A Study of the Modification of the Speed and Size of the Cursor for Simulating Pseudo-Haptic Bumps and Holes

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In previous work on so-called pseudo-haptic textures we investigated the possibility of simulating sensations of texture without haptic devices by using the sole manipulation of the speed of a mouse cursor (technique called hereby Speed technique). In this paper, we describe another technique (hereby called Size technique) to enhance the Speed technique and simulate texture sensations by varying the size of the cursor according to the local height of the texture displayed on the computer screen. With the Size technique, the user would see an increase (decrease) in cursor size corresponding to a positive (negative) slope of the texture.

We have conducted a series of experiments to study and compare the use of both the Size and Speed technique for simulating simple shapes like bumps and holes. In Experiment 1, our results showed that participants could successfully identify bumps and holes using the Size technique alone. Performances obtained with the Size technique reached a similar level of accuracy as found previously with the Speed technique alone. In Experiment 2, we determined a Point of Subjective Equality between bumps simulated by each technique separately, which suggests that the two techniques provide information that can be perceptually equivalent. In Experiment 3, using paradoxical situations of conflict between the two techniques, we have found that participants' answers were more influenced by the Size technique, suggesting a dominance of the Size technique over the Speed technique. Furthermore, we have found a mutual reinforcement of the techniques, i.e., when the two techniques were consistently combined, the participants were more efficient in identifying the simulated shapes. By conducting Experiment 4, we further observed the complex interactions between the information associated with the two techniques in the perception and in the decision process related to the accurate identification of bumps and holes.

Taken together, our results promote the use of both techniques for the low-cost simulation of texture sensations in applications such as videogames, internet, graphical user interfaces, etc.

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1. INTRODUCTION

This research is part of an ongoing effort dealing with the integration of haptic sensations in human-computer interaction. It is devoted to simulating texture sensations, for instance when moving a cursor in a 2D desktop, or when manipulating the objects of a 3D virtual reality simulation. For this aim, previous work [Lécuyer et al., 2004] exploited changes of the speed of the cursor to simulate texture sensations, without using any haptic device i.e., without a device with mechanical actuators able to provide the real physical stimulation. This previous technique was called “pseudo-haptic textures” as a reference to the more general technique known as “pseudo-haptic feedback” [Lécuyer et al., 2000]. In the pseudo-haptic textures technique, 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. From this variation of the speed as the cursor passes over the simulated shape (hereby called “Speed technique”), it was shown that users could easily identify between macroscopic shapes like bumps or holes.

In the following paper, we aim to explore the possibility of reinforcing the effect of the pseudo-haptic textures provided by the Speed technique, in order to give a more fulfilling sensation to the user. To do so, we study another technique based on a change of the size of the cursor. If the cursor is climbing a slope its size is increased (zoom-in effect) and conversely if it descends the slope its size is decreased (zoom-out effect).

Therefore, the paper begins with a description of related work in the field of haptic simulation and pseudo-haptic feedback. Thereafter, it describes the implementation of the “Size technique” for the simulation of texture sensations by modifying the size of the mouse cursor. Then it describes the results of experiments conducted to investigate the efficiency of the Size technique, and to compare its influence with the one of the Speed technique proposed previously, for the simulation of simple shapes like bumps and holes. The paper ends with a general discussion and a conclusion.

2. RELATED WORK

2.1 Haptic Simulation of Bumps and Holes

In order to increase the sensations during the interaction between user and computer, haptic devices [Burdea, 1996] were created to generate stimulations on the sense of touch. Various tactile devices were developed to simulate the wide range of properties sensed by our skin and involved when exploring textures with our fingers. For instance, vibratory tactile devices can be used to display globally the texture profile of different types of material [Ikei et al., 1997]. More sophisticated tactile displays made of pin arrays

[Shimojo et al., 1999] can approximate precisely the profile of a touched texture. Thermal feedback can also be added to enhance the overall perception of the object's surface [Jones and Berris, 2002].

Force-feedback devices are another type of haptic interface that physically constrains the motion of the user by exerting forces on the body [Burdea, 1996]. Minsky [1995] showed that a 2D force-feedback device (the "sandpaper system") could be used to provide the sensation of passing over a texture and feeling its 3D relief. The lateral forces exerted by the sandpaper system could be used for simulating simple textures like bumps and holes [Minsky, 1995]. The simulation of a bump with such a 2D force-feedback device 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.

Since the pioneer experimentations of Minsky, work of Robles-De-La-Torre and Hayward [2001] demonstrated the pre-eminence of lateral force cues when exploring textures by touch. They explored the relationship between force cues (lateral forces) and geometrical cues (height changes) regarding the perception of textures. In reality, an object ascending a bump would experience a resistance and at the same time be displaced upward. Geometrical and force cues are correlated, but it has been commonly assumed that shape perception relies mainly on object geometry (e.g., change in height). However, Robles-De-La-Torre and Hayward's experiment has proven otherwise. It is lateral force cues that have a dominating influence on the user's perception of texture. To demonstrate this surprising property, they have set up an experiment in which participants were exploring bump and hole profiles through a haptic device, under different experimental conditions: information of lateral forces only (force cues), information of height changes only (geometrical cues), correlated information of both force and geometrical cues, and a conflict condition which used paradoxical stimuli (for example combining the force cues of a bump with the geometry of a hole). The researchers found in the latter case that, regardless of surface geometry, "*subjects identified and located shape features on the basis of force cues or their correlates. When combining the force cues of a hole with the geometry of a bump, subjects typically perceived a hole*" [Robles-De-La-Torre and Hayward, 2001].

Nowadays, several haptic software (haptic API or Application Programming Interfaces) use a modification of the lateral force fed back to the user to render sensation of textures [Haption, 2005]. This technique is comparable with the "bump mapping" technique of computer graphics for the appearance of non-smooth surfaces by perturbing the surface normal. In the 3D case, Basdogan et al. [1997] also introduced a modification of the direction and amplitude of the force vector so "*to generate bumpy or textured surface that can be sensed tactually by the user*".

2.2 Sensory Substitution and Pseudo-Haptic Feedback

Several researchers have proposed alternative solutions in order to simulate haptic sensations without using haptic interfaces. For instance, Avanzini et al. [Avanzini et al., 2005] have proposed to use sensory substitution based on friction sounds to enhance interaction with virtual objects in absence of haptic display and provide a substituted sensation of textures. Pseudo-haptic feedback is another simple way of simulating haptic sensations without using expensive haptic interfaces [Lécuyer et al., 2000]. Pseudo-haptic feedback relies on visuo-haptic coupling i.e., combination of the user's actions in the simulation (for example, via a passive input interface like a computer mouse) with the visual feedback. As an example, to simulate the friction when inserting a virtual object inside a narrow passage, the visual speed of the manipulated object is reduced 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. As a consequence, "*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*" [Lécuyer et al., 2000]. It has been shown already that pseudo-haptic feedback could be used to simulate various haptic properties such as the stiffness of a virtual spring [Lécuyer et al., 2000], torque feedback [Paljic et al., 2004] or the mass of a virtual object [Dominjon et al., 2005].

2.3 Pseudo-Haptic Textures: the "Speed Technique"

In « pseudo-haptic textures », Lécuyer et al. [2004] have proposed a technique for simulating texture and relief of 2D images displayed on a computer screen using pseudo-haptic feedback (technique called hereby "Speed Technique"). A similar approach was also proposed by Van Mensvoort [Van Mensvoort, 2002]. When the user manipulates a computer mouse, the Speed technique consists of altering the cursor's motion as it moves over the image. To create the impression that the cursor is climbing up a slope, it is slowed down. Inversely, to simulate the cursor sliding down a slope, it is sped up. For example, to simulate the cursor moving over a bump, as displayed in Figure 1, the cursor is slowed down until it reaches the top of the bump. Once it is past the top, the cursor accelerates until it reaches the foot of the bump. After that, it returns to its normal speed.

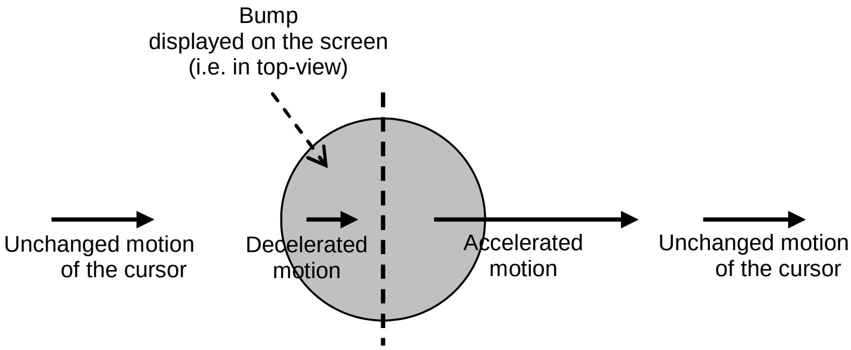

Fig. 1. Speed technique: Modification of the speed of the cursor when passing over a bump (gray disk) [Lécuyer et al., 2004].

This technique can be related to the results obtained by Minsky [1995]. Indeed, it aims at providing "virtual lateral forces", at the level of the visual feedback, by accelerating and decelerating the cursor. Here, however, virtual lateral forces are applied to the cursor, rather than to the finger of the user.

This technique was evaluated in three experiments in [Lécuyer et al., 2004]. The first experiment showed that participants were able to identify simulated bumps and holes very efficiently. The second experiment studied the capacity to identify bumps and holes relying solely on information about cursor movement alone i.e., without any other visual information. Last, the third experiment investigated relief perception by asking subjects to draw the profile of the surfaces covered. Taken together, the results of these three experiments demonstrated that subjects were able to identify and precisely draw textures simulated using pseudo-haptic textures [Lécuyer et al., 2004].

3. CONCEPT AND IMPLEMENTATION OF THE SIZE TECHNIQUE

In this section we describe the concept and implementation of the "Size technique": a technique meant to simulate sensations of texture by using only changes in the size of a mouse cursor.

3.1 Concept of the Size technique

Assuming that the image displayed on the screen corresponds to a top-view of a texture, the Size technique consists in changing the size of the cursor according to the simulated height of the terrain over which the cursor is traveling. An increase in the size of the cursor is associated with a shorter distance from the eye (zoom-in effect), and thus with a positive slope of the texture. Conversely, a decrease in the size of the cursor (zoom-out effect) indicates a negative slope of the texture.

Figure 2 illustrates the concept of the Size technique, and displays the modification of the cursor's size during the simulation of a circular hole. When descending the hole, the size of the cursor decreases. After passing the centre of the hole, the size of the cursor increases. The simulation of a bump can be achieved conversely.

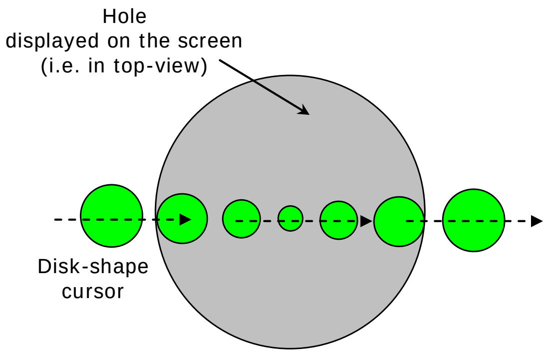

Fig. 2. Size technique: Mouse cursor (green disk) moving into and out of a hole shape (gray disk).

The Size technique can be related to the well-known Emmert's law [Emmert, 1881] [Boring, 1940] [Young, 1951], which provides the relationship between the perceived size of an afterimage and the distance of the surface upon which the afterimage is projected (see Figure 3).

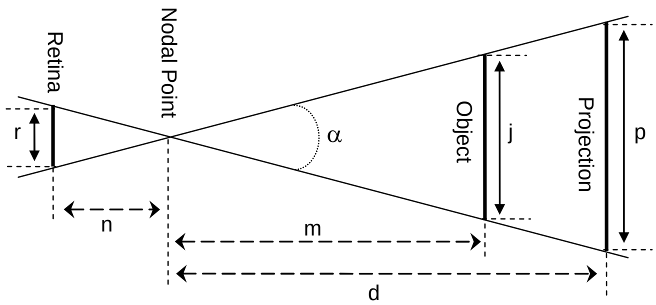

Fig. 3. The Optical Geometry of Emmert's Law [Boring, 1940].

The Emmert's law can be represented by Equation 1 [Nakamizo and Imamura, 2004], in which *s* is the perceived size of an afterimage (*p* on Figure 3), *d* is the perceived distance of the surface on which the afterimage is projected, and α is the visual angle subtended by the afterimage. If the object gets closer to the eyes (i.e., if m decreases on Figure 3), α increases and the apparent size *s* of the afterimage also increases, proportionally.

$$\frac{s}{d} = \tan(\alpha) \qquad (1)$$

The Emmert's law is generally associated with the size-distance invariant hypothesis or Size Constancy Theory, i.e., the tendency to perceive objects as constant in size, when the size of the retinal image changes, by moving closer to or farther from the objects [Hershenson, 1999]. Interestingly, the Emmert's law was found applicable in both real and virtual environments [Nakamizo and Imamura, 2004]. Changes in size of an object are then perceived as changes in depth, and this does not depend on the viewing distance, assuming that the viewing distance is considerably greater than both the interpupillary distance and the object's width [Erkelens and Regan, 1986].

3. 2 Implementation

In the initialization phase of our algorithm, we define the height map of the terrain i.e., the height of every pixel on the screen. Tracking the current position of the cursor, the algorithm determines the height (*hc*) of the terrain the cursor is currently on. Then, the algorithm computes a height difference ($dh = h_c – h_0$) by comparing the cursor's height to the height h_0 at ground level i.e., the height at the level of the screen plane. Thus, similarly to Emmert's law, the size of the cursor (radius *Rc*) is linearly changed, using Equation 2. In this Equation, R_0 corresponds to the initial value of the radius (size of cursor at h_0) and K is a constant coefficient.

$$R_c = R_0 + K \times dh \qquad (2)$$

The Size technique described here is similar to the "visual-haptics" technique developed by Watanabe and Yasumura [2003]. It can also be related to the "Fisheye view distortion techniques", with which Benderson [2000] introduced "Fisheye menus" that change the size of menu items to provide a focus area around the mouse pointer dynamically.

4. EMPIRICAL EVALUATION

A series of experiments was carried out to investigate the possibility of using the Size technique for perceiving simple shapes like bumps and holes, as well as to compare its use with the one of the Speed technique described in [Lécuyer et al., 2004]. The first experiment was conducted to determine the efficiency of the Size technique in simulating bumps and holes. The second experiment aimed at determining an ideal K coefficient (Equation 2) to make the Size technique comparable to the Speed technique for simulating bump shapes. The third experiment made use of this ideal K coefficient to compare the relative influence of the two techniques on user's perception. In the fourth experiment we re-conducted Experiment 3 using a smaller value of K, i.e., decreasing the power of the Size technique, to further investigate the user's perception and the interactions between the two techniques.

4.1 Experiment 1: Can bumps and holes be identified using the Size technique?

The first experiment aimed to study if the enables to identify simple texture shapes like bumps and holes, using a classical computer mouse and a computer screen. The visual stimulus was a 2D surface colored uniformly in grey, and a white disk (or mask) delimitating the zone where the target-shape was located (see Figure 4). The shape-related information was provided visually from the variation of the size of the cursor over the white disk. The task consisted in identifying the target-shape located under the white mask, by moving the cursor in that area.

4.1.1 Participants

Ten participants, aged between 21 and 27 (mean=24, SD=1.6) did the experiment. All were male and one person was left-handed. All participants had normal or corrected vision. None of them was familiar with the proposed technique.

4.1.2 Experimental Apparatus

Experimental apparatus was the same as in Experiment 1 of [Lécuyer et al., 2004]. We used a monoscopic 15-inches LCD computer screen with a pixel pitch of 0.297mm and a three-button optical mouse. The visual stimulus was a 2D grey surface of 800x600 pixels (237.6x178.2 mm) as displayed on Figure 4. The target-shape was delimited visually by the white disk which had a radius equal to that of the target-shape. The mouse cursor was a green circle with a 12-pixel radius (3.56 mm). The K value was set to 0.3334. As a result, the cursor had a maximum radius of 14, 15 and 16 pixels (4.16, 4.46, and 4.75 mm) at the centre of bumps with virtual heights of 60, 90 and 120 pixels respectively (17.82, 26.73, and 35.64 mm). For holes, the minimum radius of the cursor would be 10, 9 and 8 pixels (2.97, 2.67, and 2.38 mm) at the centre for the three different heights respectively. To keep the similarity with Experiment 1 of [Lécuyer et al., 2004], three different simulation profiles were used for the simulation of bump and hole shapes: a Gaussian profile, a Linear profile and a Polynomial profile (i.e. bell shape), as displayed on Figure 5. More details about these profiles can be found in [Lécuyer et al., 2004].

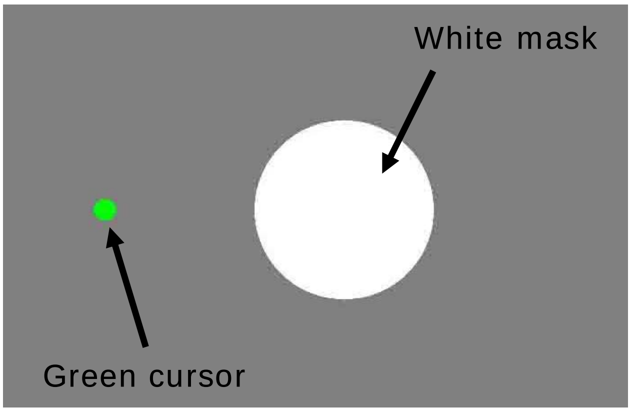

Fig. 4. Visual display.

4.1.3 Experimental Plan

The experimental plan was identical with that of Experiment 1 of [Lécuyer et al., 2004]. It was made up of 57 different targets tested 5 times. The 57 different targets were presented randomly within one series of trials. The 57 targets were:

- 54 targets generated by combining two types of shape S_2 (bump vs. hole), with three different simulation profiles P_3 (Gaussian, Linear, Polynomial), three different maximum heights at the centre of the shape H_3 (60, 90, 120 pixels), and three different radii for the bumps or holes, i.e., three radii of white mask R_3 (50, 100, 150 pixels) (respectively 14.85, 29.7, and 44.55 mm).
- 3 targets without a simulated shape (i.e. a flat surface without any change of the radius of the cursor), with three radii for the white mask R_3 (50, 100 or 150 pixels).

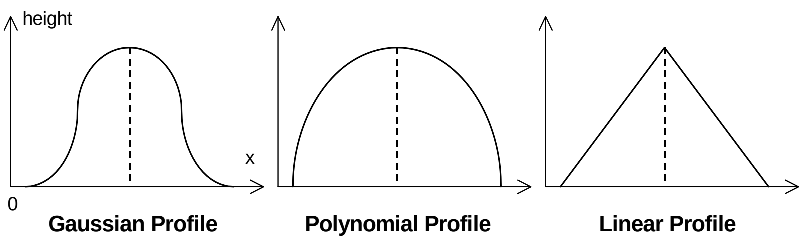

Fig. 5. Simulation profiles for the bumps.

4.1.4 Procedure

The participants sat 60cm away from the screen. The mouse was manipulated with the dominant hand. The other hand was used to enter the answers on the keyboard. The experiment consisted of a learning phase followed by a test phase. In the test phase, for each trial, the participants were first asked to place the mouse at an initial position indicated by a line on the mouse pad. The cursor was automatically positioned on the left of the screen at coordinates x=130p (38.61 mm) and y=300p (89.1 mm), as shown in Figure 4. When the participants were ready, they had to move the cursor over the white mask and determine the shape located under it. They were allowed to make as many passes as they needed until they were confident of the answer. Then they had to choose among the three options: “bump”, “hole”, or “flat”, on the keyboard. The participants were allowed to rest anytime between the trials.

In the learning phase, the participants tested 7 targets with the same procedure. The 7 targets were 6 combinations of the two shapes S_2 and three profiles P_3 with predefined radius and height. The last target was a flat surface. At the end of the experiment, the participants had to fill up a questionnaire. The entire experiment lasted on average 25 minutes.

4.1.5 Collected Data

For each trial, we recorded the participants’ response i.e., “bump”, “hole” or “flat”.

4.1.6 Results

Globally, we found that participants were highly efficient in identifying the targets whatever the shape (bump or hole), as indicated by an average percentage of correct responses of 92.5% (sd = 16%). This result was slightly less than the level of correctness observed in the case of flat surfaces (mF = 97.8%, sd = 5%).

An analysis of the Variance (ANOVA) with repeated measures was performed on the average percentage of correct responses. There was a significant main effect for Shape ($F(1,8)=6.462$, $p<.035$). The correctness for Holes (mH = 95.8%, sd = 20%) was higher than for Bumps (mB = 89.1%, sd = 12%). This suggests that a decrease in the size of the cursor is more easily identified.

The Profile used to simulate the shapes had also a significant influence on the percentage of correct answers ($F(2,16)=5.677$, $p<.014$). The correctness was higher for Polynomial profile (mP = 95.3%, sd = 15%) than for Gaussian profile (mG = 91.6%, sd = 17%) and Linear profile (mL = 90.4%, sd = 19%). Post-hoc tests (Fisher PLSD) showed that only Polynomial profile differed significantly from Gaussian ($p<.03$) and Linear ($p<.005$) profiles. This result suggests that a strong discontinuity in changes in cursor’s size improves the perception of the simulated shape.

Finally, correctness increased (and dispersion decreased) when increasing the Height of the shape ($F(2,16)=15.238$, $p<.0002$; mH60=93.6%, sd=24%; mH90=97.5%, sd=8%; mH120=99.0%, sd=5%). Post-hoc tests (Fisher PLSD) showed that H60 was significantly less correctly identified than the two other heights: H90 ($p<.0003$) and H120 ($p<.0001$). The correct identification of the shape was thus improved when using the maximum height, i.e. when the cursor's size variation was the most important.

No other significant main effect was found. Three two-ways interactions were found significant: Shape and Height ($F(2,16)=6.242$, $p<.0099$), Profile and Height ($F(4,32)=6.704$, $p<.0005$), Height and Radii ($F(4,32)=3.146$, $p<.028$). These interactions can be summarized in the following way. The type of shape (i.e., Bump vs Hole) seemed to affect the level of correctness only for the smallest value of maximum Height (H60) whereas higher values of Height ended with the same level of correctness whatever the shape. Similarly, the nature of the Profile used to simulate the Shapes appeared to have an effect only for the lowest value of Height (H60), whereas Profile did not seem to affect the correctness in the case of higher values (H90 and H120). The last interaction concerns the Height value and the Radius. For the lowest Height value (H60), correctness decreased when the Radius increased, whereas the opposite trend was observed for the highest Height value (H120). For the intermediate Height value (H90), the best identification score was found for the intermediate Radius value (R100). In the case of the Speed technique [Lécuyer et al., 2004], the speed of the cursor is modified according to the slope of the shape, i.e. to the combination of two parameters: the radius and height of the shape. In the case of the Size technique, the modification of the size of the cursor is essentially related to the height of the shape. This probably explains the stronger influence observed here for the Height parameter, the smaller influence of the Radius, and the complex interaction observed between these two parameters.

4.1.7 Conclusion

This first experiment showed that participants were able to identify simple shapes (bumps vs. holes) very efficiently using the Size technique. As shown in Table 1, the performances obtained are very similar to that obtained in the experiment of [Lécuyer et al., 2004] achieved with the Speed technique. With the Speed technique, participants were found more efficient in identifying bumps than holes. The opposite was observed in the case of the Size technique i.e., on average, holes were better identified than bumps. However, in both experiments, we observed the same general trends concerning the influence of other experimental parameters such as maximum height and simulation profile. More particularly, in both cases, Polynomial profiles (bell-shapes) were easier to identify than Gaussians, which were still better identified than Linear profiles.

Conditions	***Correctness in % (SD)***	
	Speed technique [Lécuyer et al.,	***Size technique***
Bump + Hole	92.6 (SD=20)	92.5 (SD=16)
Flat	96.7 (11)	97.8 (5)
Bump	93.3 (18)	89.1 (12)
Hole	91.8 (21)	95.8 (20)
Polynomial	95.7 (13)	95.3 (15)
Gaussian	93.3 (14)	91.6 (17)
Linear	88.7 (26)	90.4 (19)

Table 1. Comparison of results obtained for the same task using the speed technique (data from [Lécuyer et al., 2004]), and the Size technique (data from present study).

4.2 Experiment 2: Making Size and Speed techniques comparable: a psychophysical approach to find out an ideal size amplification coefficient (K)

Experiment 1 showed that the Size technique could be very efficient to convey shape-related information. Performances obtained were close to that of the Speed technique, in a similar context. However, the Size and the Speed techniques are very different in terms of information they contain. This second experiment aimed at determining if a perceptual equivalency could be made by the participants between the two types of information conveyed. We used a classical 2AFC (Alternate Forced Choice) method from psychophysics to compute a Point of Subjective Equality (PSE) between the two techniques [Gescheider, 1985]. To do so, two bumps were presented in each trial: one simulated by the Speed technique and the other by the Size technique. Participants had to choose which of the two bumps was “higher”. The PSE corresponds to the K coefficient for which participants answer somehow randomly.

4.2.1 Participants

Ten new participants aged between 21 and 43 (mean = 27, SD = 7.4) participated in experiment 2. The group was made of 9 male and 1 female. All of them were naive to the purpose of the experiment. All of them were right-handed and had normal or corrected vision.

4.2.2 Experimental Apparatus

The experimental setup was the same as in Experiment 1. However, we noticed that the speed information is available only when the cursor is moving. In order to remove this inequality between the Speed and Size technique, we made the cursor disappear when stationary. Thus, when the cursor stopped moving, only a black cross located at the position of the cursor's centre remained visible on screen. The participants had thus to make movements with the mouse to gather visual feedback from both Speed and Size techniques.

4.2.3 Procedure

For each trial, a bump simulated by the Speed technique was paired with one simulated by the Size technique. The participants had first to press the spacebar to move the cursor. A bump was presented hidden under the white mask (see Figure 4). The participants had to pass the cursor over the bump to assess its height. They had to press another key on the keyboard for the second bump to be displayed. They had to repeat the procedure and assess the height of the second bump. Participants had to estimate which of the two bumps was higher, by answering the '1' or '2' keys on the keyboard, followed by the "Enter" key.

Prior to the test, a learning phase was proposed, in which participants had to achieve five trials which appeared in random. The experiment lasted on average 25 minutes.

4.2.4 Experimental Plan

The bumps had all a pre-defined virtual height of 90 pixels (26.73 mm) and a radius of 100 pixels (29.7 mm). The simulation profile used was the Gaussian Profile. The Speed technique was implemented as in [Lécuyer et al., 2004]. For the Size technique, the cursor size could change differently according to five different K coefficients (see Equation 2): K1 to K5 with values of 0, 0.03, 0.05, 0.07 and 0.09 respectively. As such, for a bump with a virtual height of 90 pixels, the radius of the cursor would change (at the centre) to a maximum of: 12 (no change), 14, 16, 18 and 20 pixels accordingly (i.e., 3.56, 4.16, 4.75, 5.35 and 5.94 mm). Order of appearance of the techniques was random. For each coefficient, 20 trials were conducted for a total of 5x20=100 trials.

4.2.5 Collected Data

The participants' responses to the question "which bump was higher" were recorded.

4.2.6 Results

We computed for each condition (i.e., each K value, or each different maximum radius at the center of the bump) the percentage of choices for a bump simulated by Speed technique as being "higher" than that simulated by the Size technique (hereby renamed as "SP > SI"). The results are displayed for every participant in Table 2.

K value	Max. radius (pixels/mm)	Number of responses "SP > SI"										Overall %
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	
0	12p / 3.564mm	20	20	20	20	18	20	20	10	20	19	93.5
0.03	14p / 4.158mm	18	19	20	20	4	17	19	7	18	20	81
0.05	16p / 4.752mm	14	18	19	11	0	13	11	11	8	20	62.5
0.07	18p / 5.346mm	10	10	8	4	0	4	6	9	3	19	36.5
0.09	20p / 5.94mm	2	1	1	2	0	1	4	10	0	20	20.5

Table 2. Results of Experiment 2: number of responses of type "the bump simulated by Speed technique is higher".

Generally, when no change in cursor's size was made (i.e., K equals to 0, and maximum radius at centre still equals to 12 pixels), the participants logically found that the bump simulated by the Speed technique was higher than that simulated by the Size technique. For the maximum change in size (K equals to 0.09 and maximum radius of 20 pixels), the results were clearly opposite. However, we could observe that one participant (S8) seemed to answer somehow randomly (percentage of "SP > SI" responses close to 50% in all conditions). Another participant (S10) chose "SP > SI" regardless of the K used, and thus regardless of the changes in size of the cursor. This suggests that this participant was much more influenced by the Speed technique than the Size technique.

Using classical psychophysical methods [Gescheider, 1985], we computed from these data a Point of Subjective Equality (PSE). The PSE corresponds to the K value for which the compared stimulus (bump simulated by the Size technique) is perceived as being equal to the stimulus of reference (bump simulated by the Speed technique). Assuming that the global psychometric function found for the participants corresponds to a normal distribution, its z-score transformation would result in a linear function [Gescheider, 1985]. The PSE value corresponds to the ordinate of a z-score equals to zero on the approximation line, corresponding to a probability of "SP>SI" responses of 50%. In our case, the PSE was found equal to 17.02 pixels, i.e., 5.06 mm (R^2=0.9982). This implies that for a maximum cursor radius of 17.02 pixels at the center of the bump (K equals to 0.06), participants were unable to choose which bump was higher, and thus perceived the two bumps of equal height.

4.2.7 Conclusion

This experiment showed that participants were globally able to compare bump shapes simulated with the Speed technique with other bumps simulated with the Size technique. This suggests that the two techniques provide information that can be perceptually equivalent. We could determine a Point of Subjective Equality between the two techniques. It corresponds to an amplification coefficient K (used in Equation 2) that enables participants to perceive bumps simulated with each technique of equal height.

Two subjects (i.e., 20%) responded differently from the others, however. One subject responded randomly to Speed and Size techniques whatever the strength of the latter, suggesting that he failed in discriminating the two competing sources of information. The other subject always responded according to the Speed technique as if he did not make use of the information provided by the size change.

4.3 Experiment 3: Which technique is more influential on user's perception of pseudo-haptic textures?

Experiment 2 showed that the information provided by the size and Speed techniques could be compared by the users. In this third experiment we wanted to study how the two techniques could be combined and what would be the relative influence of each technique on the perception of simulated bumps and holes.

We were inspired by the experiment of Robles-De-La-Torre and Hayward [2001] (see related work), which we transposed into a set-up that does not require haptic devices. When passing the cursor over the white mask, different combinations of the size and Speed techniques were possible: unique presence of either Speed or Size technique, or simultaneous presence of both techniques but with two possible cases: consistent case and conflict case. The participants were forced to identify the simulated shape by choosing between bump, hole or flat surface.

4.3.1 Participants

Ten new subjects aged between 20 and 31 (mean = 23, SD = 3.7) participated in this third experiment. All participants were male and two were left-handed. All had normal or corrected vision. All participants were naive and not familiar with the proposed techniques.

4.3.2 Experimental Apparatus

The setup of this experiment was the same as that of Experiment 2. The radius of the shape and its height was kept constant: R=100 pixels, H=90 pixels. We used only the

Gaussian simulation profile. The coefficient K used for varying the radius of the cursor had a value of 0.06, as obtained from the results of Experiment 2.

4.3.3 Procedure

What was required of the participants was the same as in Experiment 1. They had to pass the cursor over the white mask and identify the shape located under it. In a learning phase, participants followed the same procedure and tested 9 conditions in a random order. The experiment lasted on average 20 minutes.

4.3.4 Experimental Plan

The experiment plan was made up of 9 conditions tested 20 times each. The 9 conditions were made up by 1 flat condition (Flat), plus 8 combinations of 2 types of shape (Bump, Hole) and 4 types of combination of the two techniques: size alone (Size), speed alone (Speed), consistent combination of size and speed (Combination), conflicting size and speed (Conflict). In the conflict condition, the movement of the cursor generated by the Speed technique was opposed to the information of variation in cursor's size. For example, if the shape simulated by the Speed technique was a hole, the cursor would accelerate when descending into it. The radius however would increase instead of decreasing, which provided a paradoxical indication to the users that the shape was a bump instead of a hole. If the participants were to answer "hole", it meant that they relied on the Seed technique to make their judgment. If they answered "bump", it meant that they used the Size technique. The conflict condition is somewhat complex to analyze, since there is no "correct" answer. In this case, for the purpose of the analysis, we will thus refer to SPeed-Consistent Answers (SPCA, or answers consistent with the Speed technique information), and to SIze-Consistent Answers (SICA, or answers consistent with the Size technique information).

4.3.5 Collected Data

For each trial, the participants' responses (bump, hole or flat) were recorded.

4.3.6 Results

The highest correctness (in identifying bumps and holes) was found for the consistent Combination condition (mCombi=93.0%, sd=25%), followed by the Size technique alone (mSize=77.2%, sd=42%). Surprisingly, the participants obtained poor results with the Speed technique alone (mSpeed=35.5%, sd=48). When exposed to the Conflict condition, the answers of the participants were much more influenced by the Size technique (mSICA=77%, sd=30%), than by the Speed technique (mSPCA=17%, sd=38%). Last, the level of correctness observed in the case of the Flat stimuli remained very high (mF=99%, sd=2%).

An analysis of the variance (ANOVA) with repeated measures was performed on the correctness of participants (i.e. the percentage of correct responses in the several conditions). For the purpose of the analysis, in the conflict conditions, we arbitrarily coded as a "correct answer" the speed-consistent answer (SPCA). No significant effect was globally found on correctness for the Shape (Bump vs. Hole) of the profile ($F(1,9)=1.901$ n.s.). No significant effect was also found for Trials. We then found a significant main effect of the Condition on correctness ($F(3,27)= 13.816$, $p>.0001$). Post-hoc tests (PLSD Sheffer) showed that the Combination condition was significantly better than the Speed alone condition ($p<.0002$), while no significant difference between Combination and Size alone was found. Similarly, Size technique showed better results than Speed alone ($p<.0045$).

4.3.7 Discussion

The participants were on average more efficient in identifying the shapes in the case where both the Size and the Speed techniques were combined consistently. The combination of the two techniques provided the participants with information leading to an easier identification of the shapes. This suggests that, when consistent, both techniques interact positively and it provides an easier support for the perception of pseudo-haptic textures. However, the lack of significant test between the Combination condition and the Size alone condition could also imply that the observed superiority of the Combination case came mainly from the sole use of the Size technique.

The participants were globally less efficient in identifying the targets with only one technique (Size or Speed), when compared to the results found with the Speed technique alone (in [Lécuyer et al., 2004]) and with the Size technique alone (in Experiment 1). One explanation would be that people were confused by the conflict situations which globally deteriorated their answers during the experiment. In the Speed condition, nearly half of the subjects (5/10 for Bumps and 4/10 for Holes) gave correct identification whereas the remaining subjects selected the Flat response. This suggests that due to the conflict cases, participants used the size information for deciding the shape and considered the speed information as less relevant.

When observing the individual responses in the Conflict situations (as shown in Table 3), we may notice different behaviors among the subjects. For nearly all the subjects, the conflict was solved as if information from the Size technique was only considered. However, two subjects (S6 and S9) seemed to pay more attention to the information provided by the Speed technique. These two subjects showed accordingly a high level of correctness in the Speed technique alone condition. These results suggest that the Size technique had globally a dominating influence on the choice of participants, except for few participants who presented the opposite dominance.

Condition:	**Conflict**						**Speed technique**						**Combination**						**Size technique**					
Shape:	**SPCA=Bump SICA=Hole**			**SPCA=Hole SICA=Bump**			**Bump**			**Hole**			**Bump**			**Hole**			**Bump**			**Hole**		
Responses:	**B**	**H**	**F**	**B**	**H**	**F**	**B**	**H**	**F**	**B**	**H**	**F**	**B**	**H**	**F**	**B**	**H**	**F**	**B**	**H**	**F**	**B**	**H**	**F**
S1	2	12	6	18	1	1	0	2	18	4	1	15	9	10	1	5	11	4	14	4	2	4	12	4
S2	3	15	2	6	7	7	11	3	6	1	10	9	19	0	1	0	18	2	9	0	11	0	4	16
S3	0	20	0	20	0	0	14	1	5	0	15	5	20	0	0	0	20	0	19	0	1	0	19	1
S4	0	20	0	20	0	0	0	0	20	0	0	20	20	0	0	0	20	0	19	0	1	0	19	1
S5	0	15	5	20	0	0	0	0	20	0	0	20	19	0	1	2	18	0	18	0	2	0	19	1
S6	11	9	0	4	16	0	20	0	0	0	20	0	20	0	0	0	20	0	9	0	11	0	5	15
S7	0	20	0	20	0	0	0	0	20	0	0	20	20	0	0	0	20	0	19	0	1	0	19	1
S8	0	20	0	20	0	0	0	1	19	0	0	20	20	0	0	0	20	0	19	0	1	0	19	1
S9	16	4	0	7	10	3	18	2	0	1	14	5	20	0	0	0	20	0	5	0	15	0	6	14
S10	2	18	0	20	0	0	10	8	2	10	9	1	20	0	0	2	18	0	19	0	1	1	18	1
Mean:	*3*	*15*	*1*	*16*	*3*	*1*	*7*	*2*	*11*	*2*	*7*	*12*	*19*	*1*	*0*	*1*	*19*	*1*	*15*	*0*	*5*	*1*	*14*	*6*
SD:	*5,6*	*5,5*	*2,3*	*6,9*	*5,7*	*2,3*	*8,2*	*2,5*	*9,1*	*3,2*	*7,7*	*8,4*	*3,4*	*3,2*	*0,5*	*1,7*	*2,8*	*1,3*	*5,4*	*1,3*	*5,5*	*1,3*	*6,6*	*6,6*

Table 3. Experiment 3: responses of the participants.

4.3.8 Conclusion

In this third experiment, we used paradoxical situations of conflict between size information and speed information for the estimation of pseudo-haptic textures. We found that participants generally selected the size information to assess the type of the simulated shaped. Thus, our results suggest a dominance of the Size technique over the Speed technique.

Two subjects (i.e. 20%) tended to respond differently from the others, advantaging the Speed technique over the Size technique in the conflict condition. The same ratio was found in the previous experiment, although the task and experimental design differed. A possible explanation is that in the two experiments, the subjects had to make a decision with two competing informational sources that were either unrelated (random association in Experiment 2) or inconsistent (conflict condition, Experiment 3).

Furthermore, we also found that on average the consistent combination of the Size and Speed technique leads to a better identification of the shapes as compared to the use of only one technique at a time. Such a superiority of the consistent combination condition over the Size and the Speed technique alone may suggest that both techniques reinforce each other to provide the subjects with information leading to an easier identification of the shapes. However, the lack of significant test may indicate that this observed superiority could be mostly explained by the effect of the Size technique. A mean way could be that when consistent, both techniques are interacting positively to provide an easier support for the identification of the shapes. An interesting issue concerns if it may be explained by low-level perceptual processes or by higher level cognitive processes, like a specific strategy.

4.4 Experiment 4: Re-conducting Experiment 3 with a smaller size amplification coefficient K (smaller influence of Size technique)

Experiment 3 showed a dominance trend for the Size technique over the Speed technique. By decreasing the strength of the Size technique, we should observe a growing influence of the Speed technique. Thus, Experiment 4 is a control experiment in which we re-conducted Experiment 3 but we decreased the size amplification factor K used (i.e., we decreased the power of the Size technique). We expected to observe a consecutive stronger weight for the Speed technique information.

4.4.1 Experiment

Experimental set-up, experimental plan and experimental procedure were the same as in Experiment 3. The K coefficient used in this experiment had a much smaller value of 0.033 which corresponded to a maximum radius of the cursor of 15 pixels (4.46 mm) at the centre of the bump. Ten new naive participants, aged between 21 and 28 (mean = 23, sd = 2.4) did the control experiment. All were male and one person was left-handed. All participants had normal or corrected vision. None of them were familiar with the proposed techniques. The experiment lasted on average 23 minutes. Data collected were the same as in Experiment 3.

4.4.2 Results

In the Combination condition in which both Size and Speed techniques were consistent, the participants obtained again the higher percentage of correct responses (mCombi=97.5%, sd=16%). Then, the performance was high with the Speed technique alone (mSpeed=86.5%, sd=34%). A less efficient identification was found with the Size technique alone (mSize=61.1%, sd=49%). When exposed to the Conflict condition, the answers of the participants were this time strongly influenced by the Speed technique (mSPCA = 81.5%, sd=39; mSICA = 16%, sd = 30). Last, the Flat surfaces were still identified very successfully (mFlat=99%, sd=0.7).

As in Experiment 3, no significant effect on the percentage of correct responses was found for the Shape or for the Trial. Then, we found again a significant main effect for the Condition ($F(3,27)=3.214$, $p<.0386$). Post-hoc tests (Fisher PLSD) showed that Size condition was significantly different from Combination ($p<.0054$) and Speed ($p<.0439$).

4.4.3 Comparative analysis of results of Experiment 3 and 4

Table 4 summarizes the main results of both Experiment 3 and Experiment 4. In both experiments, the best performance was systematically observed in the consistent Combination condition. There is a small increment from 93% to 98% as K decreases. In the same time, the decision process in the Conflict condition shifts from a "pro-size" behavior, to a "pro-speed" one. Furthermore, as K decreases, the correctness for the Speed technique used alone strongly improves from 36% to 87%, which suggests that the sensibility to the Speed technique is somehow dependent to the exposition to the Size technique in the other experimental conditions. The performance of the Size technique alone is more constant, since it drops only from 77% to 61% as K decreases. This result seems to confirm the stronger influence of the Size technique.

	Experiment 3	***Experiment 4***
K	*0.06*	*0.033*
Max. radius (pixels/mm)	*17pixels / 5.05mm*	*15pixels / 4.46mm*
Size alone	77.2 % (SD=42)	61.1 % (SD=49)
Speed alone	35.5 % (48)	86.5 % (34)
Consistent	93% (25)	97.5 % (16)
Conflict	SPCA = 17 % (38) SICA = 77 % (30)	SPCA = 81.5 % (39) SICA = 16 % (30)

Table 4. Percentage of correct responses according to the several experimental conditions and K values in both Experiment 3 and Experiment 4.

To go further in the analysis of individual responses, we have focused on subjects' individual *sensitivity* to the techniques in Experiment 3 and Experiment 4. The rules used for coding subject's sensitivity were as follows. In each experimental condition, and for all the 20 trials, there were three possible responses: (1) the correct shape was identified, (2) the opposite shape was identified (e.g., bump was selected whereas a hole was simulated), or (3) no shape was identified (flat response). When a subject perceived a flat shape at least 70% of the time (i.e., >14 trials, out of 20) although a bump or a hole was simulated with the Speed (Size) technique, s/he was considered as *insensitive* to the Speed (Size) technique. Inversely, when a subject identified 14 times or more the correct shape (bump or hole) in the Speed (Size) condition, then s/he was coded as *sensitive* to the Speed (Size) technique. When no clear dominant pattern appeared within the 20 responses, subject was coded as *undecided* (e.g., 10 "hole" answers, 8 "bump" and 2 "flat"). As insensitive/undecided patterns of responses showed no significant difference in the way they are distributed within each condition (Fisher's exact test, p=.81), we have merged them for the remaining part of the analysis.

The number of subjects "sensitive" to Speed technique increases when the power of the Size technique decreases

	Experiment 3		Experiment 4	
	Speed	Size	Speed	Size
Sensitive	6	14	16	15
Insensitive+Undecided (Undecided only)	14(4)	6(3)	4(2)	5(3)

Table 5. Frequency of Sensitivity to the techniques in single technique conditions (Size only or Speed only situations) in experiments 3 and 4 (max. is 20, corresponding to 10 subjects*2 shapes, in each condition).

As reported in Table 5, sensitivity of subjects to the Speed technique appears to be affected by the changing experimental conditions between Experiment 3 and 4. The subjects were sensitive to the Speed technique in only 30% of the cases in Experiment 3, whereas they were sensitive to the Speed technique in 80% of the cases in Experiment 4 (Fisher's exact test, p=.00364). Inversely, we found no significant difference of subjects' sensitivity to the Size technique between Experiment 3 and Experiment 4 (Fisher's exact test, p=.99). Furthermore, in Experiment 4, no significant difference was observed between the Speed and the Size technique in terms of sensitivity (Fisher's exact test, p=.99). Finally, the distribution of sensitivity profiles do no significantly differ between Bumps and Holes, suggesting that the two shapes did not affect differently the subjects' sensitivity (Fisher's exact test, p=.88; table not reported here). Actually, in five cases only, subject was sensitive to the technique for only one of the two shapes (in four cases, the unidentified shape was a hole). Three subjects were « half » sensitive to the Size technique in Experiment 3, and two subjects were half sensitive to the Speed technique in Experiment 4.

Four different profiles of sensitivity to the Size and Speed techniques

When further analyzing the results of the subjects in the single technique conditions (Size only and Speed only conditions), we can actually identify four profiles of subjects: (1) subjects that are sensitive to both the Size and Speed techniques (Size+Speed), (2) subjects that are sensitive only to the Size technique (Size only), (3) subjects that are sensitive only to the Speed technique (Speed only) and (4) subjects that are insensitive to both techniques or that systematically exhibit undecided pattern (Insensitive/undecided). The frequency of the four profiles in the two experiments is displayed in Table 6. It shows a strong relationship (V2 Cramer =.32), meaning significant changes in profiles of subjects between the two experiments (Fisher's exact test, p=. 0024). When K decreased, from Experiment 3 to 4, noticeable relative deviations show that more subjects were sensitive to both size and Speed technique and, inversely that there is a decreasing number of subjects only sensitive to the Size technique.

	Experiment 3	Experiment 4
Size+Speed	3	13
Speed only	3	3
Size only	11	2
Insensitive+Undecided	3	2

Table 6. Four profiles of subjects (Sensitivity to the techniques) in single technique conditions (Size only or Speed only situations), in experiment 3 and 4.

Sensitivity to the Size and Speed techniques in Combine and Conflict conditions

The frequency of subjects' responses in terms of sensitivity to (at least) one technique is reported in Table 7 for the four conditions of experiments 3 and 4, i.e., including Combine and Conflict conditions. For the Conflict conditions, sensitivity is computed using the total of subjects exhibiting responses consistent with Speed technique and subjects with responses consistent with the Size technique.

Interestingly, the Combine condition obtains systematically the best sensitivity to the technique(s). The worst performance, in terms of sensitivity to at least one of the two techniques, is observed in the Speed condition of Experiment 3, followed by the Conflict condition of Experiment 4.

	Speed (sensitive to speed)	Size (sensitive to size)	Combine (sensitive to size or speed)	Conflict (sensitive to size or speed)
Experiment 3	6	14	18	16
Experiment 4	16	15	20	12

Table 6. Frequency of Sensitivity to the techniques in the four conditions of experiments 3 and 4.

Reconsidering the conflict condition using subjects' profiles of sensitivity

Then, we reconsidered the Conflict conditions using the sensitivity to the techniques and the profiles of subjects identified. First, we studied the responses of subjects sensitive to both techniques (Population 1: Size+Speed) in the Conflict condition, as displayed in Table 8. There is a strong relationship between the orientation of responses and the considered experiment (V2 Cramer = .24) although the test is not significant (Fisher's exact test, p=.287), possibly due to the small number of subjects. At a descriptive level, the results suggest that the more subjects are sensitive to both techniques, the more speed-oriented and undecided responses are found. Speed could be seen as dominating in Experiment 4, while Size could be slightly seen as dominating in Experiment 3, for this specific profile of subjects.

	Size-oriented responses	Speed-oriented responses	Undecided
Experiment 3	2	1	0
Experiment 4	2	6	5

Table 8. Frequency of orientation of responses in the Conflict condition, for subjects that are sensitive to both Size and Speed techniques.

Second, we studied the responses of subjects sensitive to only one of the two techniques (Population 2: Speed only, or Population 3: Size only) in the Conflict condition, as displayed in Table 9 (data from experiments 3 and 4 are combined). The relative frequencies of sensitivity-consistent, sensitivity-inconsistent and undecided responses in the conflict condition show no significant difference whatever the single technique (Speed vs. Size) for which the subjects are sensitive to (Fisher's exact test =.99). The subjects responded in their majority consistently with the technique they are sensitive to (50% for Speed and 62% for Size). Undecided/random patterns of responses are less observed (34% for Speed, 15% for Size), and sensitive-inconsistent responses even less (17% for Speed, 15% for Size).

Thus, surprisingly, even when subjects' performances show clearly that they are not sensitive to one technique presented in isolation, the performances observed in the conflict condition suggest that this technique, when combined with the technique subjects are sensitive to, can still disturb the responses of the subject (number of Undecided + Sensitivity-inconsistent responses of nearly 50%). For a few subjects, the performances show paradoxically that the shapes are identified consistently with the technique they are supposed to be insensitive to, and thus, inconsistently with the one they are sensitive to.

	Sensitivity-consistent	Sensitivity-inconsistent	Undecided
Speed-only	3	1	2
Size-only	8	2	3

Table 9. Frequency of Sensitivity-consistent, Sensitivity-inconsistent and Undecided patterns of responses in the Conflict condition, for subjects that are sensitive to only one of the two techniques.

4.4.4 Conclusion

Results of Experiment 4 showed that when decreasing the power of the Size technique (decreasing the size amplification coefficient K), the participants could become more influenced by the Speed technique than by the Size technique for identifying the shapes. With a reduction of two pixels for the maximum radius of the cursor at the centre of bumps and holes (from 17 pixels in Experiment 3, to 15 pixels in control experiment), participants shifted from being “pro-Size” to being “pro-Speed”.

An associated issue deals with the processes related to the interaction between information derived from the Speed technique and information derived from the Size technique. The results showed that a significant change occurred between Experiment 3 and Experiment 4 in the profiles observed within the subjects’ population. In Experiment 4, more subjects became sensitive to both the Size and the Speed techniques, while the number of subjects that are sensitive only to Size decreased in parallel. Interestingly, the number of subjects that are only sensitive to speed information remained the same in the two experiments. Indeed, the sensitivity to the Size technique varied from 70% (Experiment 3) to 75% of the subjects (Experiment 4). Only 30% of the subjects exhibited a clear response to the Speed technique in Experiment 3, while 80% of the subjects were sensitive to this technique in Experiment 4. The ratio of subjects that were sensitive simultaneously to both Size and Speed techniques increased from 25% to 65% from Experiment 3 to Experiment 4. The Speed technique was tuned exactly the same way whatever the experiments. An interpretation could then be that from Experiment 3 to 4, the decrease in power of the Size technique has enabled more people to process efficiently both techniques. In other words, it seems that the predominance of the Size technique in Experiment 3 may be explained by a provoked “blindness” to (or, at least, an impossibility to use) information provided by the Speed technique. Additionally, the set of subjects that are able to process information from both techniques exhibited the following trend: they favoured size-consistent responses in Experiment 3, whereas a majority of speed-consistent responses were found in Experiment 4.

5. GENERAL DISCUSSION

We have studied the use of a novel technique to simulate pseudo-haptic textures without using a haptic interface: the Size technique. The Size technique modifies the size of the cursor according to the local height of the image displayed on the computer screen. With the Size technique, the user would see an increase (decrease) in cursor size corresponding to a positive (negative) slope of the texture.

A first experiment has been conducted to evaluate the efficiency of the Size technique to simulate simple shapes like bumps and holes. Our results showed that participants successfully identified bumps and holes by using changes in size of the cursor. The performance could reach high scores (superior to 95%) for strong changes in the cursor's size. The similarity observed with the performances obtained previously in [Lécuyer et al., 2004] with the Speed technique (modification of the speed of the cursor to simulate the climbing or descending of a slope) suggested that the two pseudo-haptic techniques could be comparable.

Based on a classical psychophysical paradigm, we have then conducted a second experiment to determine empirically a parameter (the size amplification coefficient K for the variation of the cursor's radius) that would enable a direct comparison between the two techniques. Participants were asked to answer which of two bumps, one simulated by the Speed technique and one simulated by the Size technique, was "higher". A Point of Subjective Equality could be computed, which suggests that the two techniques provide texture information that can be perceptually equivalent.

Then, a third experiment was conducted to compare the influence of each technique on the final perception of bumps and holes simulated with pseudo-haptic feedback. We found globally that, when the two techniques were combined consistently, the participants were on average more efficient in identifying the shapes. This suggests that a mutual reinforcement and a fuller sensation of pseudo-haptic textures can be achieved by associating these two techniques. Second, using paradoxical conflict situations, we globally found that when the two techniques were opposed, the participants' answers were slightly dominated by the information provided by the Size technique.

The global trend of the results of Experiment 3 suggests a slight dominance of the size information vs. the speed information for simulating simple shapes like bumps and holes. This suggests that, in our "visual environment", people relied mainly on geometrical cues (Size technique) as compared to "pseudo-force" cues (Speed technique). This could be seen as the opposite of what has been found in the haptic environment of Robbles-De-La-Torre and Hayward [2001]. Indeed, Robbles-De-La-Torre and Hayward found that force cues dominated geometrical cues for the perception of bumps and holes during a similar discrimination task achieved in a purely haptic experiment (see related work section). This contradicting result could be explained by the naturalness of vision to estimate spatial properties whereas force perception is known to be the domain favored by touch [Hatwell et al., 2003] [Lederman and Abbott, 1981].

However, in the fourth experiment, the responses of the participants in the conflict conditions could vary strongly when manipulating the power of the Size technique. Modifying the K value used for simulating the Size technique globally affected the proportion of subjects that were able to process (or not) either the Speed technique or the Size technique between Experiment 3 and 4. When subjects tested only one technique at a time (Size technique alone in Experiment 1, or Speed technique alone in previous experiments of [Lécuyer at al., 2004]), strong efficiency and similar results were found whatever the technique. However, in Experiment 3 and 4, both techniques exhibited rather different and sometimes very poor performances when tested within a 4-condition design involving a Conflict condition. Both the presence of a conflict and the different tunings of the Size technique in Experiment 3 and 4 affected the performances. Subjects that performed accurately with both techniques favored size-oriented responses in Experiment 3 and speed-oriented responses in Experiment 4. In Experiment 3, most of the subjects were unable to perceive the shapes in the Speed-only condition whereas most of them succeeded in this condition in Experiment 4. This suggests that subjects exhibited a kind of “blindness” to the Speed technique in Experiment 3.

The combined results reported in experiments 3 and 4 suggest complex interactions between the information associated with the two techniques in the perception and in the decision process related to the accurate identification of bumps and holes. Both the reliability and the content of information generated by each technique are good candidates to interpret the changes observed across the conditions and across the two experiments regarding the ability of subjects to accurately identify the shapes. Sensor fusion models and Bayesian decision process [Ernst and Banks, 2002] could be good candidates for analyzing the mechanisms involved in the perception of information generated by the two techniques. But further specific experiments would be needed to confront these models.

In experiments 3 and 4, there first seems to be a situational effect, i.e., a between-trials effect, related to the entire situation of the experiment. This is suggested by the observation of different levels of ability to process the speed information depending on the presence/absence of concurrent information (Size technique) and on how they are associated in each condition of the experiment. Interestingly, the information associated with each technique seems to be treated differently regarding this effect, since the results are very similar between experiments 3 and 4 for the Size technique whereas they strongly vary for the Speed technique. However, the absence of influence observed on the Size technique could also be due to the small number of K values used (only two). Second, there also seems to be a local effect, i.e., a within-trials effect, as we observed that: (1) consistent combination of information provided by both techniques led systematically to the best sensitivity to the technique(s), as if a mechanism of reinforcement was present, and (2) conflicting situations led to either the impossibility to decide between the two information, or either to the choice of only one information among the two for the entire experiment. Interestingly, even if our results show clearly that the "dominant" information (for each subject) is chosen in priority in the conflict cases, in few other cases, the subjects decide to "follow" the information provided by the competing technique, even if s/he is unable to process it efficiently when it is presented in isolation.

Preliminary findings reported here suggest then that: (1) subjects' sensitivity to each technique could depend on the experimental context, i.e., single vs. combined vs. conflict situations; (2) information provided by the two techniques could interfere, i.e., one technique could affect positively or negatively the efficiency of the other and its potential to generate the perception of a shape; (3) effects of these interferences could be further distinguished in between-trials and within-trials effects. Therefore, further works are needed in several directions: (1) to elucidate the nature of processes involved in the perception of texture information generated by the size and the Speed techniques, and (2) to evaluate and model the principles related to the within and between-trials effects observed.

The results of the current paper should also be taken into account when designing interaction techniques and applications based on pseudo-haptic textures, e.g., when selecting which technique (Size or Speed) should be used, in a given context. First, it seems that some subjects might remain systematically oriented toward one of the two techniques, either be it due to some perceptual limits or be it due to strategic choice or orientation towards one preferred technique against the other. Second, the consistent combination of both techniques seems to ensure maximum chances for the user to perceive pseudo-haptic effects. However, future work would be necessary to evaluate the use and efficiency of the two pseudo-haptic techniques in a more applicative context.

Pseudo-haptic feedback is already used in various virtual reality applications. The studies of Rodgers [2005] and Mandryk et al. [2005] are focused on the application of pseudo-haptic textures in the field of Graphical User Interfaces (GUI). They introduced “pseudo-haptic widgets” which are classical widgets (e.g. icons or sliders) augmented with pseudo-haptic textures (Speed technique) so to be rendered sticky or repulsive. The researchers found that “sticky” pseudo-haptic widgets (corresponding to hole shapes) could improve performance and significantly reduce errors for accessing boundary widgets when using multiple displays. The Speed technique was also tested in a medical simulator, for the training to regional anesthesia procedures [Lippincott-Williams and Willkins, 2005]. The first step of the anesthesia procedure consists in a palpation of the body of the patient, before inserting the needle and stimulating electrically the nerve. The palpation is necessary to locate the patient’s organs under the skin, and find a proper location to stick the needle. To simulate the palpation step, the user manipulates a spherical mouse cursor which follows the surface of the skin of the virtual patient. Pressing the left button of the mouse simulates a higher pressure on the skin, in order to palpate the organs with the cursor. The Speed technique is then applied to the visual motions of the cursor to simulate the bumps and hollows corresponding to the presence of organs and veins under the skin. With such a technique, it is expected that the user can explore the skin and body of the patient more physically and realistically. However, in all the applications aforementioned, the results of the current paper suggest that the Size technique could be additionally introduced, in order to further enhance the sensations of the users.

6. GENERAL CONCLUSION

We have described the implementation of a novel technique to simulate pseudo-haptic textures without using a haptic interface: the “Size technique”. The Size technique modifies the size of the mouse cursor (zoom-in or out), according to the height of the terrain it passes over, i.e., according to the height of the texture or image displayed on the computer screen.

A series of four experiments was conducted to evaluate this technique and to compare its performance with the previous pseudo-haptic technique known as the “Speed technique”. In a first experiment, we showed the efficiency of the Size technique to simulate simple shapes like bumps and holes. In a second experiment, using a psychophysical paradigm, we determined a numerical parameter (a Point of Subjective Equality) that enables a direct comparison between the two techniques for simulating bumps, suggesting that the techniques provide global height information that can be perceptually equivalent. Within a third and a fourth experiment, we compared the influence of each technique on the final perception of bumps and holes simulated with pseudo-haptic feedback. We found that, when the two techniques were combined consistently, the participants were on average more efficient in identifying the shapes. This suggests that a mutual reinforcement and a fuller sensation of pseudo-haptic feedback can be achieved by associating these two techniques. We also found that when the two techniques were opposed, a slight "dominance" of the Size technique over the Speed technique could be observed.

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