 0.4 (where C = M/h). Also, this size illusion is closely dependent on the strategies used by subjects in order to recognize the size and the nature of the presented shapes.

1. Introduction

Virtual worlds offer to human being different experiences that can be, less or more, close to reality. But in most of cases, the real world remains pregnant and confusions often appear [10, 15]. The real world, which corresponds to corporeal space, is the space of the body, the space where are occurred actions and sensations in order to perceive tangible or intangible (numerical) objects. The numerical space is the displacements of the sensor in order to perceive numerical objects.

If vision and sound are more present in most virtual systems, the kinesthetic and haptic feedback is less present whereas it brings a precious help to the user because it efficiently contributes to proprioception [6] (As many studies [7, 13], proprioceptive effects can also be induced at postural and perceptual levels from a visual and auditory flows). Indeed, in a virtual world, while exteroception is immersed in a simulation, proprioception remains unchanged in relation to the real world and this is a source of conflict in some virtual environments [19].

Likewise, virtual environments without vision can exist, i.e. that the exploration in the virtual world is only haptic and/or auditory. Devices known as sensory substitution systems offer the possibility to create these environments. In these systems, signals from an artificial sensor (for example a camera) are transformed into stimuli for a natural sensor (for example the skin). One of the first sensory substitution devices was the TVSS (Tactile Visual Substitution System) [2] which allows the conversion of the image obtained by a camera into a "tactile picture". This tactile image is produced by a matrix of vibrotactile stimulators (400 or 64 stimulators) which are placed on the abdomen, the back or the forehead of the subject.

Bach-y-Rita's work with the TVSS showed that perception is 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 our actions and our sensations [16] and which enable us to perceive things.

With the TVSS, the human subjects (sighted and blind) displayed a real recognition of shapes but only if they handled all the camera functions. If this one is fixed, the subject feels a prickling sensation on his/her skin but won't be able to describe the object in front of him/her. On the other hand, by handling the camera oneself, it is possible to understand that a particular

[*] The numerical object is which is displayed on the computer screen and is perceived by means of interactive tools.

action corresponds to a particular sensation and that such a sensation corresponds to such an action; he/she thus activates the circular process between actions and sensations in order to be able to perceive via the device.

An absolutely essential observation is that this shape recognition capacity is accompanied by perception externalization. Whilst moving, not only does the user manage to recognize objects but he/she forgets the prickling sensation and perceives an object in front of him/she in space.

From this observation was born the idea within our research team to create an ultra simplified device (1 sensor and 1 stimulator) [14] to explain and understand how a human subject learns to perceive and recognize objects by means of this type of device. From this initial situation, one can improve the interface either by increasing the number of stimulations (points of sensations) or by enriching the possibilities of actions. Several results showed that the subjects were able to deploy efficient strategies enabling them to perceive simple shapes and letters [20, 21].

2. Work context

Which is also interesting with these devices is the possibility of studying the two aspects of space: the numerical and the corporeal ones. In this study, we carried out an experimental study in order to understand the manner that human beings apprehend a 2D haptic space and the manner of which they estimate sizes, but the most important is to know on which kind of space they situate their movements.

A sensory substitution device named Tactos allows the exploration of shapes. Blindfolded subjects explore a 2D graphical shape, which is displayed on a computer screen, by using a stylus on a graphics tablet. The stylus, in contact with the tablet surface, allows the detection of pixels (which is drawn in black) and activates tactile pins when it crosses black pixels. This detection is possible by the definition of what we call a matrix of elementary fields. Matrices can have several forms (square, circular, rectangular, etc…) and can be composed of one or several elementary fields. Each elementary field is sensitive to black pixels and activate one or several pins. For the need of the experiment, we chose a square matrix of 16 elementary fields which allows the activation of 16 pins on the tactile stimulator.

As shown on figure 1, 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.

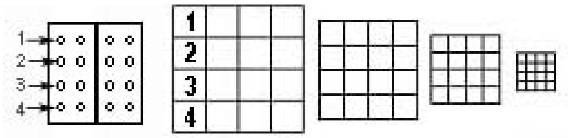
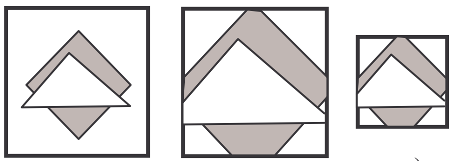


Fig. 1. a) Tactile stimulators (16 pins). b) Virtual square matrices (M) used as sensors. From left to right: M4, M3, M2 and M1 (see sizes on table1).

As said before, the virtual space is the space of sensor displacements relatively to numerical objects, i.e. the virtual space is the displacements space of the matrix relatively to the shape. The corporeal space, in which actions and sensations are operated, is the space on the graphics tablet coupled with the space of tactile stimulators; it corresponds to subject's hand movements and pins sensations.

Matrix size plays an important role in the resolution; it is like a step of discontinuous zoom. Indeed, more the matrix is small, more the resolution is higher and conversely, more the matrix is big, more the resolution is lower. The same size of a figure isn't perceived in the same manner with two different matrices. Technically, it corresponds to two different scales. Indeed, a level of scale is a relative ratio between the perceived image and the capture window (in our case, it's the matrix). By scale change, one modifies this ratio either by increasing the image size inside the capture window or, by decreasing the window size and keeping the image size unchanged (see figure 2).



a) b) c)

Fig. 2. a) Initial image b) zoom on the image with a fixed capture windows c) zoom on the window with a fixed image.

In a precedent study [24], we compared the two situations which prove to be haptically identical only if the subject reduces his/her velocity of exploration movements of the object when the scale is done on the sensor.

An example is given to explain the necessity of movements' reduction when the scale is made on the matrix (method 1 on figure 3). As shown on the figure 3a, the matrix position on a portion of the triangle gives a certain configuration of stimulations. On the figure 3b, the pins activation is similar in both scaling methods. But pins activation isn't activated in the same manner after a displacement x by the subject for both methods. It's necessary for the subject of adjusting his/her movements to keep the same relation between his/her actions and sensations, i.e. the subject must reduce his/her speed movement in the method 1 in order to perceive the same sensations that he/she will perceive in method 2 when he/she makes the same movements.

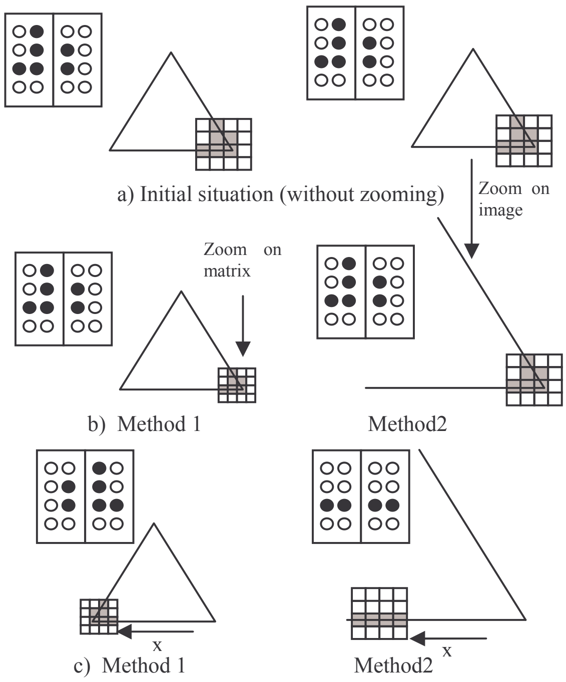


Fig. 3. Stimuli configuration according to the matrix position on the triangle. a) without zoom b) at the same place after a zoom b) after a displacement x.

This movement reduction is often spontaneous because of what we called "the sweeping interval". Subjects' movements are closely dependent on the matrix size. Indeed, as shown on figure 4, the interval that allows to the matrix to be in permanent contact with the line is smaller in a) than in b) and in most cases, this makes that subjects are constraint to produce smallest movements in a) in order to be in contact with the shape and/or its proximity. In consequence, the size increasing of the matrix increases the velocity range in order to keep contact with the shape.

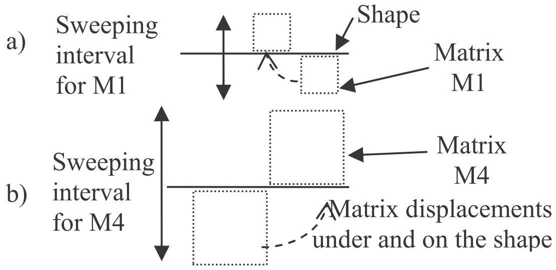


Fig. 4. Sweeping interval changes according to the matrix size.

In this present study, we persuaded subjects that they have to explore different sizes of shapes but in fact the size shapes remain fixed throughout the exploration. The size change is just operated on matrices.

Our hypothesis is that the perceived size is in the numerical space (space of sensor's displacements on the object). If subjects are able to perceive a scaling on image sizes that don't change in the real world (tablet space), their space perception is based mainly on what they perceive in the numerical space because the scaling is operated on matrices and then on this numerical space. The corporeal space should be a check sense in order to validate or invalidate this first perception. At the opposite, the inverse hypothesis is that subjects' corporeal perception is so much present that the simulation of varying sizes on a same portion of space isn't possible even if this change is operated in the virtual world.

We believe that movements deployed by subjects can create an illusion of size. Indeed, if subjects base their perception on the numerical space when the scaling is made on matrix, the illusion of crossing a big distance on the same portion of space is created. By same portion of space we mean the real space on which the real exploration is operated. Since the shape size in the real world is the same during all the exploration, the crossed distance is the same whatever the matrix used.

3. Experiment

3.1. Subjects

Twenty one (21) subjects, 25±5 years old, which were divided in three experimental groups (7 subjects each one), took part in this study. Subjects are all students of the University of Technology of Compiegne (UTC).

3.2. Experimental device

The experimental device Tactos allows the exploration and the recognition of 2D geometrical shapes. The computer is connected to a graphics tablet and tactile stimulators (2 Braille cells). By moving the stylus on the graphics tablet, the subject moves the cursor on the screen and then moves the matrix of elementary fields. When this last is crossing the shape (black pixels), the corresponding pins will be activated (see figure 5).

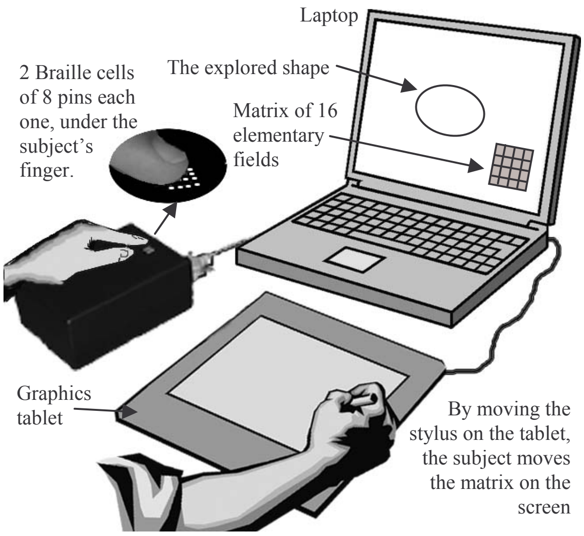


Fig. 5. The experimental device: Tactos

3.3. Experimental design

The experimental procedure comprises two phases: the first one allows subjects to understand how the device is working and to pass to the second phase which comprise the experimental phase that allows of checking the hypothesis.

3.3.1. Procedure. The study was realized with ellipses and circles and with matrices of 16 elementary fields. We defined a ratio C = M/h (M: matrix size, h: circle diameter or ellipse major axis) that enabled us to define the sizes of ellipses and matrices.

Table 1. Different sizes of matrices for the three groups according to C values

h for each group	Matrix size M (elementary field size)			
	M1	M2	M3	M4
2 cm (Grp1)	4mm (1mm)	6mm (1.5mm)	8mm (2mm)	10mm (2.5mm)
3 cm (Grp2)	6mm (1.5mm)	9mm (2.25mm)	12mm (3mm)	15mm (3.75mm)
4 cm (Grp3)	8mm (2mm)	12mm (3mm)	16mm (4mm)	20mm (5mm)
C	0,2	0,3	0,4	0,5

The table 1 summarizes the different sizes of shapes for values of C equal to 0.2, 0.3, 0.4 and 0.5. One thus obtains for each group of size, 12 possible combinations (4 sizes ((M1, M2, M3 and M4) and 3 possible orientations (Circle, horizontal ellipse and vertical ellipse) [1].

Subjects explore a fixed size of shape (T4) with different sizes of matrix. If subjects are basing their estimation of sizes on the relation between the matrix size and the shape size, perception of distances is numerical and subjects' responses are given by referring to the virtual world wherein they made their learning. Different sizes in the virtual space and sizes on a test form are showed in the figure 6.

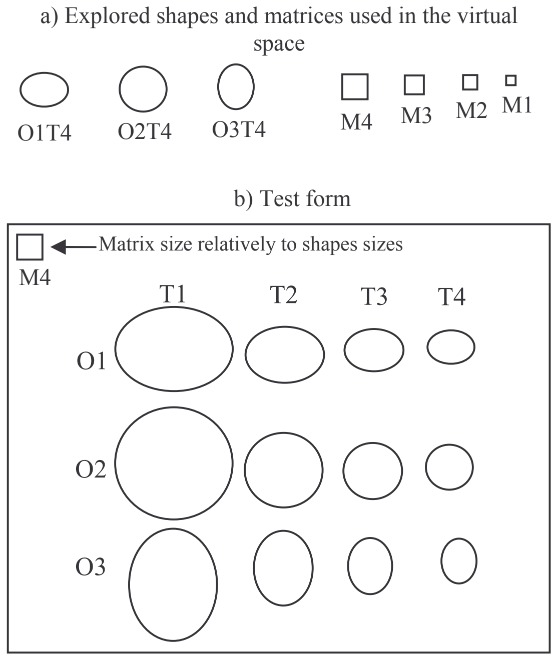


Fig. 6. a) explored shapes; b) The twelve possible combinations on a test form (reduced scale)

3.3.2. Learning phase. After explaining the device working, blindfolded subjects, must find the size and the orientation of the shape and validate visually their answers on a test form (figure 6). On this latter are illustrated the 12 possible combinations with an image scaling (see sizes on table 2).
In this learning phase, subjects have a feedback concerning their responses in order to correct their size estimation and to adjust their movements according to the presented figure. The subject has 6 trials which lasts each one 90s, chosen at random among 12 possible combinations (each subject explore at least each size among four and each orientation among three).

[1] The "circle" is a control condition and doesn't correspond to a privileged orientation.

Table 2. Different sizes of shapes (displayed in a test form) for the three groups according to C values

M (matrix size)	Shape height (ellipse major axis and circle diameter)			
	T1	T2	T3	T4
10mm (Grp1)	5 cm	3.33 cm	2.5 cm	2 cm
15mm (Grp 2)	7.5 cm	5 cm	3.75 cm	3 cm
20mm (Grp 3)	10 cm	6.66 cm	5 cm	4 cm
C	0,2	0,3	0,4	0,5

3.3.2. Experimental phase. Experimental conditions are the same that those of the learning phase (except that subjects haven't a feedback concerning their answers before the end of the experiment), i.e. that the blindfolded subject explores shapes during a maximum time of 90s and he validates his answer on a test form (The number of trials is of 24).

Our hypothesis is that subjects can base their perception of size first on the numerical space and then on the corporal space that plays a checking role for the purpose of invalidating or confirming their initial perception. This hypothesis is validated by an overestimation of the presented size.

In other words, this hypothesis supposes: If subject explores size T4 with M1 (in the virtual and real world), he will perceive and respond T1 which is displayed on the test form. The table 3 summarizes the expected responses. Performances are supposed to be better for the expected size with the corresponding matrix as shown on table 3. Subjects estimate distance by comparing the size relation between the matrix and the shape, i.e. four possible sizes of shapes to be compared to one size of matrix displayed on the test form.

Table 3. Expected responses according to the used matrix

Explored shape (in the real and virtual world)	Expected responses (Displayed on a test form)
T4 with M1	T1
T4 with M2	T2
T4 with M3	T3
T4 with M4	T4

4. Results

To calculate correct responses frequency, we coded the answers of the subjects as 0 when they were incorrect and as 1 when they were correct. Table 4 summarizes rates of correct responses for each matrix size for all the groups (there is no significant effect between the groups for the size estimation). Rates of the expected responses are displayed in light grey cells and rates of best performances with each matrix are displayed in deep grey cells.

Table 4. % of correct responses for each size according to different matrices

	T1	T2	T3	T4
M1T4	28 %	37 %	18 %	17 %
M2T4	19 %	48 %	18 %	15 %
M3T4	12 %	40 %	31 %	17 %
M4T4	11 %	29 %	35 %	25 %

Results with M1 show that better responses are obtained for biggest sizes (T1 and T2) and that this effect is significant [$F(3, 80) = 4.67$; $p = 0.004$]. Tukey post-hoc tests reveal that performances for T2 are distinguished from T3 and T4 but not from T1. Difference between performances of biggest sizes (T1 and T2) and smallest sizes (T3 and T4) are clearly made with M1 which is the smallest matrix and which corresponds, according to our hypothesis, to T1. But we also notice that the difference between T1 and T2 isn't evident.

We notice that performances with M2 are better for T2 and this corresponds to the expected responses. This effect is significant [$F(3, 80) = 16.43$; $p < 0.01$] and Tukey post-hoc tests (to significativity threshold of $p<.05$) reveal that T2 is significatively distinguished from T1, T3 and T4.

Effect is significant with the matrix M3 [$F(3, 80) = 10.89$; $p < 0.01$], post-hoc tests reveal that performances of T2 and T3 are clearly distinguished from T1 and T4 and the difference between T2 and T3 isn't significant. With M3, subjects situate shape size between T2 and T3 and reject the two other possibilities, i.e. T1 and T4.

Finally with M4, the effect is significant [$F(3, 80) = 7.86$; $p < 0.01$] and subjects seem to be more destabilized because the distinction between T2, T3 and T4 is not at all evident. However, they made a clear distinction between T1 vs. (T2, T3 and T4). Indeed, post-hoc tests reveal that performances of T2, T3 and T4 are clearly distinguished from those of T1.

We notice that performances in this experiment are near 50%. This result is relative to the choice of shapes. Indeed, with the same device, we obtain a better rate (70% and more) for flat ellipses [20]. In our case, in one hand, the eccentricity of chosen ellipses being of 0.66, ellipses are rounded and then more difficult to differentiate from a circle. In the other hand, the presence of proprioception in the perception process makes falling the performances. In order to improve these rates, a longer time of learning is necessary.

4.1. Strategies

In order to find the orientation and to estimate the size of shapes, subjects call on one or several strategies during the experiment. The definition on these strategies was defined by the recorded subjects' trajectories and verbalization (We ask to subjects to explain their manner to find the orientation and the size of the shapes).

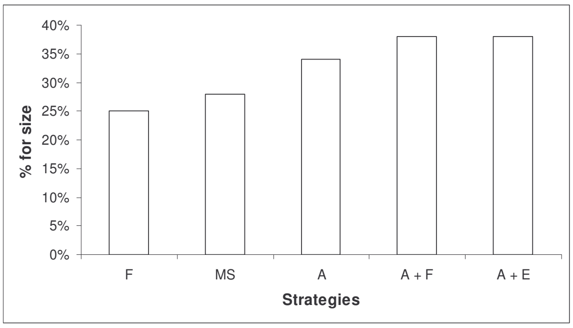


Fig. 7. % of correct answers for the size according to different strategies

Three principal strategies were deployed by subject: axes strategy (A) used by 7 subjects, outline follow-up technique (F) used by 2 subjects, macro-sweeping technique (MS) used by 5 subjects. 3 subjects combined follow-up technique with axes strategy (A + F) and finally 3 subjects used the axes strategy combined with extremities strategy (A + E).

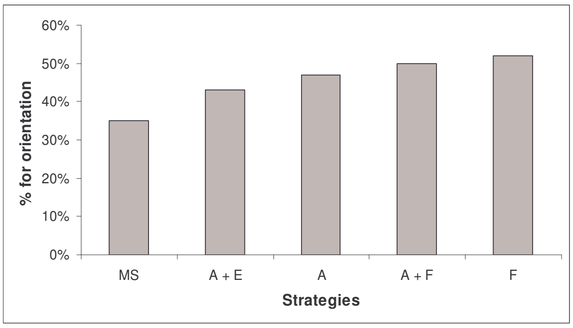


Fig. 8. % of correct answers for the orientation according to different strategies

4.1.1. Axes strategy from the center. Used alone or combined with another strategy, it is the most efficient strategy to evaluate sizes of shape (see figure 7). From the center of the shape, the subject draws symmetry axes (figure 12) in order to cross intersection points with it. This strategy can allow to the subject of having a precise estimation of the crossed distance and then of the real shape size since the distance is the same during the whole exploration but instead of this, the subjects count the number of times that the matrix can be placed inside the shape even if they haven't any idea of the matrix size. As show on figure 9, with the biggest matrix size (M4), space inside the shape is smaller than the space inside the shape with the matrix M1 (the smallest one). A small displacement with M4 inside the shape activates the pins in a brief time in comparison to the required time for displacing M1 inside the shape in order to activate pins. This time, being longer, gives the illusion of crossing a longer distance.

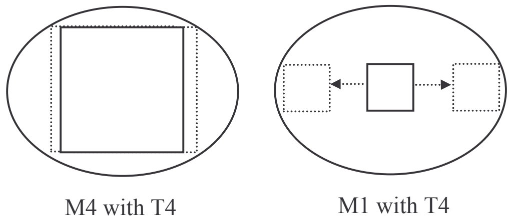


Fig. 9. Displacements of M4 and M1 inside same size shapes

This strategy is also used to find the orientation of shapes (figure 8). In this case, it isn't the circular or elliptical shape that allows to subject of giving her/his answer but it is the comparison between the horizontal and vertical axes.

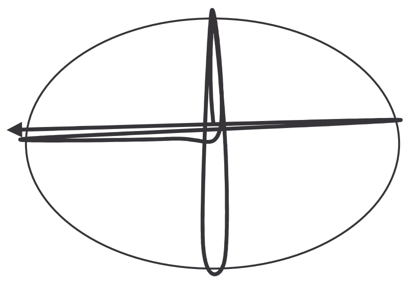


Fig.10. Axes strategy

4.1.2. Outline technique. In this strategy, the subject makes the tour on the shape by using either a continuous follow-up or a micro-sweeping strategy: With the continuous follow-up, the subject tries to circumnavigate the outline without leaving it (figure 11a). During the micro-sweeping strategy, the subject makes a rhythmical sweeping on the shape. He/She voluntarily leaves it to find it while trying to keep a regular interval between the moment when he/she leaves it and the moment when he/she finds it again (figure 11b).

This strategy is very efficient for shapes orientation. Indeed, according to figure 8, performances reach 53% when it's used alone and 50% when it's combined with the axes strategy. By the circumference of the shape, this strategy allows to subjects to have a more precise idea on the elliptical movement which they execute. According to the shape, their hand's movement is either more rounded or more flattened (vertically or horizontally).

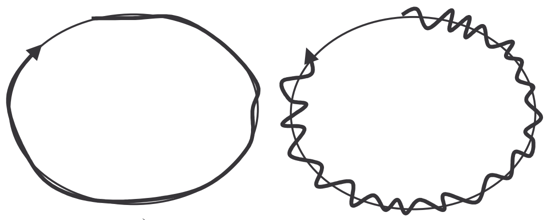


Fig. 11. Outline technique: a) continuous follow-up, b) micro-sweeping

4.1.4. Macro-sweeping technique. It consists to making a sweeping in the two senses (vertical and horizontal) on the shape (figure 12). It seems the strategy the least efficient for detecting the orientation and for estimating the size (only 28% and 35% respectively for the size and the orientation (figures 7 and 8)).

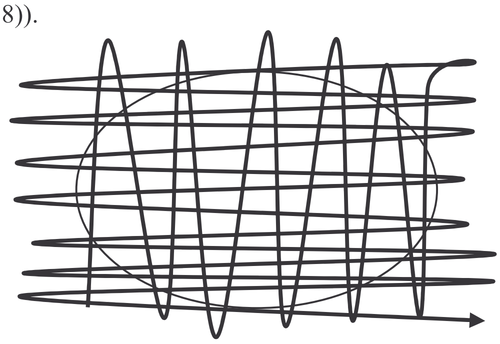


Fig. 12. Macro-sweeping strategy

5. Discussion

Results show that, whatsoever the matrix used, there is, in general, an overestimation of the real size of shape (T4) and this goes in the sense of our hypothesis. This last postulates that perception is based on the numerical space; the corporeal space is used as a checking sense to confirm or invalidate the numerical perception. Indeed, with the smallest matrix M1 subjects situate shape sizes between the biggest ones, i.e. T1 and T2. Thus the illusion of crossing a big size than the real portion of the explored space is really created but subjects have difficulties to make differentiation between T1 and T2. At this level of scale, hand's movements with M1 isn't so different of hand's movements with M2 because the size difference between the two is relatively small (4mm for group 1, 6mm for group 2 and 8mm for group 3) and this, according to the strategies used, doesn't allow them to make distinction between the two. We believe that performances will be better for T1 if hand's movements with M1 become smaller than hand's movements with M2. This can be obtained by a longer learning because six trials, even if they give to subjects an idea on sizes, aren't sufficient to make the difference between two adjacent sizes.

With M2, subjects' responses are more precise and in general without confusion. The corresponding ratio between matrix size and shape size that seems to be the more efficient in this experiment corresponds to a value of C of 0.2 and which we have called a minimal comfort threshold. Indeed, with a ratio of 0.2, performances are better than those obtained with the other values of C. In fact, the smallest matrix M1, which gives the best resolution and thus gives more details to the subject, makes him cross a biggest distance than the one crossed when he is using the biggest one (M4), but also the smallest matrix doesn't allow him to have a precise adjustment of his movements. At this level of scale, the positioning on the shape and its hanging become delicates whereas with the matrix size just above performances increase.

With the biggest matrix M4, subjects' responses are more scattered and confused. Indeed, it is clear that the presented shape doesn't correspond to the biggest size (T1) but there is no possibility to them of making distinction between the three other remaining sizes. This allowed us to define a maximal comfort threshold which corresponds to a C value of 0.4. It corresponds to the moment where the subject receives a global information but very few detailed and doesn't allow him to rule on the perceived shape.

We expect to make experiments with others geometrical shapes in order to generalize these thresholds values. Our first impression is that these values concern the shape sizes but they aren't influenced by the nature of the shape. In other words, if the task is to recognize sizes, these thresholds values remain unchanged since the factor C (shape height – matrix height) is independent on the figure nature.

Finally, subjects' strategies confirm that they based their answers on the produced movements in the virtual world because they take in account the matrix size relatively to shape size. Indeed, better performances are obtained with the axes strategy (which is used by most of subjects) for the size estimation. This is paradoxical because these strategies call on the hand displacements on the graphics tablet and call on corporeal perception but the subjects are immersed in the virtual task that they have to do and they appropriate these strategies at profit of the numerical space. Indeed, in function of the matrix size, subjects reduce or increase their exploration speed in order to perceive correctly the shapes. This speed variation isn't spontaneous in the beginning, but it becomes more and more intuitive. Indeed, at the beginning of experiment, subjects think to the task that they have to accomplish and their exploration isn't immersive but it's cognitive [1]. To avoid a cognitive exploration, we chose to give a feedback concerning subjects' responses in the learning phase in order to give them the possibility of learning one size relatively to others and of correcting their size estimation.

6. Conclusion and perspectives

Subjects are able to produce effective strategies allowing them to have a size illusion. Indeed, in order to estimate different sizes, they cross a distance on a given space and have the illusion that shapes sizes are changing whereas sizes remain fixed throughout the experiment and the only size change is made on matrix.

The illusion will be more evident if subjects are handling successive sizes in the same task. For this, in a future study, we are going to submit subjects to a continuous manipulation of matrix size in order to compare relative sizes as defined in the visual world.

We have also validated the comfort thresholds: the minimal threshold which correspond to a C value of 0.2 and a maximal threshold which correspond to a C value of 0.4. Numerical perception can be better exploited in order to immerse subjects in the virtual world if the ratio between the shape and the matrix is situated between these thresholds.

Thus, it is possible that the numerical perception constrains and calibrates the corporeal perception in a virtual world if the subject is immersed in this world but some interference can appear and make him coming back to the real world and make distinction between two adjacent objects difficult.

These changes in scale, either on the figure size or the matrix size, allow us to study multi-scales interfaces. One of these interfaces is zoomable user interfaces (ZUI) which were created in the domain of information visualization in order to remedy to problems of WIMP traditional display [3] and in order to visualize a great quantity of information on a limited space (the one of the screen). PAD [17] is one of the first zoomable user interfaces which were realised by Perlin and Fox in 1993. It led to PAD++ in 1994 [4] and Jazz in 2000 [5]. There space is infinite in length and width that which allows to the user to employ infinite pans and zooms in order to navigate in this multi-scales space.

Except works of Guiard [8] and Hightower [9], few experimental and fundamental works were carried out on zoomable user interfaces. In our case, if the subject handles directly different sizes of either matrices or shapes, it becomes clear that he will handle different levels of scales and thus different levels of zoom.

Precedent experiments [22 - 24] show that the relationship between the haptic dimension of scale (on a 2D surface) and subject depends essentially on kinaesthetic cues and relative sizes. Indeed, in a first study, we tested haptic acuity through Tactos in order to define the smallest object that a human being can perceive haptically by using a sensory substitution device. The study showed that blindfolded subjects reach a recognition rate of 80% for letters sizes smaller than 3mm [22] and a recognition rate exceeding the 50% for letters of 1.5mm [23]. However, another study has showed that performances for small sizes decrease and don't exceed the 43% [24] if the subjects must recognize in the same task big and small objects. The reason for this is that produced movements by the subjects for recognizing small objects are the same produced movements for recognizing large objects. The reduction of movements which is necessary to recognize small objects doesn't occur because it seems more practical to subjects of keeping same movements. Indeed, when they have to recognize right away very small sizes (since learning phase), subjects recognize it without no difficulty because they were able to reduce their movements according to the scale since this movements reduction is learned at the beginning of the exploration [24].

In order to put in applications these results concerning the scale, we are developing, with ENST-Paris, a Tactos prototype intended to mobile devices. Tactipen [12], the PDA stylus, which was coupled with Braille cells of 8 pins (see figure 13), was developed by Gerard Mouret of the ENST.

Fig. 13. Tactipen

Our idea is to use the Tactipen with a PDA in a pointing task of no visible objects on the screen and available only through a haptic scaling. We opted for the change in scale made on matrices instead of the scaling on images. Indeed, PDA screens being small, it's more functional of keeping a fixed image and of making a zoom on sensor than of changing the image size because of screen dimension and in order to avoid excessive use of scrollbars [11].

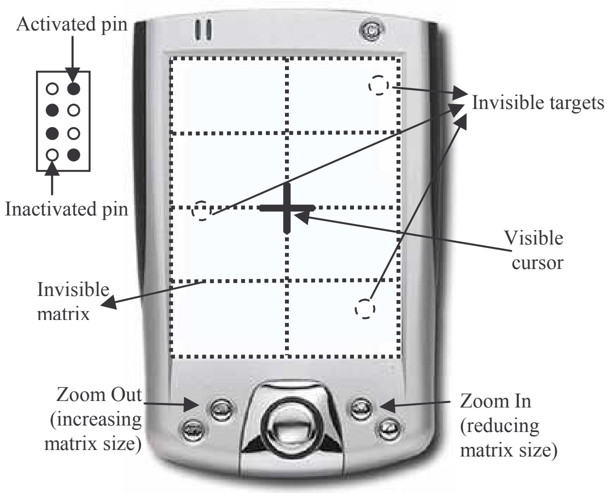


Fig. 14. A pointing task on a PDA using a mobile version of Tactos

As show on the figure 14, we are going to explain to subjects that several non visible targets are on the screen and the game principle is of detecting all targets the more rapidly possible. They know that they have to manipulate a zoom on matrix by using two keys on the PDA (one for zoom-in and another for zoom-out). The larger size of matrix has exactly the screen size in order to have a global view of the present targets and this global view is what one calls context in the zoomable user interfaces [18]. This "context" matrix allows the activation of pins which correspond to space portions where the subject can find targets (see figure 14). Matrices aren't also visible on the screen in order to choose the good matrix which will make appear the target on the screen. By "good matrix" we mean a matrix with corresponding resolution. Indeed, each target is defined of a manner to being sensitive to one specified resolution; this last is different from one target to another. In other words, only a defined size of matrix can make appear the corresponding target (see figure 15a and 15b). The cursor (a cross in bold on figure 14) is visible to allow a precise pointing on the targets. When the subject finds the good resolution and thus points on the target, the four inner pins will be activated and the target will appear on the screen (see figure 15c). The game will finish when the player finds all the targets.

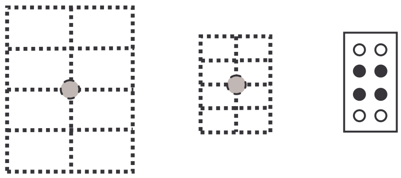


Fig. 15. a) the four inner elementary field on the target, the size of the matrix is to large to make appear the target "bad resolution", b) the four inner elementary field on the target, the resolution correspond and activate the four inner pins (c).

One of the aims of this future experiment is of testing the subjects' accuracy in a pointing task and of finding the factors which make them choose the matrix size. Strategies of the current study showed that subjects based their responses on relative size between shape size and matrix size. This future experiment will allow us to understand the phenomenon of estimation of matrix sizes (no visible at the screen) only by cursor displacements on the screen.

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References

[1] Auvray, M. *Immersion et perception spatiale. L'exemple des dispositifs de substitution sensorielle*, Ph.D Thesis. Laboratory for Experimental Psychology of the University of Paris 5, Paris, France, 2004

[2] Bach-y-Rita, P. *Brain Mechanisms in Sensory Substitution*. New York, Academic Press, 1972. 182 p.

[3] Beaudouin-Lafon, M. Instrumental Interaction: an Interaction Model for Designing Post-WIMP User Interfaces. In *CHI'00*, ACM Press, 2000, 446-453.

[4] Bederson, B. B. and Hollan, J. D. Pad++: A Zooming Graphical Interface for Exploring Alternate Interface Physics. In *UIST' 94*, ACM Press, pp. 17-26.

[5] Bederson, B. B., Meyer, J. and Good, L. Jazz: An Extensible Zoomable User Interface Graphics Toolkit in Java. In *UIST'00,* CHI Letters, 2(2): 171-180.

[6] England, R., Sensory-motor systems in virtual manipulation, In *K. Carr & R. England (eds.), Simulated*

and virtual realities: elements of perception, Taylor & Francis, Inc., Bristol, PA, 1995.

[7] Gibson, J. *The ecological approach to visual perception*, Hillsdale, New Jersey, Lawrence Erlbaum Associates, Publishers, 1986.

[8] Guiard, Y., Beaudouin-Lafon, M. and Mottet, D. Target acquisition in multiscale electronic worlds. *In Int. J. of. Hum. Comp. Stud*. Elservier, 61(6):875-905, December 2004.

[9] Hightower, R. R., Ring, L., Helfman, J., Bederson, B. B. and Hollan, J. D. PadPrints: Graphical Multiscale Web Histories. In *UIST 98*, ACM Press, 1998, pp. 121-122.

[10] Howard, I. P., and Templeton, W. B. *Human Spatial Orientation*. John Wiley & Sons, 1966.

[11] Jones, M., Marsden, G., Mohd-Nasir, N., Boone K., and Buchanan, G. Improving Web Interaction on Small Displays, *Int. J. of Comp. and Telecom. Network*. Vol. 31, 1999, p. 1129–1137.

[12] Lecolinet, E., Mouret, G. TACTIBALL, TACTIPEN, TACTITAB ou comment « toucher du doigt » les données de son ordinateur, to apear in *the proceedings of IHM'05*, ACM Press, Toulouse, September 27-30, 2005.

[13] Lee, D. N. & Aronson, E. Visual proprioceptive control of standing in human infants. *Perception & Psychophysics,* 15, 529-532.

[14] Lenay C., Gapenne O., Hanneton S., Marque C. and Genouëlle C. Sensory Substitution, Limits and Perspectives. In *Touch for Knowing*, John Benjamins Publishers, Amsterdam, 2003.

[15] Oman, C. M., Sensory conflict in motion sickness: an observer theory approach. In *Stephen R Ellis, editor, Pictorial Communication in Real and Virtual Environments*, pp 362-376. Taylor & Francis, 1991.

[16] O'Regan, J. K. and Noë, A. A sensorimotor account of vision and visual consciousness. *In Behavioral and Brain Sciences*, 24 (5), 2001, 939-1011.

[17] Perlin, K. and Fox, D. Pad: An Alternative Approach to the Computer Interface, In *Proceedings of 1993 ACM SIGGRAPH Conference*, 57-64.

[18] Pook, S., Lecolinet, E., Vaysseix, G. and Barillot, E. Context and interaction in zoomable user interfaces. In *AVI 2000*, ACM Press, 2000, 227-231 and 317.

[19] Ross, H.E. *Behaviour and Perception in Strange Environments*. London: Allen and Unwin, 1974.

[20] Sribunruangrit, N., Marque, C., Lenay, C., Hanneton, S., Gapenne, O. and Vanhoutte C. Speed-Accuracy Tradeoff During Performance of a Tracking Task Without Visual Feedback. In *IEEE Trans. Neural Syst. Rehabil. Eng.* 2004 Mar,12 (1): 131-9.

[21] Stewart, J. and Gapenne, O. Reciprocal Modelling of Active Perception of 2-D Forms in a Simple Tactile-Vision Substitution System. In *Minds and Machines*, 14: 309-330, 2004.

[22] Ziat, M., Gapenne, O., Lenay, C. et Stewart, J. Prothèses Perceptives: Acuité dynamique et stratégies d'explorations. *Journée du RESCIF*, Collège de France, Paris 2002, p. 50

[23] Ziat, M., Gapenne, O., Lenay, C. and Stewart, J. Acuité perceptive via une interface pseudo-haptique, In *IHM'04*, ACM Press, Namur, Belgium, 2004, 263-266.

[24] Ziat, M. Gapenne, O., Stewart, J. and Lenay, C. A comparison of two methods of scaling on form perception via a haptic interface, to apear in *the proceedings of ICMI'05,* ACM Presse, Trento, Italy, 2005.