

Feeling Bumps and Holes without a Haptic Interface: the Perception of Pseudo-Haptic Textures

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Abstract

We present a new interaction technique to simulate textures in desktop applications without a haptic interface. The proposed technique consists in modifying the motion of the cursor on the computer screen – i.e. the Control/Display ratio. Assuming that the image displayed on the screen corresponds to a top view of the texture, an acceleration (or deceleration) of the cursor indicates a negative (or positive) slope of the texture. Experimental evaluations showed that participants could successfully identify macroscopic textures such as bumps and holes, by simply using the variations of the motion of the cursor. Furthermore, the participants were able to draw the different profiles of bumps and holes which were simulated, correctly. These results suggest that our technique enabled the participants to successfully conjure a mental image of the topography of the macroscopic textures. Applications for this technique are: the feeling of images (pictures, drawings) or GUI components (windows' edges, buttons), the improvement of navigation, or the visualization of scientific data.

Categories & Subject Descriptors: H.5.2 [Information Interfaces and Presentation]: User Interfaces – *evaluation/methodology, haptic I/O, input devices and strategies, interaction styles, user-centered design*; H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems – *evaluation/methodology*; H.1.2 [Information Systems]: User/Machine Systems – *human factors, human information processing*

General Terms: Design, Experimentation, Human Factors.

Keywords: Texture, Control/Display ratio, bump and hole, pseudo-haptic.

INTRODUCTION

Haptic interfaces [5] can be used to simulate textures in a wide range of applications, such as computer games or

electronic commerce (e.g. feeling the texture of a cloth or a furniture). However, haptic interfaces are not widely used yet because they are still relatively expensive and complicated to use.

The aim of the present paper is thus to propose and evaluate a new interaction technique for simulating textures without a haptic interface, but with a passive input device combined with the visual feedback of a basic computer screen. The concept relies on the idea of pseudo-haptic feedback [12], applied to the simulation of textures.

The paper begins with a description of related work in the field of haptic simulation of textures and pseudo-haptic feedback. Then, we describe the concept of our alternative technique and how it is presently implemented for the simulation of two simple shapes: the bump and the hole. In the following part, we describe the results of three different empirical studies conducted to evaluate the efficiency of this technique in simulating bumps and holes. The paper ends with a conclusion and a description of potential perspectives.

RELATED WORK: FROM HAPTIC TO PSEUDO-HAPTIC TEXTURES

Researchers have recently connected several scientific fields such as mechanics, electronics, computer science, as well as psychology or neuroscience, in order to propose innovating haptic interfaces [5] [10].

The force-feedback devices simulate haptic information by addressing the user's kinesthesia. For example, a force-feedback mouse [1] [8] [10] sends forces to the user on the 2D horizontal plan. The lateral forces generated by the mouse may be used to simulate several haptic effects, such as textures. The simulation of a bump with a force-feedback mouse is achieved by sending a lateral resistive force to the user until the top of the bump is reached and, after the top, by pulling the mouse in the other direction. This technique was proposed in a pioneer work by Minsky et al. [14] who developed the "Sandpaper System", in order to simulate textures with a 2D force-feedback device. Empirical evaluations suggested that the vertical motion is not necessary to feel textures [7] [14] [16]. Hayward and Robbles-De-La-Torre [16] showed recently that even in situation of a perceptual conflict between the vertical motion and the lateral force information, subjects globally refer to the lateral force information to estimate bumps and holes.

Other approaches may use tactile matrices [11] in order to approximate the surface of the texture straight away. Tactile

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CHI 2004, April 24–29, 2004, Vienna, Austria.

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matrices can be used by blind people in order to “feel” the classical Graphical-User-Interface (GUI) in desktop applications. To simulate textures in a more abstract or symbolic manner, some interfaces may use vibrations [6].

Today several software toolkits are dedicated to simulating forces and textures with a force-feedback device [15]. The algorithms used (i.e. the “haptic rendering”) are often inspired by computer graphics techniques such as “bump mapping” [3] [5]. Bump mapping is a graphical technique for generating the appearance of a non-smooth surface by perturbing the surface normals. In the haptic case, Basdogan et al. [3] proposed to modify the direction and amplitude of the force vector “to generate bumpy or textured surface that can be sensed tactually by the user”.

The use of haptic interfaces might however remain limited for a long time yet because it is expensive and complicated to use. In order to simulate haptic sensations without haptic interfaces, several researchers have thus proposed other solutions such as sensory substitution [2], passive interfaces (or “props”) [9], and pseudo-haptic feedback [12].

Pseudo-haptic feedback was initially obtained by combining the use of a passive input device with visual feedback [12]. It was used to simulate haptic properties such as stiffness or friction [12]. For example, to simulate the friction occurring when inserting an object inside a narrow passage, researchers proposed to artificially reduce the speed of the manipulated object during the insertion. Assuming that the object is manipulated with an *isometric* input device, the user will have to increase his/her pressure on the device to make the object advance inside the passage. “The coupling between the slowing down of the object on the screen and the increasing reaction force coming from the device gives the user the illusion of a force feedback as if a friction force was applied to her/him” [12].

Pseudo-haptic effects have intuitively been used in different applications such as videogames. For example, during a driving simulation, if the car passes over the grass, the gamer must force on his/her input device to bring the car back to the main road. This effect provides the gamer with the sensation of being “glued” to the grass.

CONCEPT AND CURRENT IMPLEMENTATION OF PSEUDO-HAPTIC TEXTURES

Basic Concept

The main idea of pseudo-haptic textures consists in modifying the motion of the cursor displayed on the computer screen, during the manipulation of the input device by the user. Assuming that the image displayed on the screen corresponds to a top-view of the texture, the Control/Display¹ (C/D) ratio for the mouse is then adjusted as a function of the simulated “height” of the terrain over

which the mouse cursor is travelling. A deceleration of the cursor indicates a positive slope of the texture and conversely an acceleration of the cursor indicates a negative slope of the texture. The variations of the speed of the cursor are used here to transpose the effect of lateral forces when passing over the texture. During the exploration of textures, the lateral forces were shown to dominate other perceptual cues, in particular vertical motions [7] [14] [16]. Thus we assume that this technique is likely to make the user feel that his/her input device actually passes over the simulated texture.

Figure 1 illustrates the technique and displays the modification of the C/D ratio during the simulation of a circular bump. The bump is displayed on the screen in top-view, i.e. as a disk. When climbing the bump, the speed of the cursor decreases. Once the center of the bump is reached, the speed of the cursor increases. The simulation of a hole is achieved conversely.

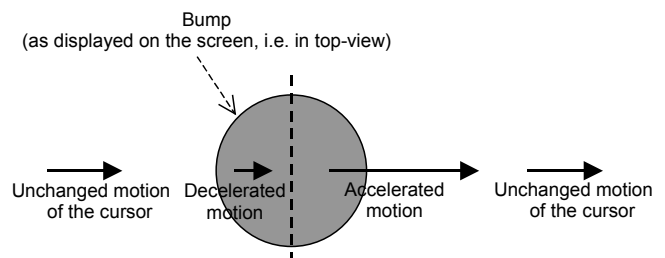


Figure 1. Modification of the speed of the cursor when passing over a bump.

It is worth noting that modifying the visual motion of the pointer – which is the cornerstone of pseudo-haptic textures – was previously proposed in other applications. It was used to facilitate drawing in CAD applications. The “snap-dragging” technique was introduced by Bier et Stone [4] in order to simplify the drawing of 2D lines and curves. This technique snaps the cursor to vertices, curves or objects edges when it is close to them, using a gravity function. The cursor can also be warped to the eye gaze area which encompasses the targets, when using an eye tacking system [18]. Swaminathan and Sato proposed to make the cursor move faster in “empty” zones and to slow it down in the vicinity of controls, “making them sticky” [17]. This technique was suggested to cover the entire display of a large screen with a simple 2D mouse. Last, the Flash software toolkit [13] is dedicated to the creation of animated and interactive web pages. This toolkit provides the web designers with several functions which can change both the C/D ratio and the shape of the cursor. Some relevant examples of applications may be found on the web [13].

Algorithm

The algorithm that we implemented is described on Figure 2. This algorithm can be used to simulate any texture, assuming that we know its height map (i.e. the distribution of heights, for the pixels of the screen).

¹ Control/Display ratio : the speed of hand movement (Control) to speed of cursor movement (Display) gives a ratio called the Control-to-Display (or C/D) ratio.

The algorithm computes an iterative solution (pixel after pixel) for the modification of the C/D ratio. When the user moves the input device, a theoretical movement of the cursor is measured along the x and y axes, and a total “amount of pixels” is computed. Then, the new position of the cursor is computed pixel after pixel by using this amount of pixels, along the theoretical path. The “cost of displacement” from one pixel to another one is related to the difference in height between the two consecutive pixels. When climbing (i.e. if the difference in height is negative), this cost is superior to 1 – i.e. it costs more than 1 pixel to move 1 pixel forward. Conversely, when descending, this cost is inferior to 1 – i.e. it costs less than 1 pixel to move 1 pixel forward. When the amount of pixels is used, the motion of the cursor is stopped and its new position is sent to the operating system and to the graphic display.

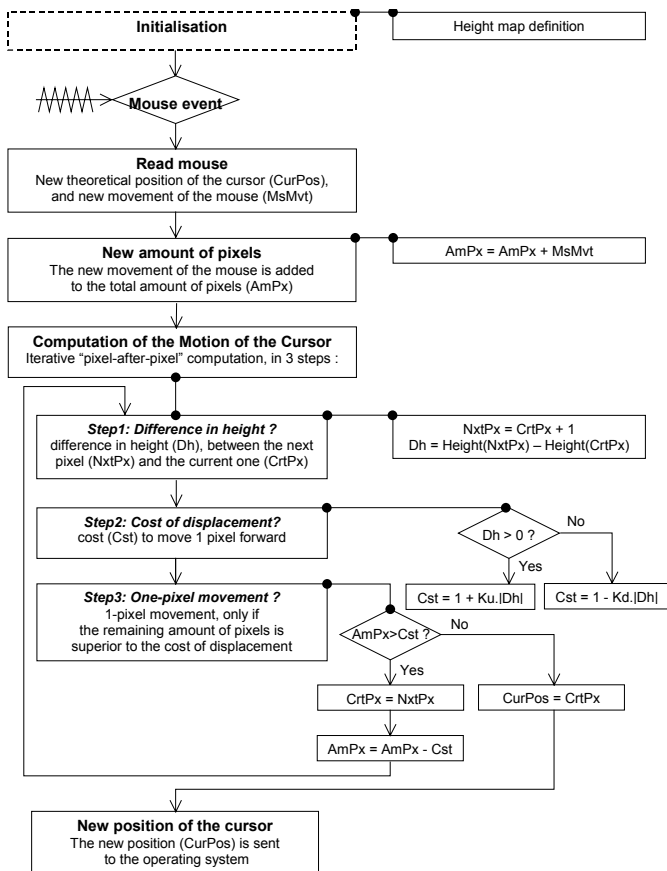


Figure 2. Algorithm used.

Simulation of bumps and holes

The algorithm was used to simulate two classical shapes: the bump and the hole – which are well-known examples of macroscopic textures [16]. Our simulation of bumps and holes used three known mathematical profiles [14] [16] (see Figure 3). Figure 3 shows the cross-section of these profiles for the simulation of bumps. These profiles were used to define the height maps of the shapes. Each profile corresponds to a mathematical distribution of heights, for the

points (or pixels) located around the center of the bump. These profiles are: a gaussian² profile, a linear profile, and a polynomial³ profile (a larger bump, with a strong slope at its base). The same three profiles were used for the simulation of holes – but in the opposite direction (i.e. with heights < 0).

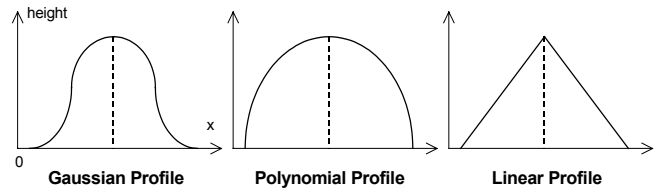


Figure 3. Profiles used for the simulation of bumps.

EMPIRICAL INVESTIGATION OF BUMPS AND HOLES SIMULATION

Three experiments were carried out with 20 participants to investigate the perception of the bumps and holes simulated with pseudo-haptic textures. An additional objective was to evaluate the impact of the profiles used to simulate these shapes on the participants’ performance and preference.

Experiment 1: can bumps and holes be identified using only visual information?

In experiment 1, the visual stimulus was a 2D surface colored uniformly in gray and a white disk (or cache) delimitating the zone where the target-shape was located (see Figure 4). The shape-related information was provided visually to the participants from both the variation of the motion of the cursor over the white disk and the white disk itself. The task consisted mainly in identifying the target-shape located under the white cache.

Experimental Plan

The experimental plan was made of 57 different targets x 5 trials. The 57 different targets were presented randomly within one series of trials. The 57 targets were:

- 54 targets generated by combining the two types of shape S_2 (Bump vs. Hole), with three different radiuses R_3 (50, 100 or 150 pixels), three different maximum amplitudes of height at the center of the shape H_3 (60, 90 or 120 pixels), and the three different simulation Profiles P_3 (Gaussian, Polynomial, Linear).
- 3 targets without a simulated shape (i.e. a flat surface) and thus without any change of the C/D ratio. Each target corresponded to one of the three radiuses R_3 (50, 100 or 150 pixels).

² The Gaussian profile of height (H) was simulated by using an exponential function: $H=H_{max} \cdot \exp(-x^2)$, with $x=|X - X_{center}|/R$.

³ The Polynomial profile was simulated by using a 4-order polynomial function: $H=H_{max} \cdot (ax^4+bx^3+cx^2+dx+e)$, with $a=10.434e-9$; $b=-27.05e-7$; $c=62.544e-6$; $d=77.457e-5$; $e=0.98343445$.

Participants

10 participants, aged between 20 and 31 (mean=24). There were 7 men and 3 women. One person was left handed. All participants had normal or corrected vision. None of them were familiar with the proposed technique.

Materials

The mouse used was a three-button infra-red mouse. The visual stimulus was a 2D gray surface of 800x600 pixels, displayed on a monoscopic computer screen (see Figure 4). The shape-target was delimited visually by means of a white disk – systematically located at the center of the 2D gray surface. The radius of the white disk was equal to that of the target (R_3). The mouse cursor was a green disk with a 10-pixel radius.

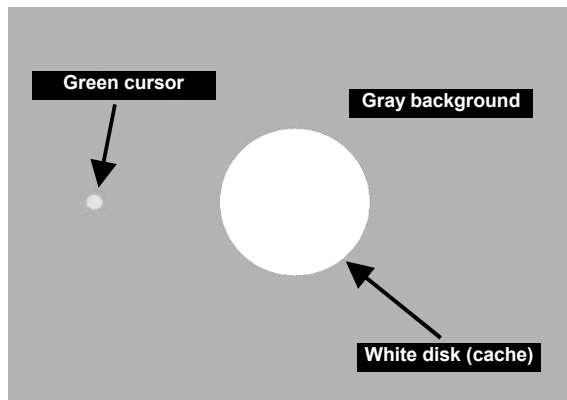


Figure 4. Visual feedback of experiment 1.

Procedure

The participants sat 60cm away from the screen. The 2D mouse was manipulated with the dominant hand. The other hand was used to enter the answers on the keyboard. This experiment consisted in a learning phase followed by a test phase.

In the test phase and for each trial, the participants were first asked to place the mouse at an initial position – indicated on the table with red marks. The cursor was automatically positioned on the left of the gray surface ($x=130;y=300$) (see Figure 4). When the participants felt ready, they pressed the space bar with the non-dominant hand to initiate the trial. They were asked to move the cursor with the mouse and pass over the white cache until they could identify the shape located under it with confidence. They had to choose between three answers: “bump”, “hole”, or “flat” surface. At the end of each series of 57 targets, the participants were invited to take a break.

In the learning phase, the participants tested 7 targets with the same procedure. The 7 targets were 6 combinations of (S_2)x(P_3) with pre-defined values of radius and height, and 1 condition of flat surface with a pre-defined radius. The 7 targets appeared in a random order.

At the end of the experiment, the participants had to fill a biographic form. The full experiment lasted approximately 45 minutes.

Collected Data

For each trial, we recorded the participants’ answer (“bump”, “hole”, or “flat”).

Results and Discussion

An ANalysis Of VAriance (ANOVA) was performed on the average percentage of correct responses (named in the rest of the paper “correctness”). The within-subjects factors were the Shape (Bump vs. Hole), the simulation Profile (Linear, Polynomial, Gaussian), the Radius of the shape (50, 100 or 150 pixels) and the Height at the center of the shape (60, 90 or 120 pixels).

The participants were highly efficient in identifying the targets when a shape was present. The average percentage of correct responses was of 92.6% for the two conditions. This is slightly less than the correctness in the flat condition, i.e. with no simulated shape (mean for Flat (mFlat) = 96.7%; standard deviation for Flat (sd) = 11%). The correctness was slightly higher for Bump (mB=93.3%; sd=18%) than for Hole (mH=91.8%; sd=21%). However, the effect of Shape was not significant on the correctness ($F(1,9)=0.67$; n.s.).

There was a main effect of the simulation Profile on correctness ($F(2,18)=17.89$; $p<.0001$). The correctness was systematically higher with the Polynomial profile (mPol=95.7%; sd=13%) than with the Gaussian profile (mGau=93.3; sd=14%). The lowest correctness (and the highest dispersion) was found with the Linear profile (mLin=88.7%; sd=26%). A posteriori tests suggested that the Linear profile was significantly less efficient than the Gaussian and the Polynomial ones (Fisher test, $p<.001$). The Gaussian and Polynomial profiles do not differ significantly. It seems thus that the strongest variations of the motion of the cursor (i.e. with polynomial profiles) enabled the participants to be more efficient in identifying shapes. Furthermore, the most continuous shapes (linear profiles) are the most difficult to identify.

Main significant effects on the correctness were found for both the Height ($F(2,18)=13.99$; $p<.0002$) and the Radius ($F(2,18)=11.66$; $p<.0006$) of the target. The two-way and three-way interactions implying Profiles, Heights and Radiuses were also significant (all at $p<.0001$). Correctness increased as Radius decreased and Height increased. Thus, when the slope of the shape increased, the participants were more efficient in identifying the simulated shape. Figure 5 shows the evolution of correctness as a function of the “slope ratio” (i.e. the ratio Radius/Height). Correctness seems to increase when the slope ratio decreases. This confirms the fact that correctness is related to the slope of the simulated shape. It also gives an insight into the ranges of Height and Radius values which ensure a correct identification of the shape. Indeed, this ratio must remain inferior to 1.25 to obtain an average correctness of at least 95% (within our experimental context).

Conclusion

This first experiment showed that, with our technique, the participants were able to identify the simulated bumps and holes very efficiently. Furthermore, the slope of the shape and more generally its simulation profile both seemed to influence the participants' performances.

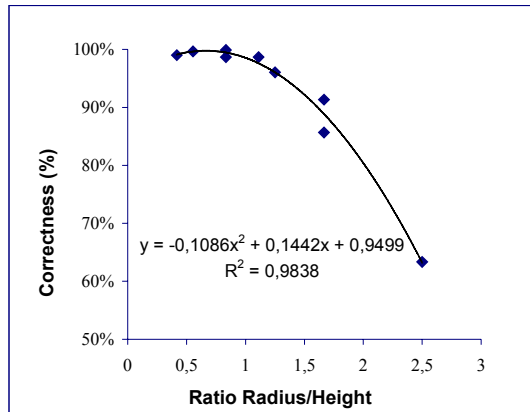


Figure 5. Effect of slope ratio (Radius/Height) on correctness.

Experiment 2: is the global topography of the shape reconstructed with the sole motion of the cursor?

Considering the materials used in experiment 1, the participants might have combined the variations detected in the motion of the cursor with the information provided by the visual white disk to estimate the shapes. It is indeed difficult to know whether the participants actually conjured a mental representation of the topography, or whether they estimated how the motion of the cursor is modified according to the white disk.

The second experiment was thus conducted to evaluate the participants' ability to extract the global topography of the simulated shape from the sole information provided by the variation of the motion of the cursor. The shapes used in this experiment remained basically the same as in experiment 1 (Bump, Hole, or Flat surface). However, we did not display the white disk on the computer screen. Thus, we did not provide additional visual information about the size and location of the target-shape – which were both conveyed in experiment 1 respectively by the radius and the center of the white cache.

Experimental Plan

The experimental plan was made of 7 targets x 5 trials. The 7 different targets were presented randomly within one series of trials. The 7 targets were:

- 6 targets generated by combining the two types of shape S_2 (Bump vs. Hole), with the three different simulation Profiles P_3 (Gaussian, Polynomial, Linear). Both the radius and height of the 6 targets were kept constant ($r=100$ pixels, $h=90$ pixels).
- 1 target without a simulated shape (i.e. a flat surface).

Participants

10 participants (who did not participate in experiment 1), aged between 20 and 46 (mean=29). There were 6 men and 4 women. One person was left handed. All participants had normal or corrected vision. None of them were familiar with the proposed technique.

Materials

The same materials as in experiment 1 were used, except that no white disk was displayed. The target shape (Bump, Hole, or Flat surface) was placed randomly at any position of the gray surface.

Procedure

The same procedure as in experiment 1 was used, except that the participants were asked to explore the *entire* gray surface until they could find and identify the shape with confidence. They were also asked to position the cursor where they estimated that the center of the simulated shape was. The participants could take a break at the end of each series of 7 targets.

In the learning phase, the 7 targets were 6 combinations of (S_2)x(P_3) – with constant radius ($r=100$) and height ($h=90$) – and 1 condition of flat surface. The 7 targets appeared in a random order and were located at the center of the gray surface. At the end of the experiment, the participants had to fill a biographic form. The full experiment lasted approximately 35 minutes.

Collected data

For each trial, we recorded the participants' answers (“bump”, “hole”, or “flat”), and the distances (in pixels) between the position of the cursor when validating the answer and the center of the simulated shape.

Results and Discussion

An ANOVA was performed on the average percentage of correct responses (correctness) and on the average distance to center. The within-subjects factors were the Shape (Bump vs. Hole), and the Profile (Linear, Polynomial, Gaussian).

When a shape was present, the participants performed the identification slightly less efficiently than in experiment 1 (mean correctness=86%; standard deviation=21%). However, they were still very efficient when no shape was simulated (mFlat=98%; sd=6%). ANOVA did not show a significant effect of the Shape ($F(1,9)=.167$; n.s.) on the correctness. Participants performed similarly regardless of the shape (mB=85.3%; sd=21%, mH=86.7%; sd=21%). These results suggest that the task of this experiment was probably more difficult than that of the first experiment – i.e. with the white disk. However, with a mean correctness superior to 85%, we consider that participants were still able to identify the shapes efficiently, with the sole variations of the motion of the cursor.

On average, the participants identified the shapes more efficiently with the Polynomial profile (mPol=90%; sd=18%) than with the two other profiles. They had nearly the same level of performance with the Linear profile (mLin=84%;

sd=22%) and with the Gaussian profile (mGau=84%; sd=23%). This seems to confirm the superiority of the Polynomial profile for the identification task. However, ANOVA did not show a significant effect of the Profile used on the correctness, since Gaussian and Linear conditions provided similar correctness ($F(2,18)=3.12$; $p<.069$).

Participants were slightly more accurate in localizing the center of Bumps (mean distance to center for the bumps (mB) = 33.8 pixels; sd = 23 pixels) than that of Holes (mH=37.2p; sd= 51). The dispersion was two times more important for Holes than for Bumps. Consequently, there was no significant effect of the Shape ($F(1,9)=0.18$; n.s.) on the distance to center. However, there was a significant effect of the simulation Profile ($F(2,18)=5.46$; $p<.014$) on the distance to center. The participants were more accurate with Gaussian profiles (mGau=23.6p; sd=24) and then with Linear profiles (mLin=30.8p; sd=18). They were much less accurate with Polynomial profile (mPol=52.3p; sd=58). This latter result is probably due to the characteristics of the Polynomial profile. Indeed, the mathematical function chosen for the Polynomial profile generates the presence of a large “plateau” at the middle of the shape (see Figure 3). The presence of this plateau may have disabled the participants to localize the center of the shape accurately.

Conclusion

This second experiment showed that even when no other visual information was added to the variations of the motion of the cursor, the participants were still able to identify the simulated shapes efficiently. However, the mental image of the topography of the shapes does not seem easy to conjure up. The participants' accuracy in localizing the shapes centers is indeed affected by the profile used to simulate the pseudo-haptic textures. This might suggest that the participants based their estimation on the local variation of the motion of the cursor, but did not actually conjure a persistent mental image of the topography.

Experiment 3: investigation of the users' preference and perception of the detailed topography

The experimental paradigm was changed for this third experiment. Our objective was to collect data about the participants' preference, and about their perception of the shapes properties, according to the different simulation profiles (Gaussian, Linear, Polynomial). Consequently, the participants were asked to explore sequentially the 6 simulation profiles of bumps and holes and to draw them on a sheet of paper.

Experimental Plan

The experimental plan was made of 6 different target shapes generated by combining the two types of shape S_2 (Bump vs. Hole) and the three different simulation Profiles P_3 (Gaussian, Polynomial, Linear). Both the radius and height of the targets were kept constant ($r=100$ pixels, $h=90$ pixels).

Participants

The 20 participants who participated in experiment 1 and experiment 2.

Materials

We used the same materials as in experiment 1.

Procedure

This experiment consisted in one test phase. The participants sat 60cm away from the screen. The 2D mouse was manipulated with the dominant hand. Six keys of the keyboard were dedicated to the activation of the six targets. The three first keys (and targets) were explicitly presented as the “hole profiles”, while the three other keys were presented as the “bump profiles”. The participants were asked to draw the cross-section of each target. For this aim, at the beginning of the experiment, the participants were given 6 graduated sheets of paper. The vertical and horizontal axes were displayed on each sheet of paper. The participants had the possibility to compare and to test each target the way they wanted. They were asked to explore all the targets before they could begin to draw. At the end of the experiment the participants were also asked to rank the targets according to “how well they simulated bumps or holes”. The full experiment lasted approximately 20 minutes.

Collected Data

The drawings of the participants for the 6 simulated shapes, and their rankings of the different simulation profiles of bumps and holes.

Results and Discussion

The participants' drawings provided some concrete indications concerning the properties of the shapes which were perceived by the participants.

Globally, 90% of the drawings (108/120) were symmetric (right-left). This suggests that the participants perceived this property of the simulated shapes. Then we measured the maximum height and the diameter of the drawn curves on the sheets of paper. The maximum amplitude of heights was similar for Bumps and for Holes (mH=16mm; sd=6mm, mB=16mm; sd=6mm). It was also the case for the diameters (mH=51mm; sd=11mm, mB=51mm; sd=11mm). Thus, the participants seemed to perceive also the symmetry between Bumps and Holes. Two distinct repeated ANOVA were performed on the Height and on the Diameter of the drawn curves. The within-subjects factors were the Shape (Bump vs. Hole) and the Profile (Linear, Polynomial, Gaussian). There was no significant effect of Profile on the drawn Height ($F(2,38)=2.26$; n.s.). However, we found a significant main effect of the Profile on the drawn Diameter ($F(2,38)=7.76$; $p<.0015$), and a two-way interaction between Shape and Profile ($F(2,38)=4.81$; $p<.014$). Indeed, the diameter of Gaussian shapes was drawn smaller than that of Polynomial and Linear shapes (mGau=46mm; sd=12mm, mPol=53mm; sd=9mm, mLin=54mm; sd=16mm, Post-hoc comparisons between Gaussian and other profiles are significant at $p<.006$).

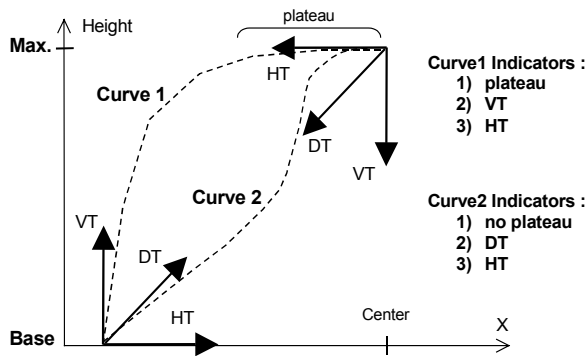


Figure 6. Indicators used to analyze the drawn curves (drawings of the left side of a bump).

Each curve drawn by the participants was then analyzed according to three indicators (see Figure 6):

1. the presence (or absence) of a “plateau”, drawn at the center of the shape,
2. the tangent at the base of the shape: horizontal (HT), diagonal (DT), or vertical tangent (VT),
3. the tangent (HT, DT, VT) at the extremum of the shape (i.e. minimum for a hole, and maximum for a bump). (When a plateau was present, we considered the tangent at the edge of the plateau).

The right and left sides of each curve were both taken into account for all analyses.

Table 1 shows the results of the analysis of the first indicator. There is a strong relation between the presence of a plateau and the Profile used (V2 Cramer =.28). The participants perceived a plateau in the case of a Polynomial profile (TDL=+1), and did not perceive it in Gaussian (TDL=-.63) and Linear (TDL=-.44) cases. This effect is significant (Khi2=45.63, dof=2, p<.0001). These results indicate that the presence of a plateau enabled the participants to characterize the Polynomial profile.

Table 1. Presence of a plateau on the drawn curve.

Drawn plateau	Linear	Polynomial	Gaussian
yes	9	33	6
no	31	7	34

Table 2 shows the results of the analysis of the second indicator. There is an intermediate relation between the tangent at the base of the shape and the simulation Profile (V2 Cramer =.15). Linear profiles were associated with the drawing of a diagonal tangent at the base of the curve (TDL=+.45). Polynomial profiles were strongly associated with the drawing of a vertical tangent (TDL=+1.68). Last, Gaussian profiles were associated with horizontal tangent (TDL=+.72). This effect is significant (Khi2=78.86, dof=4, p<.0001). These results show that participants drawn and perceived the base of the different simulation profiles correctly. They were able to distinguish the three profiles according to this indicator. However, Linear and Polynomial

profiles may sometimes be confused since they are both often drawn with a diagonal tangent at the base.

Table 2. Directions of tangents at the base of the curve.

Direction of the tangent at the base of the curve	Linear	Polynomial	Gaussian
Horizontal	22	21	58
Diagonal	58	42	20
Vertical	0	17	2

Table 3 shows the results of the analysis of the third indicator. The tangents drawn at the extremum of the curves did not differ much as far as the simulation profile was concerned (V2 Cramer=.05). This may be due to the fact that horizontal tangents were often drawn, in all cases. The effect is however significant (Khi2=25.74, dof=4, p<.0001). This indicator does not seem to show a distinction of perception between the different simulation profiles. However, it is worth noticing that the Linear profile was often drawn with a diagonal tangent at the extremum.

Table 3. Directions of tangents at the extremum of the curve.

Direction of the tangent at the extremum of the curve	Linear	Polynomial	Gaussian
Horizontal	44	59	59
Diagonal	36	19	13
Vertical	0	2	8

To summarize the characteristics of the curves drawn by the participants, it seems that: Polynomial profiles were drawn with a plateau and a strong slope at the base of the curve. Gaussian profiles were drawn thinner than the other profiles, without a plateau and with an horizontal tangent at the base. Linear profiles were drawn without a plateau and with diagonal tangents at the extremum and at the base of the curve.

Table 4. Preferences of the participants.

Shape	Profile	Ranked in 1 st place	Ranked in 2 nd place	Ranked in 3 rd place
Hole	Linear	6 times	6 times	8 times
	Polynomial	11	3	6
	Gaussian	3	11	6
Bump	Linear	5	5	10
	Polynomial	7	7	6
	Gaussian	8	8	4

The participants’ preferences were then analyzed by using the ranks given for the simulation of Bumps and Holes for the three different profiles (see Table 4). The participants’ preferences were clearly in favor of the Polynomial profile for simulating Holes. The scheme is rather different for the Bumps. Indeed, the simulation profile that came most often in 1st and 2nd is the Gaussian one. It is followed closely by the Polynomial profile. The Linear profile seems to be the less preferred profile in all cases.

The participants' preference partially confirms the results found in experiments 1 and 2. The Linear profiles lead to the lowest correctness in experiments 1 and 2, and were considered less efficient to simulate bumps and holes in experiment 3. However, although performances did not differ between bumps and holes in experiments 1 and 2, the participants strongly preferred the Polynomial profile for the simulation of holes.

Conclusion

This third experiment showed that participants accurately perceived differences between the three simulation profiles. These differences – as observed in the drawings – correspond to actual characteristics of the mathematical functions chosen for the simulation profiles (described on Figure 3). This implies that participants were able to conjure different mental representations of the shapes, which are consistent with the actual simulation profiles used.

GENERAL CONCLUSION AND PERSPECTIVES

We proposed a novel interaction technique to simulate textures in desktop applications by using a passive input device combined with visual feedback. It consists in modifying the motion of the cursor when it passes over simulated textures. The Control/Display ratio is adjusted as a function of the simulated “height” of the terrain over which the mouse cursor is travelling. Three experiments were conducted to evaluate the possibilities to simulate macroscopic textures such as bumps and holes with this technique. The results showed that participants successfully identified bumps and holes by only using the variations of the motion of the cursor. The slope of the shapes and the simulation profiles both seemed to influence strongly the participants' performance. Furthermore, the participants could draw the different profiles of bumps and holes which we simulated, correctly. These results suggest that our technique enabled the participants to reconstruct the topography of the macroscopic textures.

Future works deal with the simulation of textures finer than bumps and holes, i.e. microscopic textures. We need to study the limits of our technique in terms of perception.

We finally suggest several applications of this technique: First, the feeling of images (pictures, drawings). Second, the improvement of html pages with texture and attraction/repulsion effects. Third, the perception of GUI components (edges, buttons). Fourth, the guidance of the user during navigation. Fifth, the visualization of scientific data.

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