Master 2 SIF - Option VRI
Univ Rennes

Interactions en RV:
interfaces cerveau-ordinateur et interfaces haptiques

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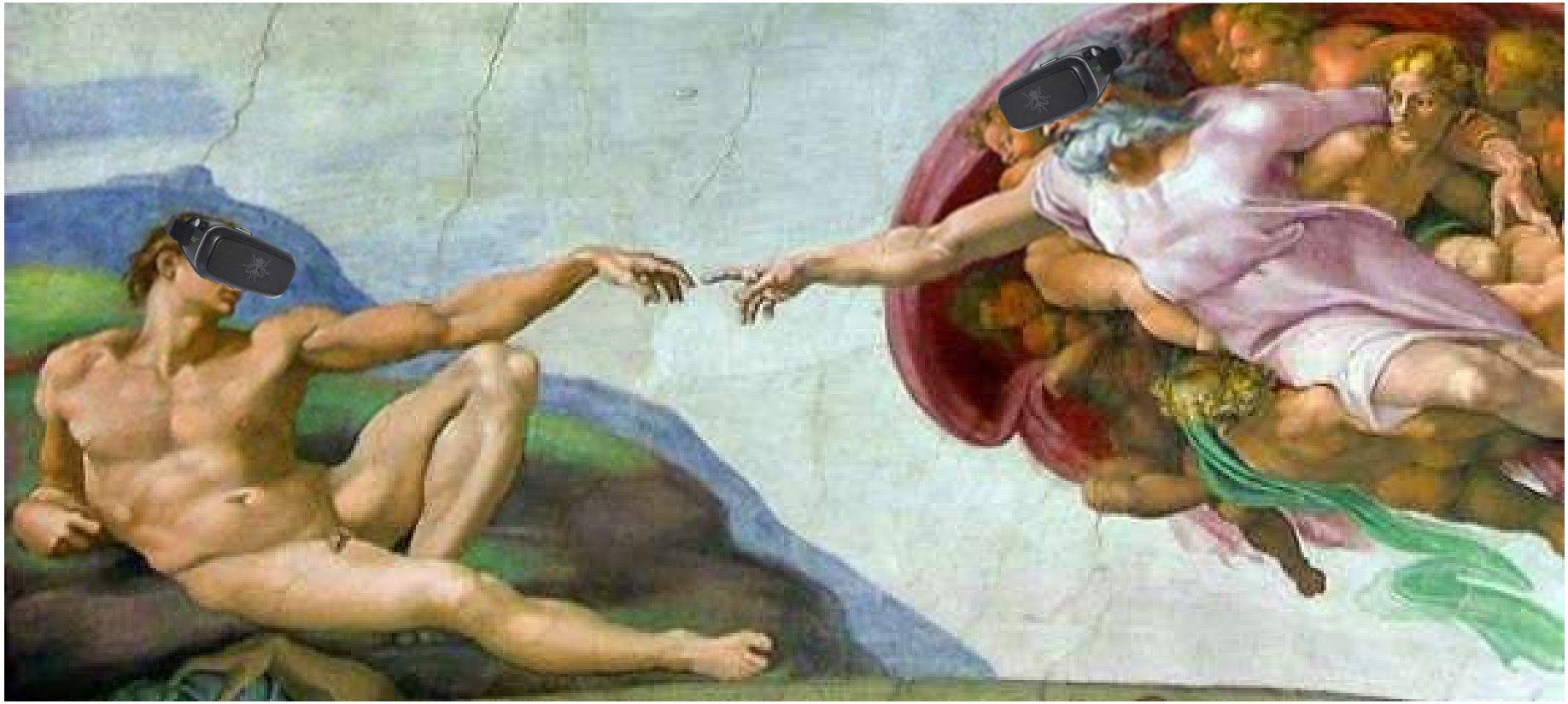
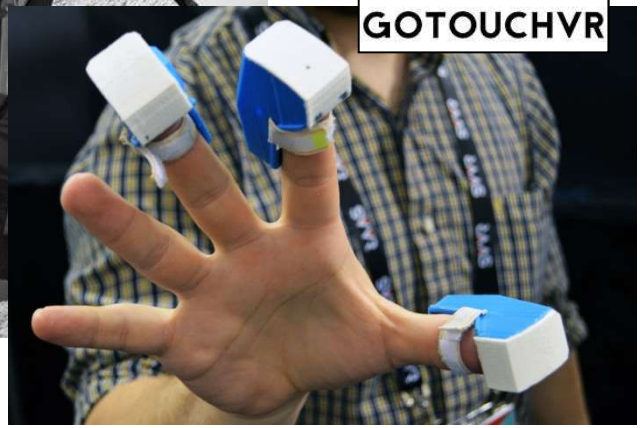
Plan

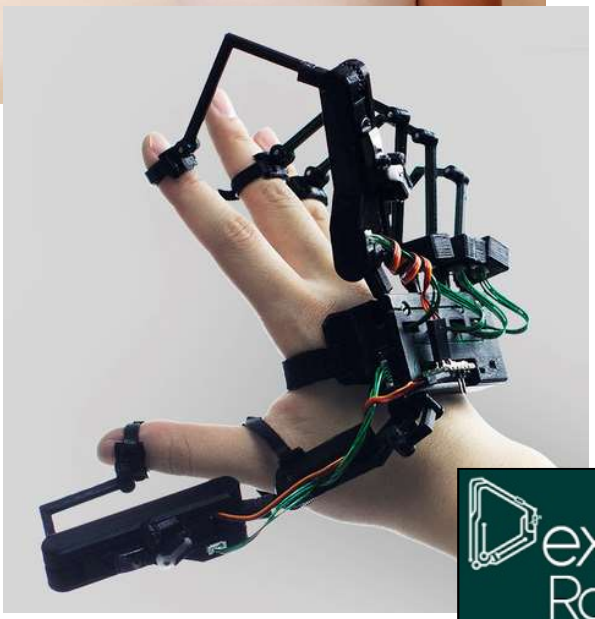
1. Interfaces Cerveau-Ordinateur
2. Interaction Haptique (avec Claudio Pacchierotti)

Haptics : the next “big move” in VR ?



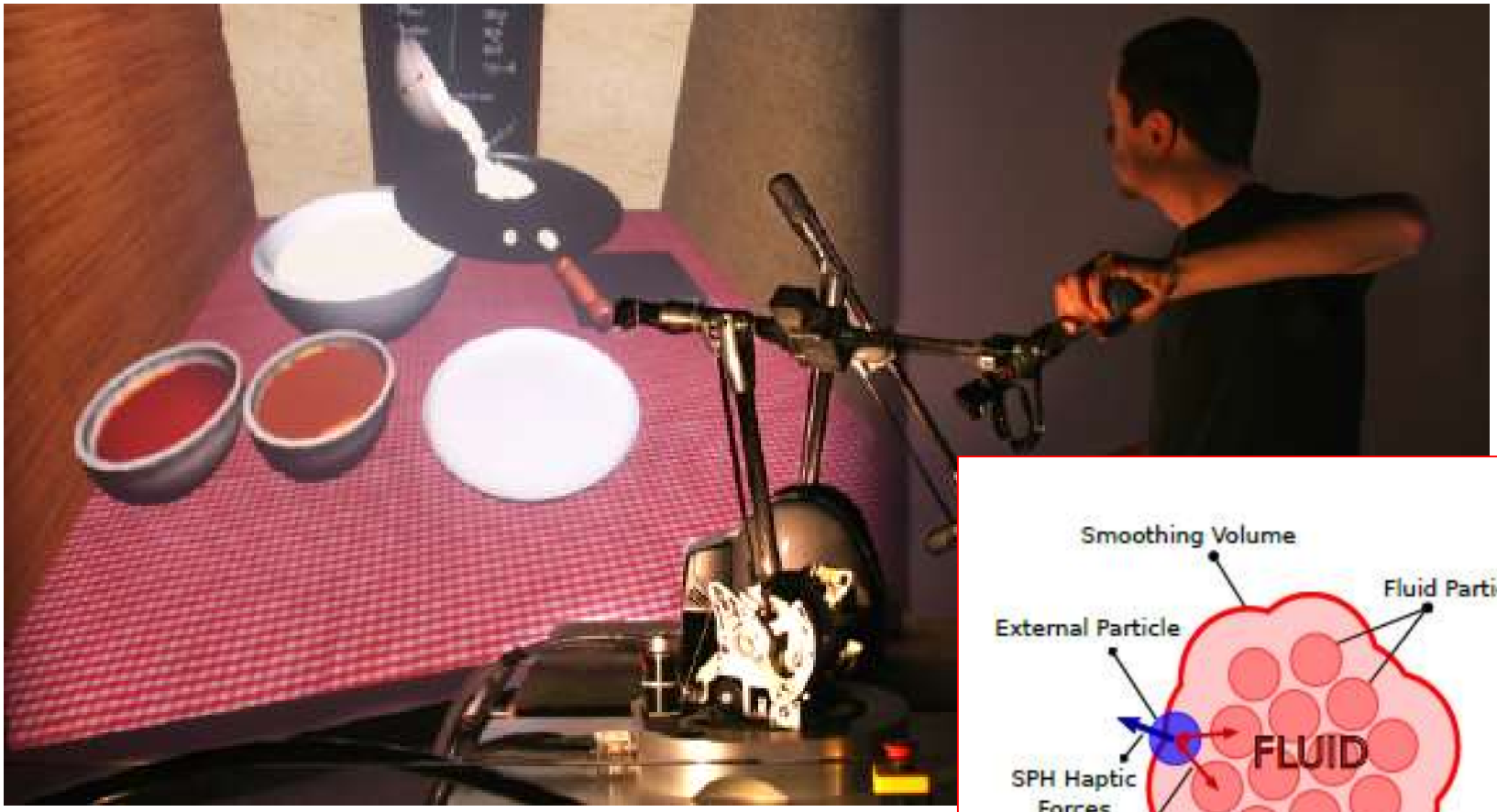
the haptic hype





actronika©

Grounded haptics



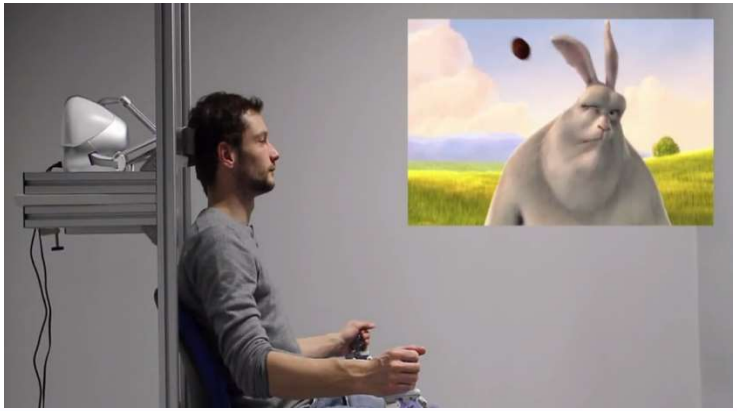
(Cirio et al., IEEE TVCG 2011)
(Cirio et al., WHC 2013)

Wearable haptics

(Girard et al., Frontiers in Robotics and AI, 2016)

Alternate uses of haptics : cinema

technicolor



(Danieau et al., ACM VRST 2012)
(Danieau et al., IEEE Multimedia 2014)

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Perception Haptique
Retour Pseudo-Haptique

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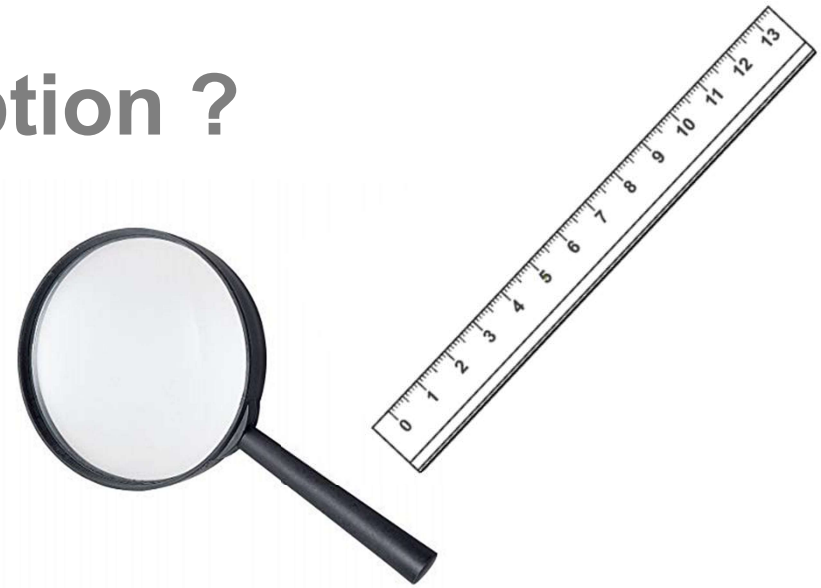
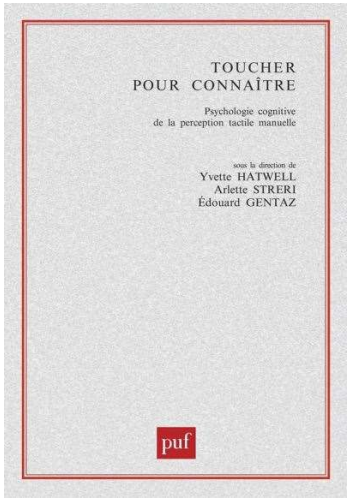
Why studying perception ?



Design of devices / rendering
- Design : what ?
- Requirements : how ?
- Simplification : less is more

Design of multisensory environments
- Vision and touch integration
- Sharing/splitting of information

Evaluation of VR systems
- Final perception of the user

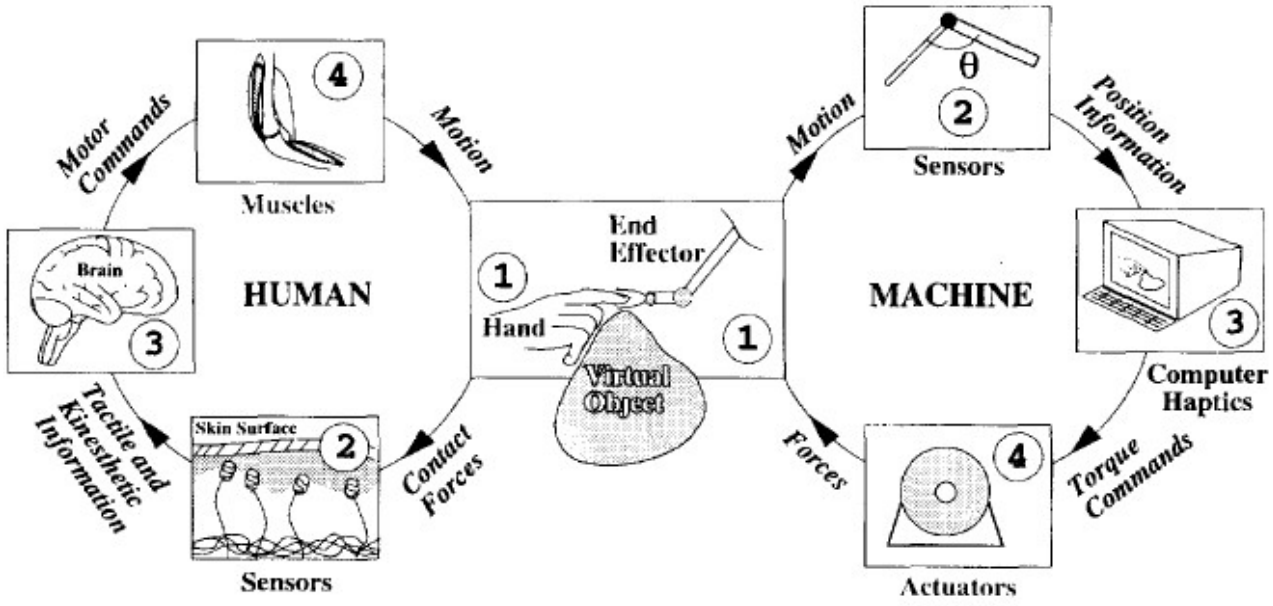


Haptic sense

Sense of : touch & forces/effort

Bilateral sense : energy transfer, afferent/efferent networks

Sensory-motor loop >> haptic loop of VR systems



Haptic perception

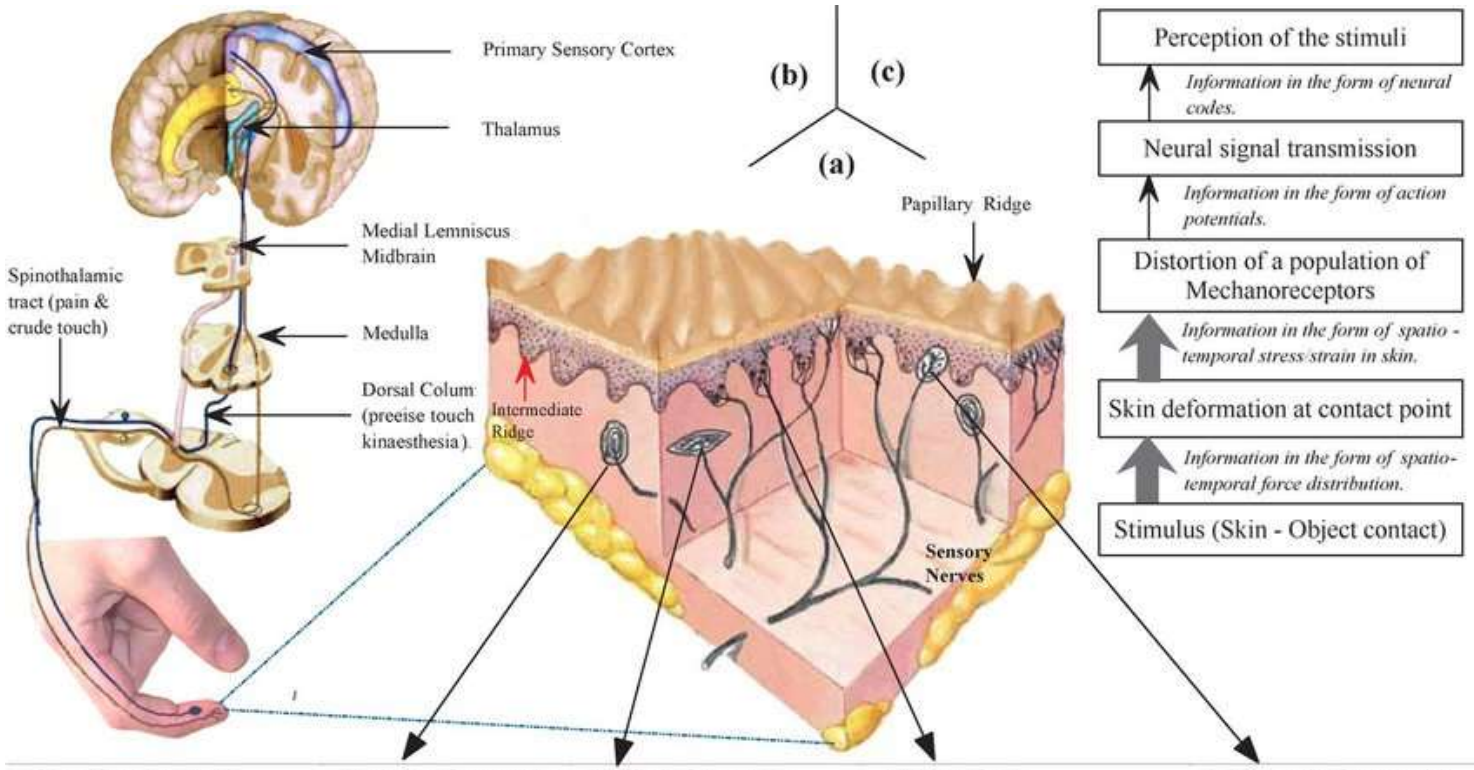
Physiology

- Characteristics and properties of human sensors/actuators
- *Respectable knowledge*

Psychology

- Subjective interpretation of stimulations
- *Limited knowledge*

Physiology of touch



Classification Basis		Pacinian Corpuscle	Ruffini Corpuscle	Merkel Cells	Meissner's Corpuscle
Type		FA II	SA II	SA I	FA I
Adaptation Rate		Fast	Slow	Slow	Fast
Spatial Acuity (mm)		10+	7+	0.5	3-4
Vibration/rapid indent. threshold	Best(μm)	0.01	40	8	2
	Mean(μm)	0.08	300	30	6
Stimuli Frequency (Hz)		40-500+	100-500+	0.4-3	3-40
Conduction Velocity (m/s)		35-70	35-70	40-65	35-70
Effective Stimuli		Temporal changes in the skin deformation	Sustained downward Pressure; Lateral skin stretch; Skin slip.	Spatial deformation; Sustained pressure; Curvature, edge, corners.	Temporal changes in skin deformation
Sensory Function		High frequency vibration detection; Tool use.	Finger position; Stable grasp; Tangential Force; Motion direction	Pattern/form detection; texture perception; Tactile flow perception.	Low frequency vibration & motion detection; Grip control; Tactile flow perception.

Perceptual parameters of interest

Activation/operating frequency

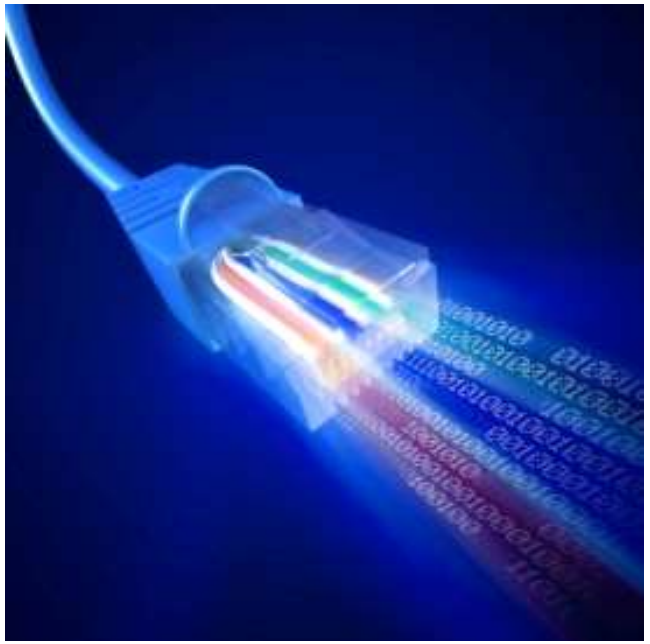
Perceptual thresholds

- Absolute thresholds (limits)
- Difference threshold (resolution)

Inform in VR about :

Frequency of rendering/display

Amplitude and variation of signals



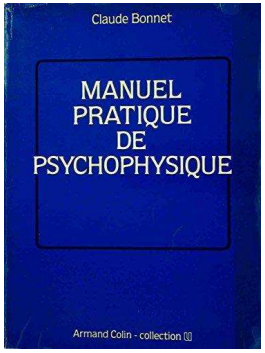
Operating frequencies

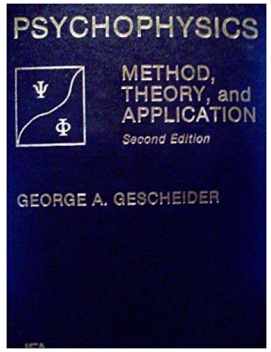
Tactile sense
- F between 1 and 300 Hz
- F can reach 1 kHz (fine textures)

Kinesthetic sense (force perception)
- F between 20 and 30 Hz

Sensory-motor control
- F = 1-2 Hz (random signals)
- F = 2-5 Hz (periodical signals)
- F = 5 Hz (learned trajectories)
- F = 10 Hz (reflex actions)

Method : Psychophysics



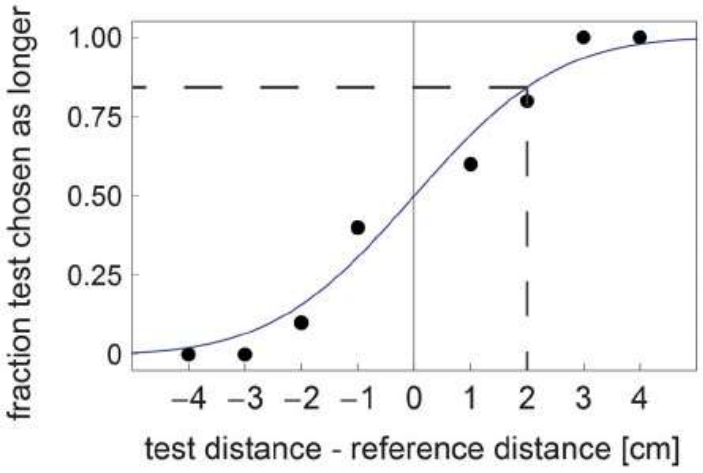


Psychophysics :

- Scientific study of the relation between stimulus and sensation

Example : Difference Threshold

- Just Noticeable Difference (JND) : *"minimum amount by which stimulus intensity must be changed in order to produce a noticeable variation in sensory experience."*
- Weber fraction (Ernst Weber, 19th century)



$$\frac{\Delta I}{I} = k$$

where ΔI (delta I) represents the difference threshold, I represents the initial stimulus intensity and k signifies that the proportion on the left side of the equation remains constant despite variations in the I term

Haptic JNDs

Tactile

Pressure

Note : Detection of contact = 63mg

JND between 2 points (spacing) = 2.5mm

JND vibrations = 20/25% (f=20-300Hz)

Thermal

JND cold = -0.27°; heat = 0.4°

Not working for T > 48°

Kinesthetic

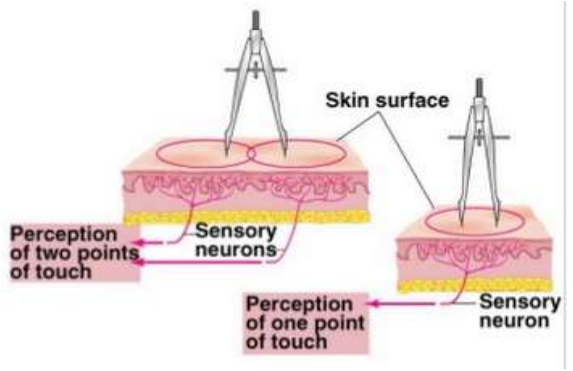
JND weight = 10%

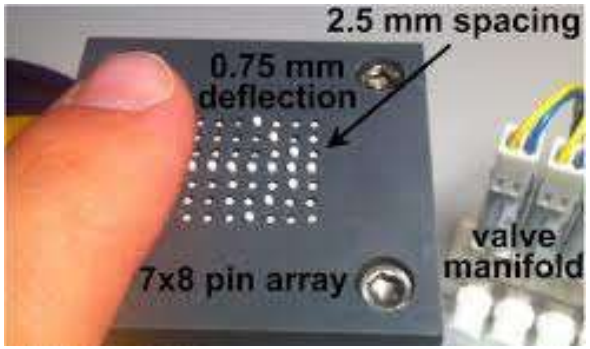
JND couple = 13%

JND force = 5-15%

JND stiffness = 22%

JND joint angle (finger) = 2,5°





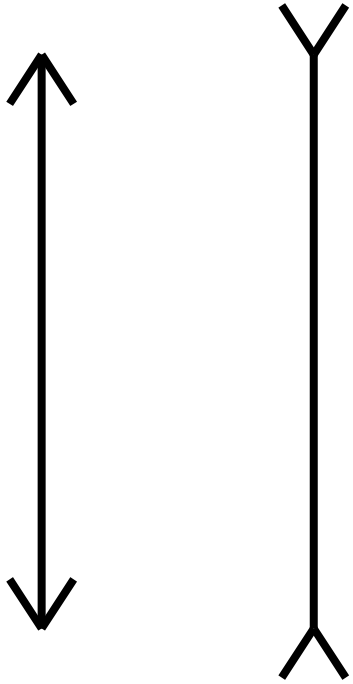
Haptic illusions

When physiology is not all..

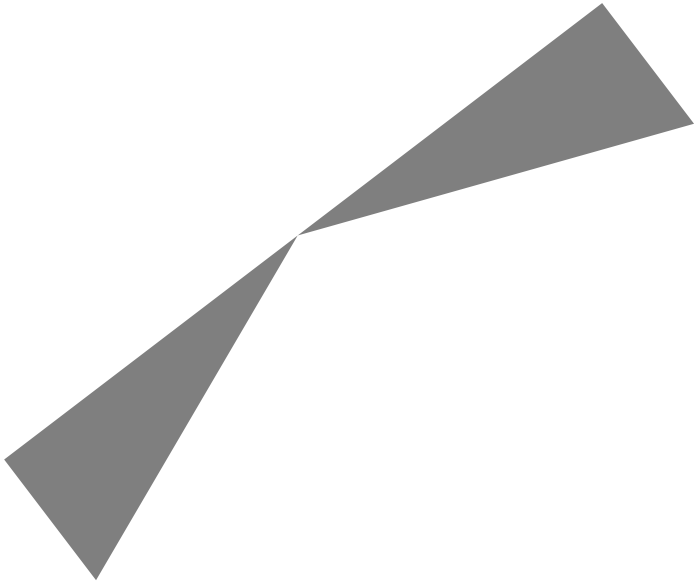
Sensory illusion is not an error or a bad solution, but the « best possible hypothesis »
(Alain Berthoz, 1998)

Optical illusions

Illusion of Müller-Lyer



Illusion of Bourdon

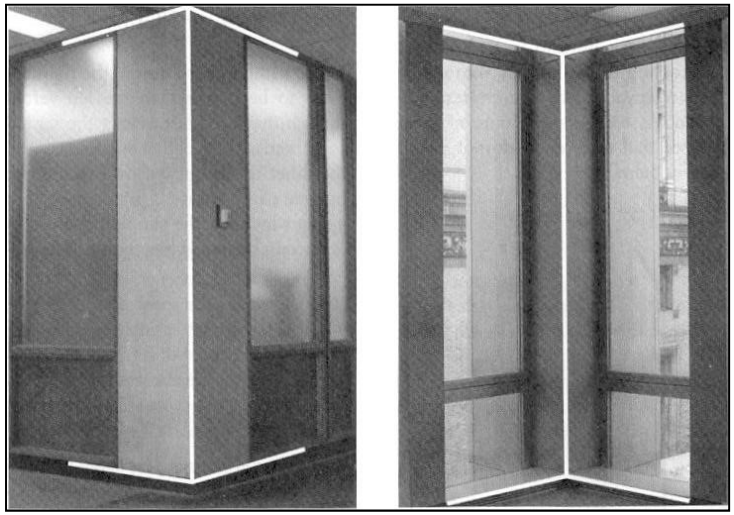


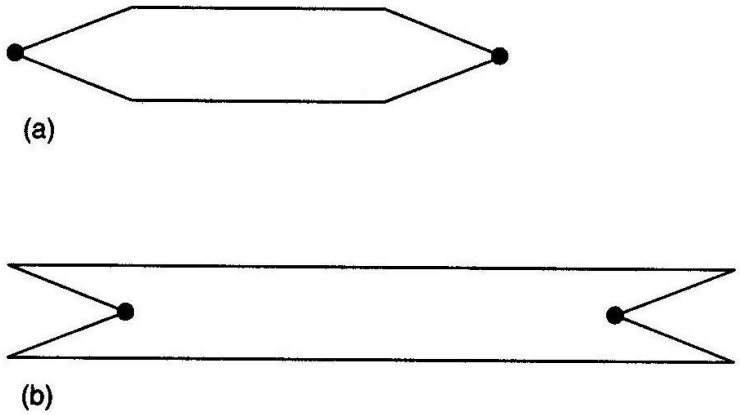
Explanations ?

Example of Müller-Lyer illusion :

Gregory (1966) : Misapplied size constancy scaling

Day (1989) : Figure (b) looks larger





>> In general.. lack of explanations !

Illusions common to visual and haptics

Some illusions exist on both modalities

Bourdon : [Day 90]

- Similar effect, similar amplitude : 2.5 degrees

Müller-Lyer : [Volker et al. 2000]

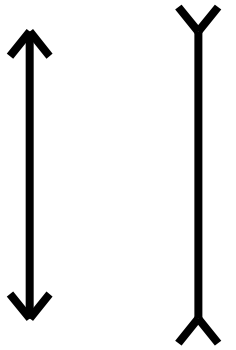
- Similar effect, illusion works for native blind people

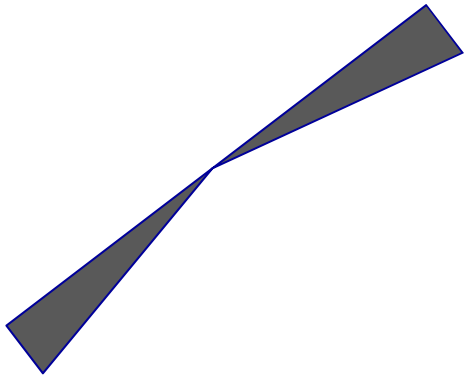
Some others do not

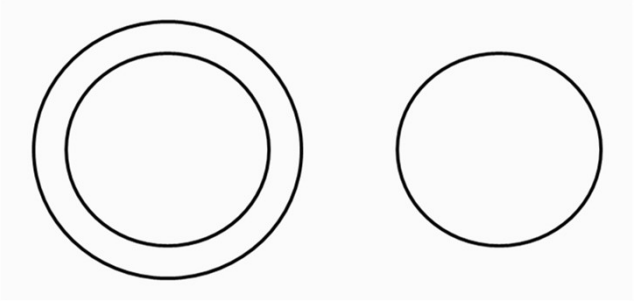
Delboeuf : no haptic equivalent

Open questions

High-level cognitive process versus Low-level perceptual process ?



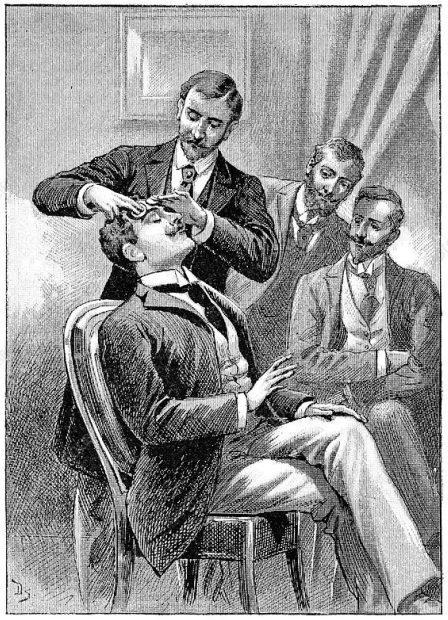


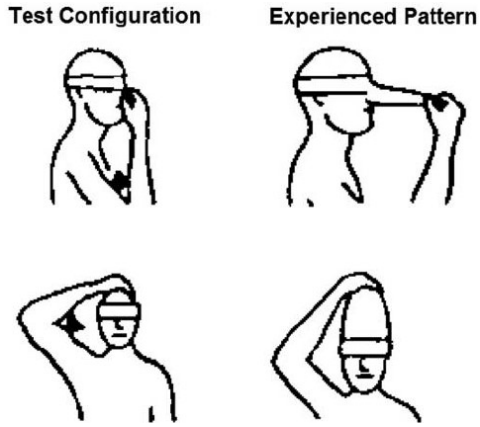


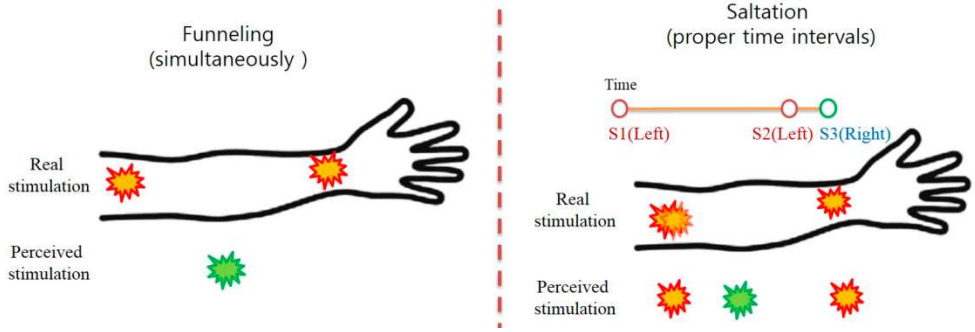
Haptic illusions

Famous examples :

- Thaler illusion : colder seems heavier
- Other thermal illusions : eg, 3 baskets of water
- Charpentier illusion : smaller seems heavier
- Funnelling & Saltation illusions : vibration-based
- « Pinocchio illusion » : tendon vibration illusion







Summary / Haptic illusions

- ✓ Numerous haptic illusions exist
- ✓ Not always explanations
- ✓ Exploitation in VR

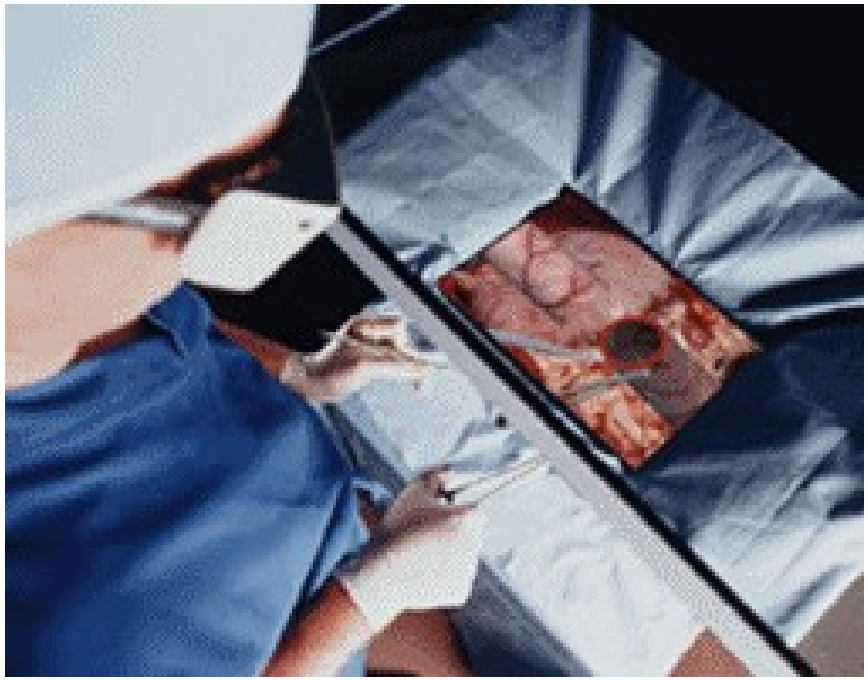
>> What about vision + haptics ?

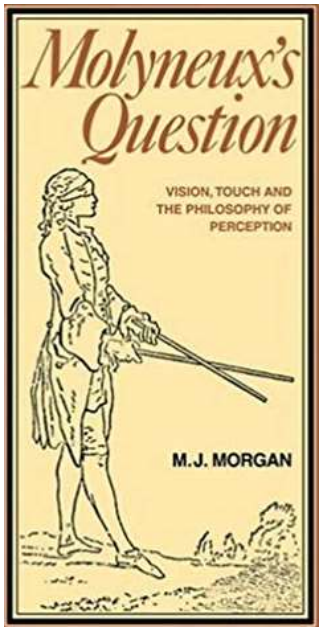
Visuo-haptic integration

Context : multi-sensory environments

Objective : understanding integration of two modalities

Application : facilitating the sharing of information across displays





William Molyneux (1656–1698, Dublin)
Letter sent to philosopher John Locke (July 7th, 1688)

Sensory conflict

Technique : put two sensory modalities in conflict

>> Which one dominates ?

Pioneer conflict : ***[Rock et Victor, Science, 1964]***

Visio-haptic conflict regarding the shape of an object : a cube

Use of a deforming lens >> vision sees a rectangle

>> Which sense wins ?

>> Result ?

Visual dominance

VH conflict related to “spatial information”

Initial result : visual dominance (Rock and Victor)

Follow-up studies : trade-off between modalities, « capture » in case of strong inconsistencies

“For spatial tasks, vision has a tendency to dominate and be more exploited than haptics. Haptics can be used in case of breaks in sensory coherence.”

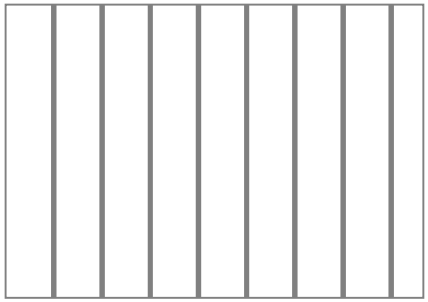
VH conflict related to “textures”

Perception of textures is privileged by touch :

- Very good performance
- Better than vision for fine textures

Contrasted results : depending on instruction

- Roughness (haptic notion)
- Spatial period (spatial notion)



If conflict is about “Roughness” : trade-off in favor of Touch

If conflict is about “Spatial period” : trade-off in favor of Vision

Models of visio-haptic integration

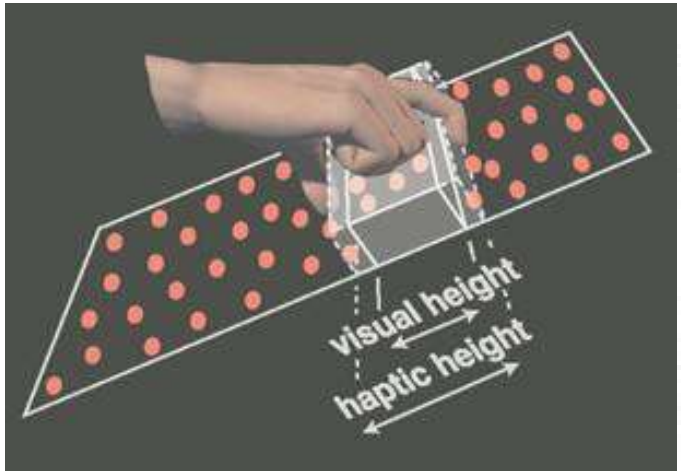
- Consensus regarding a "*Weighing*" of visual and haptic cues
- Weight of each modality related to :
  - Attention given to a modality (Canon 1971) (Kelso et al. 1975) (Uhlarik et al. 1971) (Warren and Schmitt 1978)
  - Reliability given to a modality; also related to either :
    - Ambiguity of the modality (Jacobs et al.)
    - Correlation with other modalities (Jacobs et al.)
  - Accuracy of information in every modality (Pick et al. 1969) (Welch et al. 1979) *(Ernst and Banks 2002)*

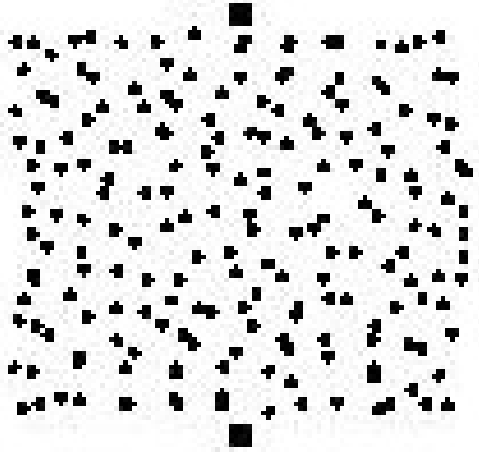
Example : Model of Ernst and Banks

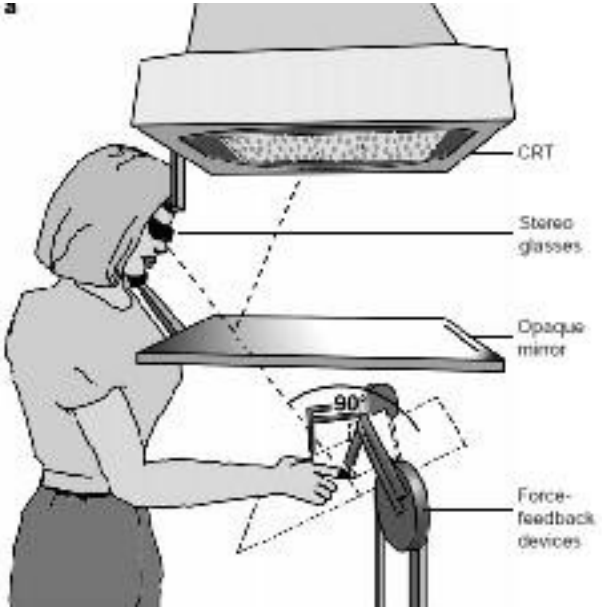
(Ernst and Banks, Nature, 2002) : weighing related to the performance of every sensory modality

Maximum-likelihood integrator : when combining the inputs, using variance in the estimation of every individual modality

Visual dominance : when the variance associated with visual estimation is lower than that associated with haptic estimation





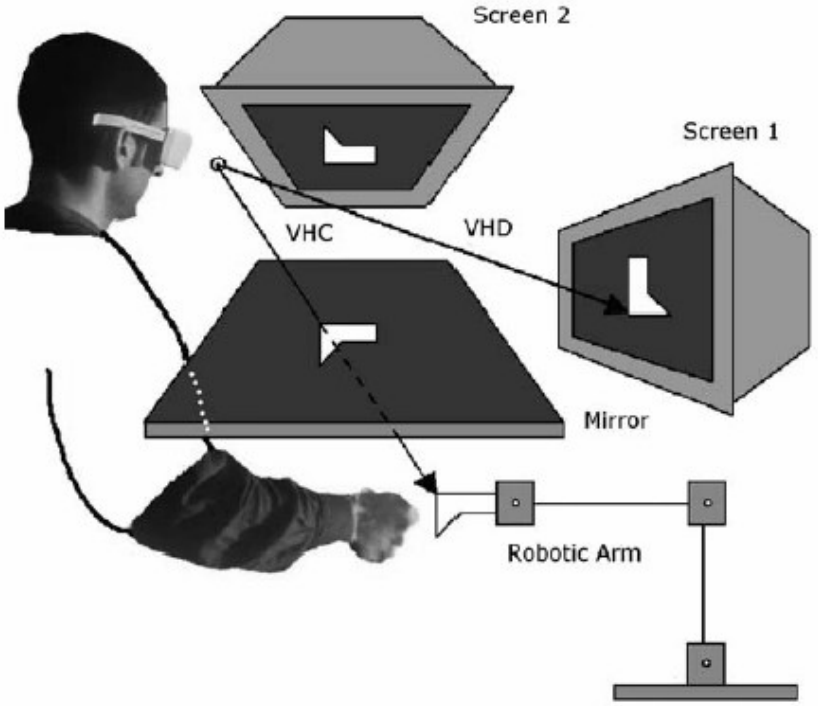


Study of visio-haptic delocalization

Result : vision dominates even more when visual and touch cues are not at the same place

Video “collocated”

Video “delocated”



(Congedo et al., Presence 2005)

Summary / Visio-haptic Integration

Visual dominance for « spatial » information

Stronger influence of haptics for « materials » and textures

Weighing of senses : related to different aspects (noise, attention, performance, etc)

Possible breaks in sensory consistency, eg delocalization

>> Break : the "6-finger illusion"

(Example of exploitation of visio-tactile integration)

“6-finger” illusion

Touching with the eyes: Pseudo-haptics

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Pseudo-Haptics : the origins

1998

Google Search Engine

This is a demo of the Google Search Engine. Note, it is research in progress so expect some downtimes and malfunctions. You can find the older Backrub web page here.

Google is being developed by Larry Page and Sergey Brin with very talented implementation help by Scott Hassan and Alan Steremberg.

Search Stanford

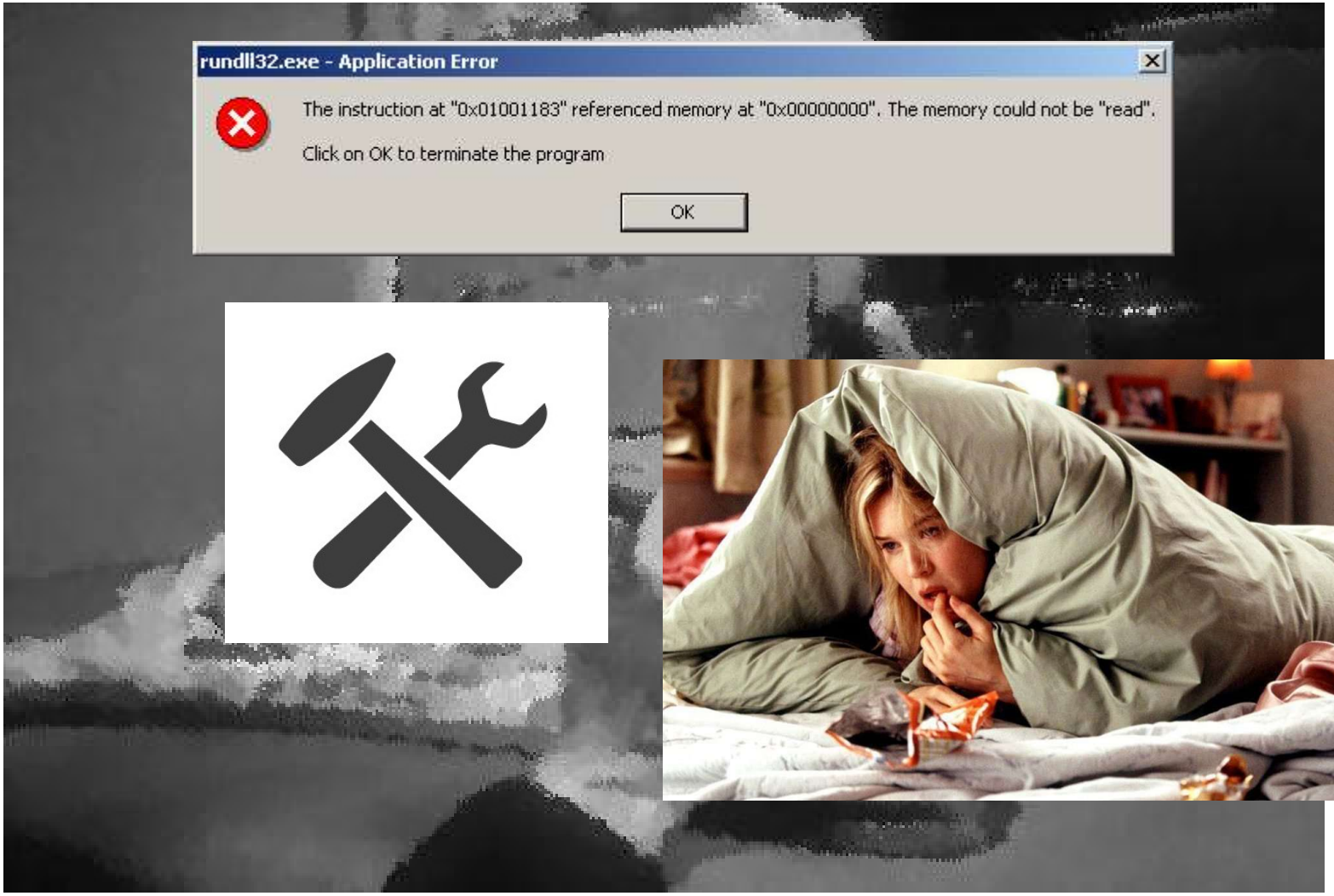
10 results | clustering on | Search

Search The Web

10 results | clustering on | Search

Pseudo-Haptics : the origins

Pseudo-Haptics : the origins



Initial motivation

How to simulate haptic sensations .. without a haptic interface ?

Sabine Coquillart (PhD Advisor) : “what about using this..”

Alternative path ?

- Exploit a passive device : Spaceball
- Rely on its passive haptic properties
- Rely on visual effects

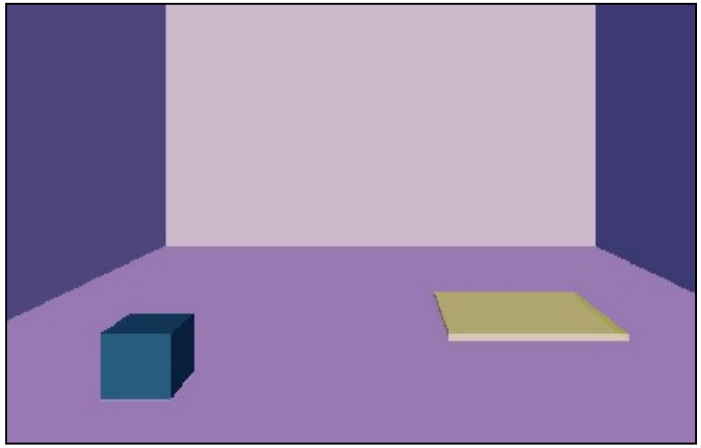
>> Touching with the eyes ?

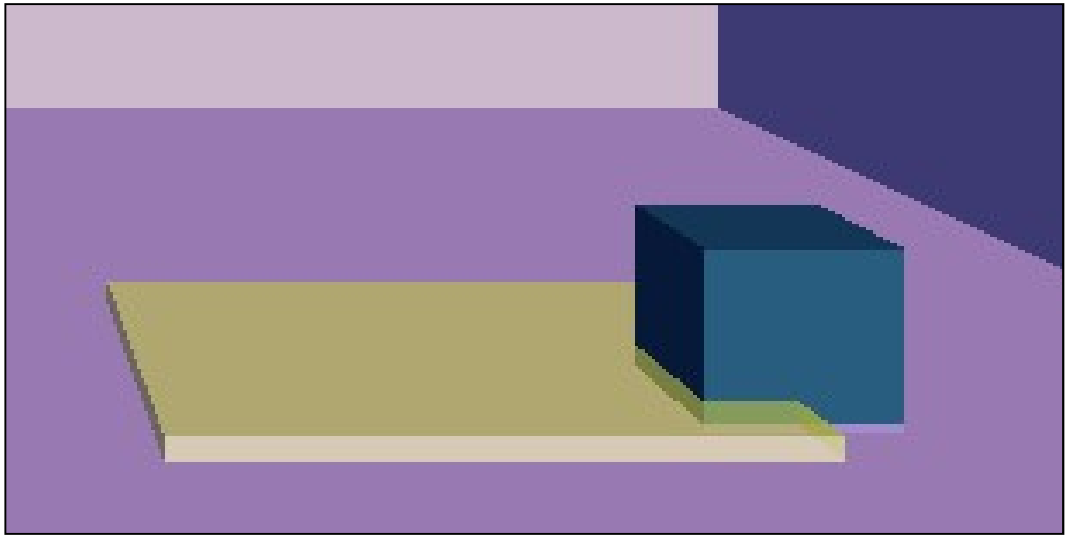
First steps : the « swamp » experiment

Simple scene : a cube crossing a gray area

Simulation of friction : artificial decrease of speed

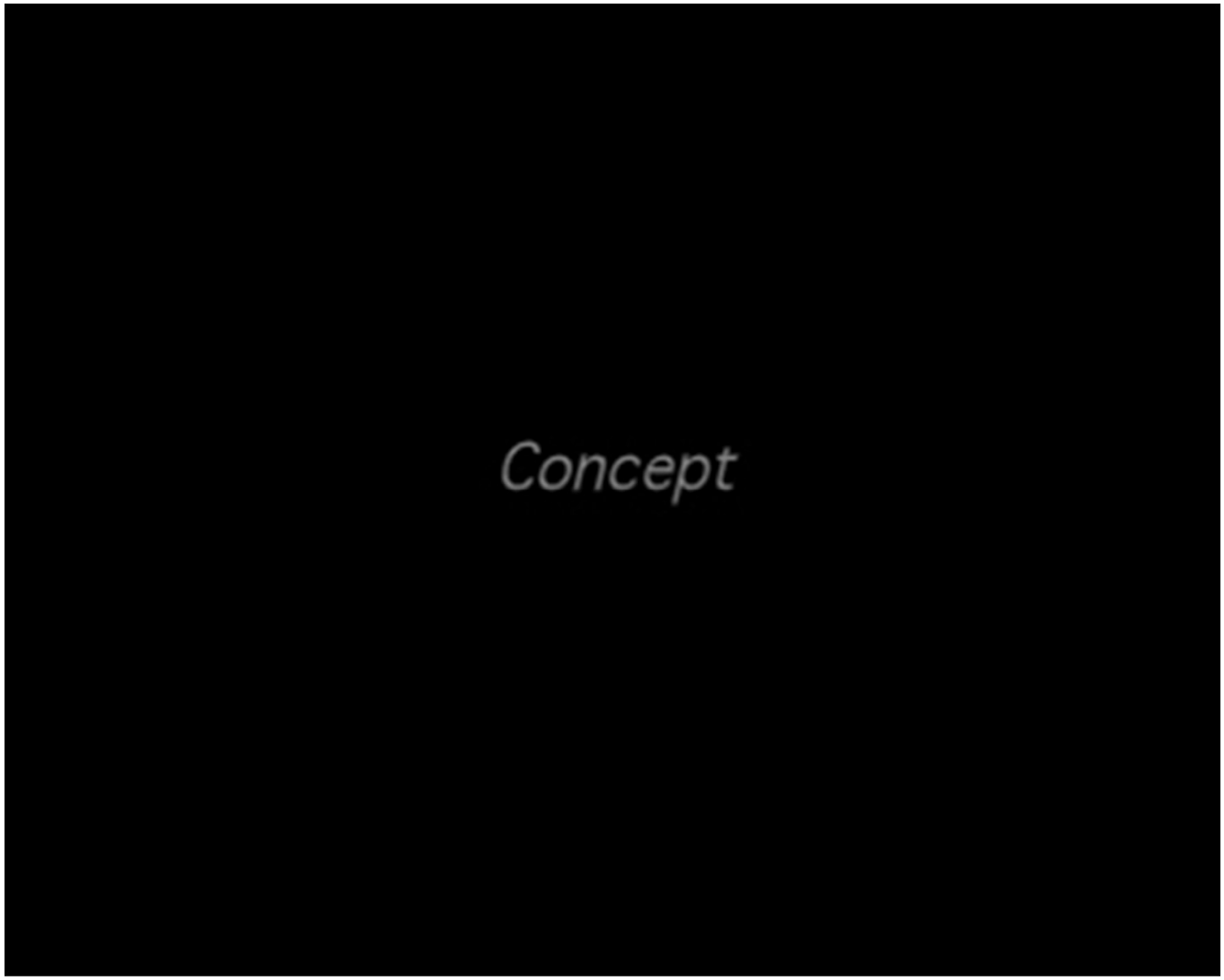
Increase in pressure >> higher force, resistance, friction





(Lecuyer et al., IEEE VR 2000)

video



Results

18 participants, Questionnaire

94% des sujets (17/18 sujets) sélectionnent « rien du tout » lorsque le facteur multiplicatif valait 1, et ont sélectionné une autre expression parmi celles proposées dès que le facteur était différent de 1. (indep. souris ou spaceball)

« plus lourd », « frottement » et « ralentissement » sont associées aux facteurs inférieurs à 1

« moins lourd », « accélération » et « glissement » sont associées aux facteurs supérieurs à 1

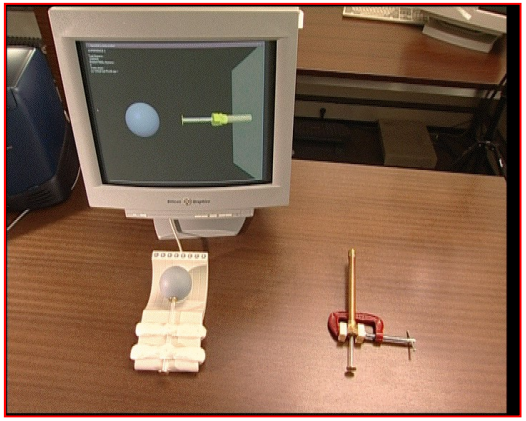
78% (14/18) ont ressenti des « différences de sensation » entre les deux périphériques

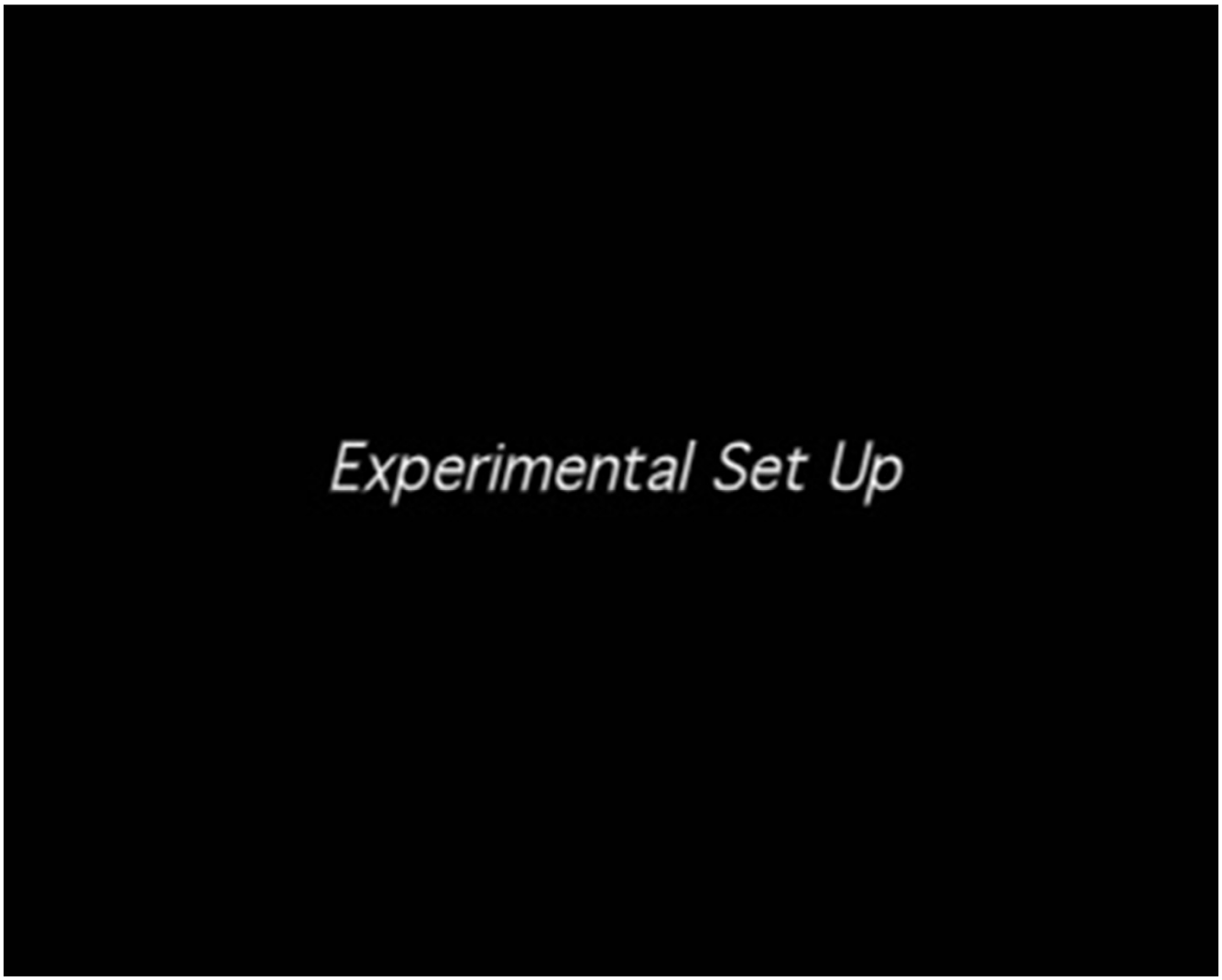
83% (15/18) les sensations étaient « plus perceptibles » avec la Spaceball

Simulation of stiffness

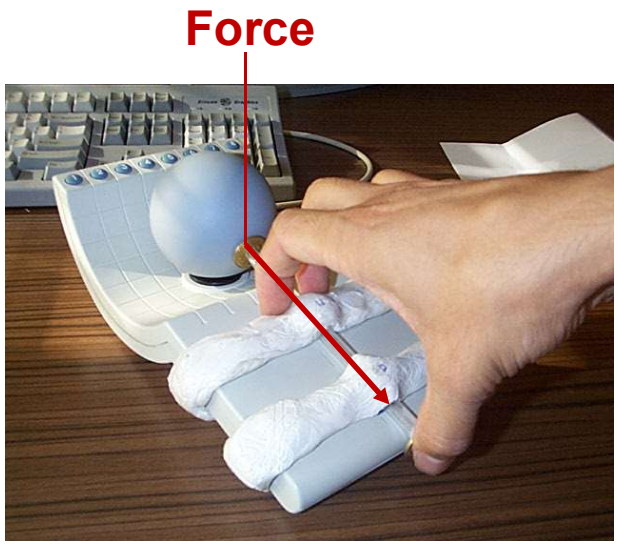
(Lecuyer et al., IEEE VR 2000)
(Lecuyer et al., IEEE VR 2001)

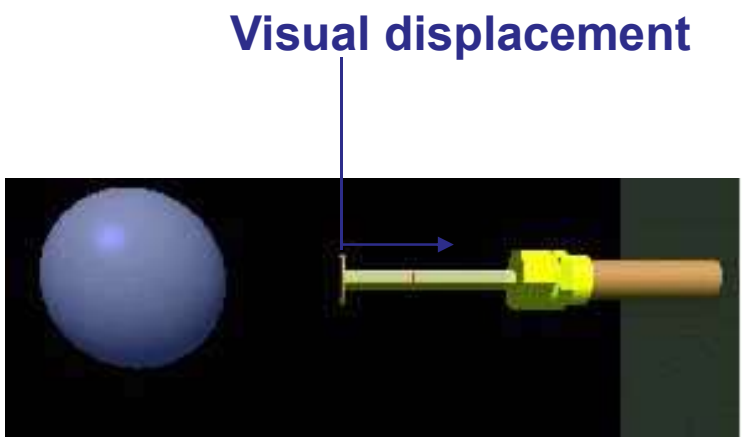
Experimental setup





Pseudo-haptic spring



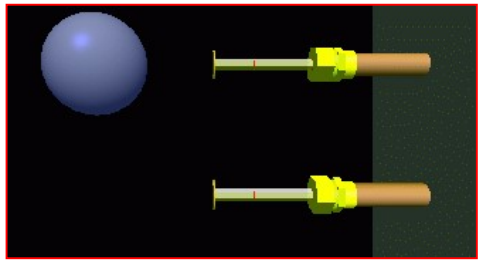


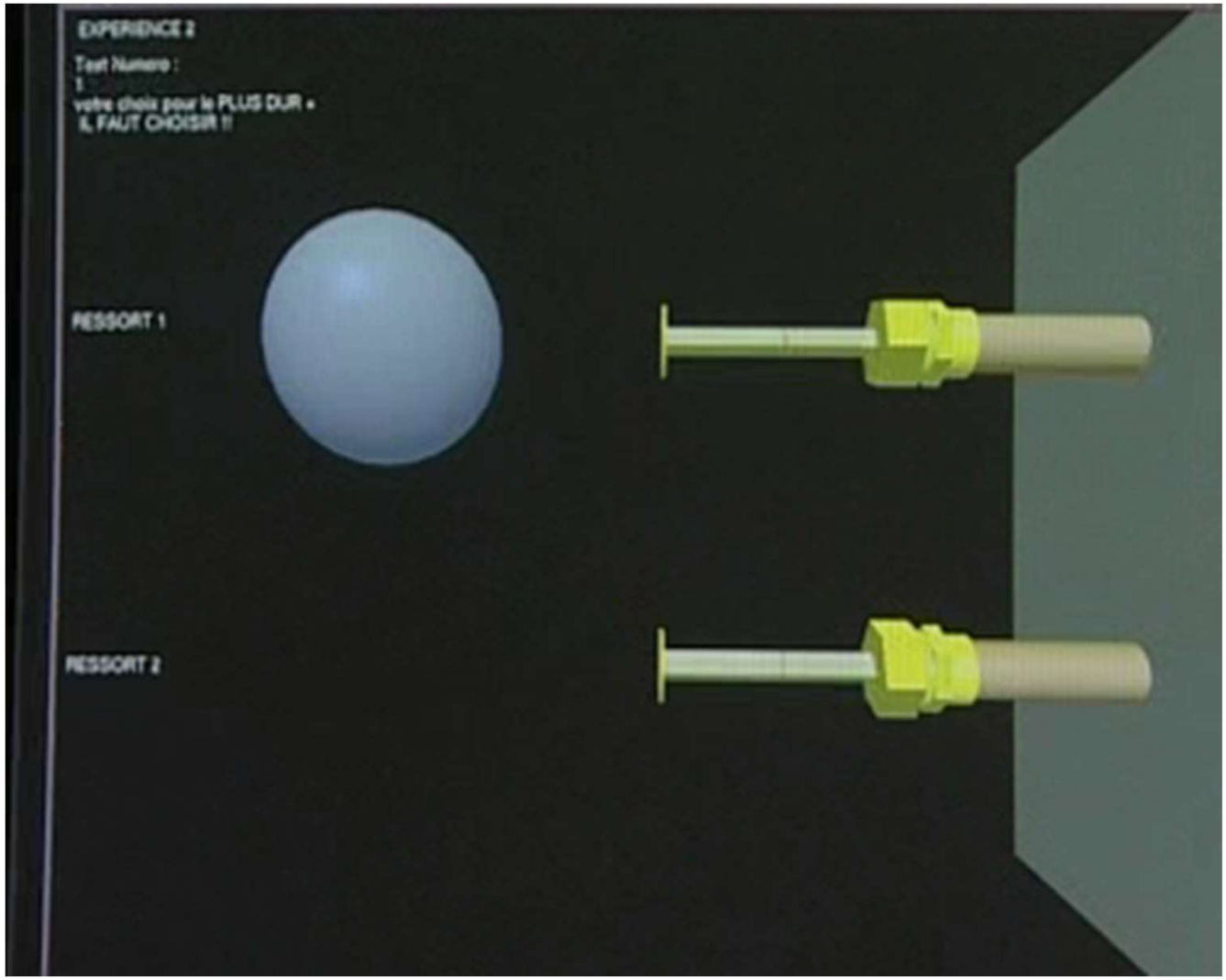
Hooke's law : F = K.Dx

$$Kv = \frac{\text{Exerted Force}}{\text{Finger Displacement}}$$

$$Kv = \frac{\text{Exerted Force}}{\text{Visual Displacement}}$$

Comparison of 2 virtual springs





Data Analysis

Psychophysical analysis : computation of discrimination thresholds *[Bonnet, 86] [Gescheider, 85]*

Parameters :

JND (Just Noticeable Difference / Weber Fraction)

Stiffness JND : 8% - 22% [Tan et al., 95] [Jones et Hunter, 92]

PSE (Point of Subjective Equality)

Valeur du stimulus de comparaison perçue comme égale au stimulus de référence

If JND values are close to real observations (20%), our simulation can be considered as realistic

Results

4 people, 1500 trials

People are able to select the “stiffest” spring

Average Just Noticeable Difference (JND) = 6.15%

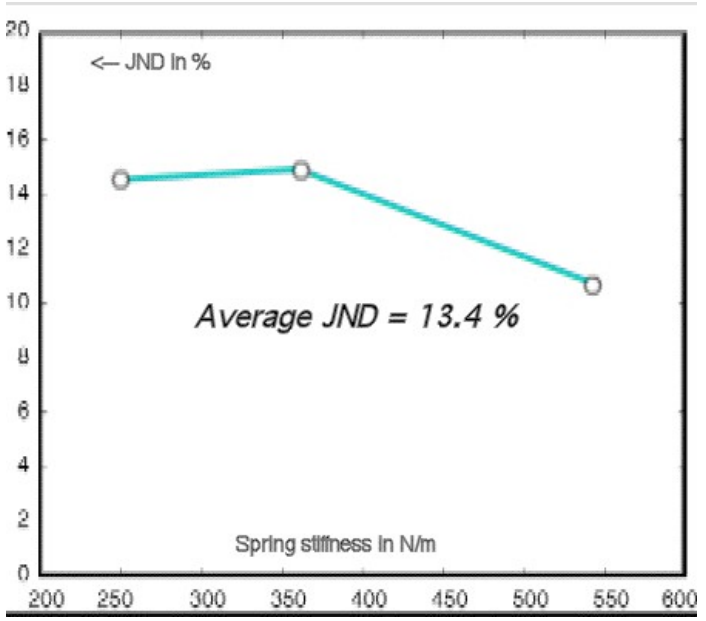
Consistent with previous work

Our model of virtual spring is credible

It can be achieved without a force feedback device

Comparison between a real spring and a pseudo-haptic spring

Results



27 participants

Average JND = 13 %

- Pseudo-haptic spring comparable to a real spring

Average PSE = + 9 %

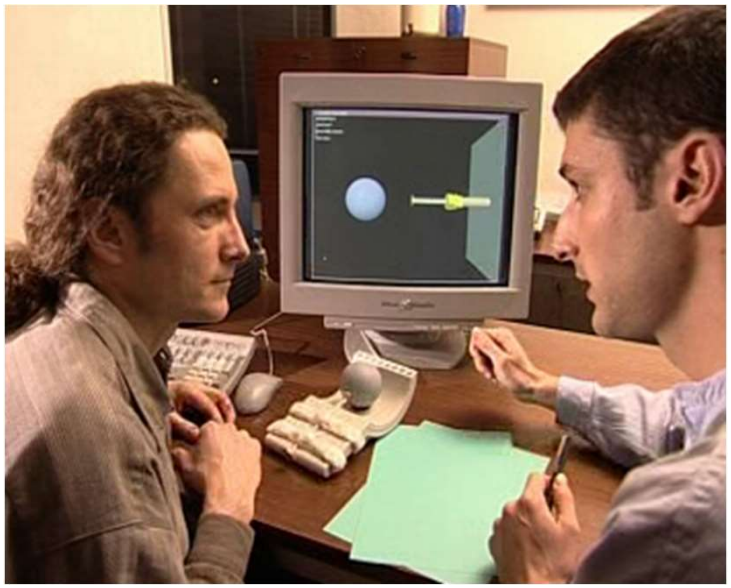
- Distortion in perception : underestimation of pseudo-haptic spring

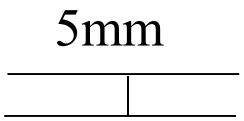
Summary of results

- ✓ Model of pseudo-haptic spring based on visual feedback
- ✓ Pseudo-haptic system can simulate haptic information which are comparable to real haptic cues
- ✓ Subjects « mapped » the force information on the visual displacement

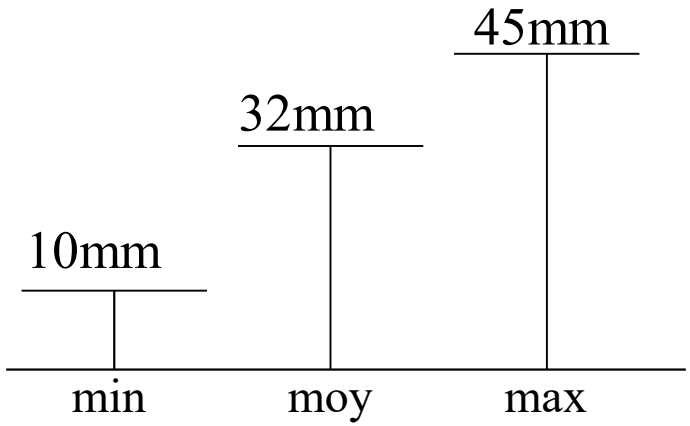
Sensory illusion

« How much did your finger move ? »





Displacement max Spaceball



Displacement max perceived

the proprioceptive sense is "blurred" by visual feedback

Toward a Pseudo-Haptic Manual

How to simulate haptic properties with pseudo-haptics

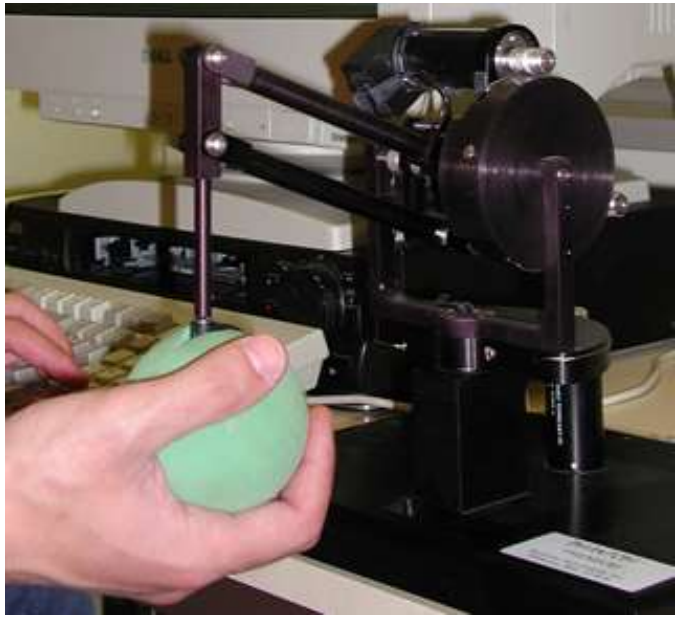
Table of Contents :

- Friction/Viscosity
- Stiffness/Elasticity
- Mass/Weight
- Texture/Relief
- Material

Simulation of mass

(Dominjon et al., IEEE VR 2005)

Visual motion amplification >> objects feel lighter



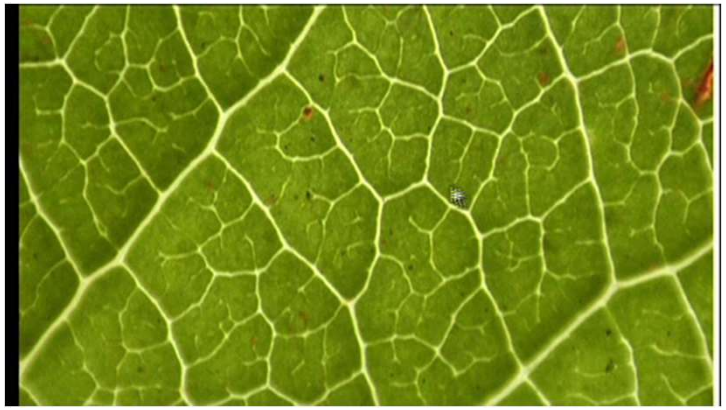
video

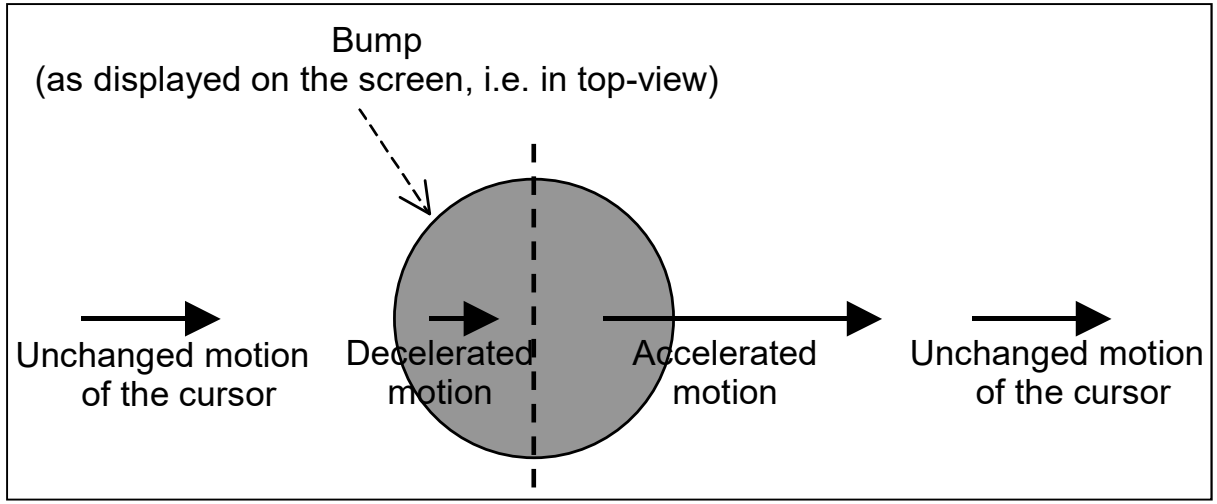
Simulation of texture

Simulate the relief of 2D images

Change the motion (speed) of cursor

Function of height

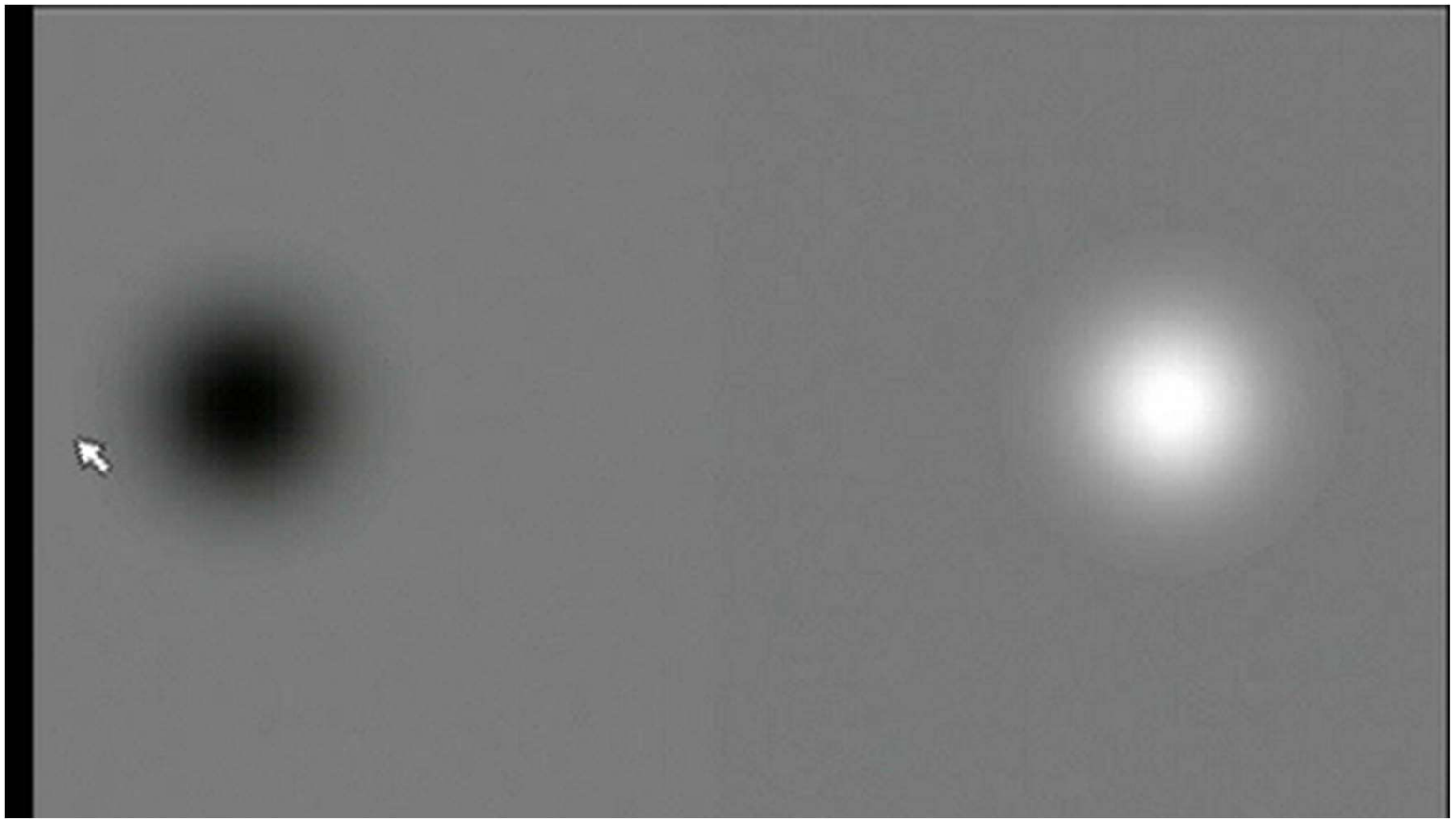




(Lécuyer et al., ACM CHI 2004)

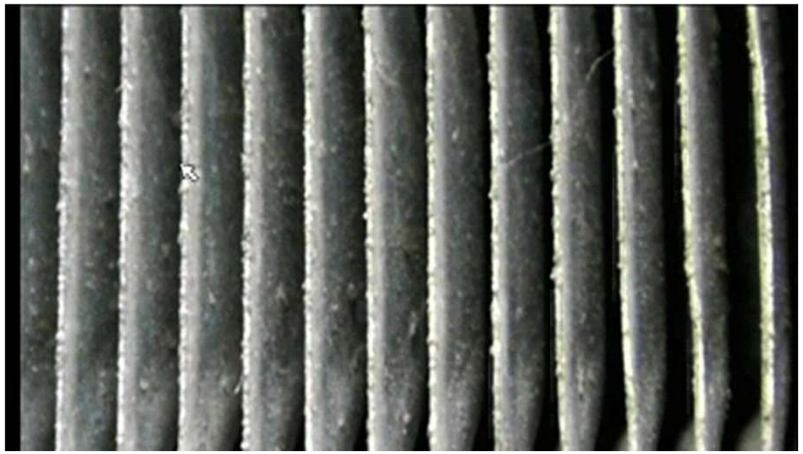
bumps and holes

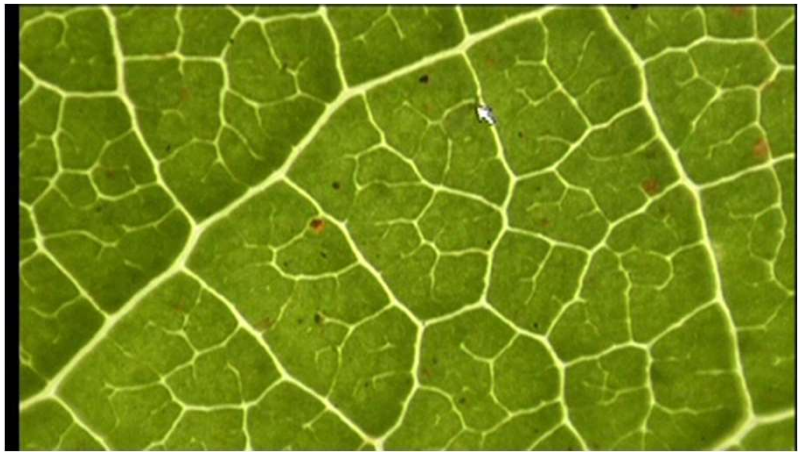
Video

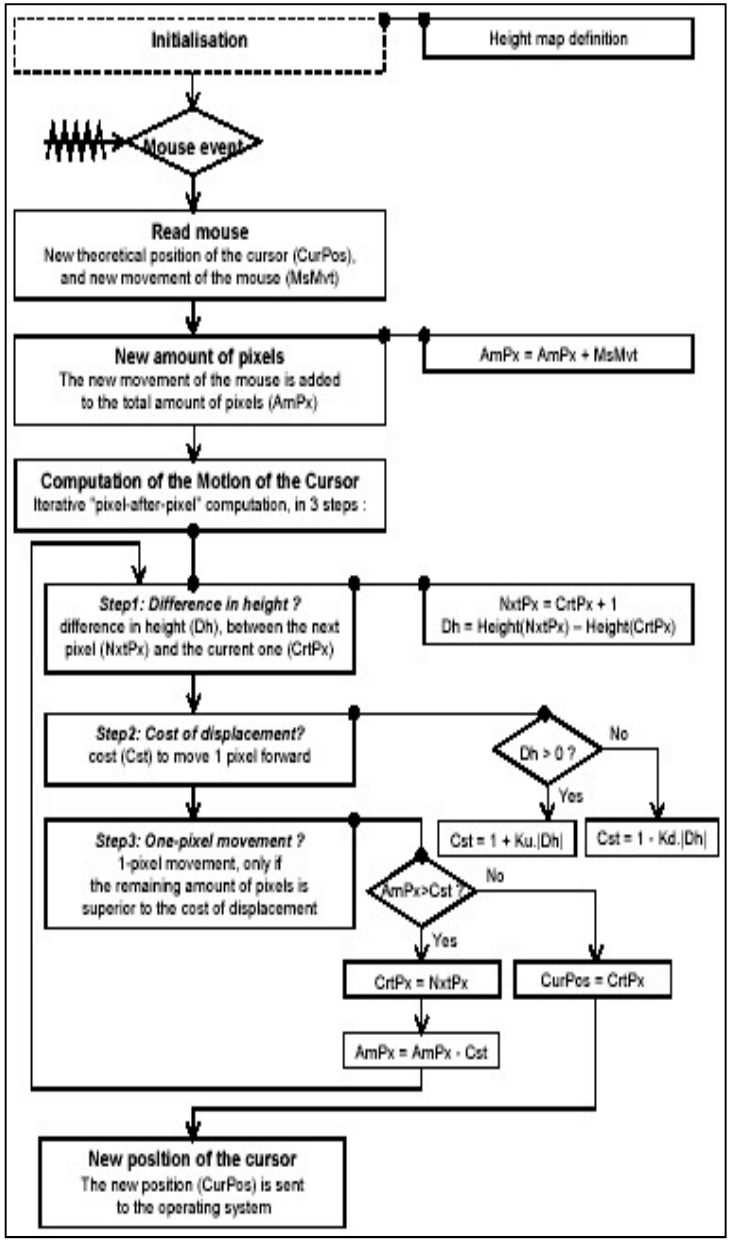


Pseudo-haptic textures

Generic algorithm for 2D images





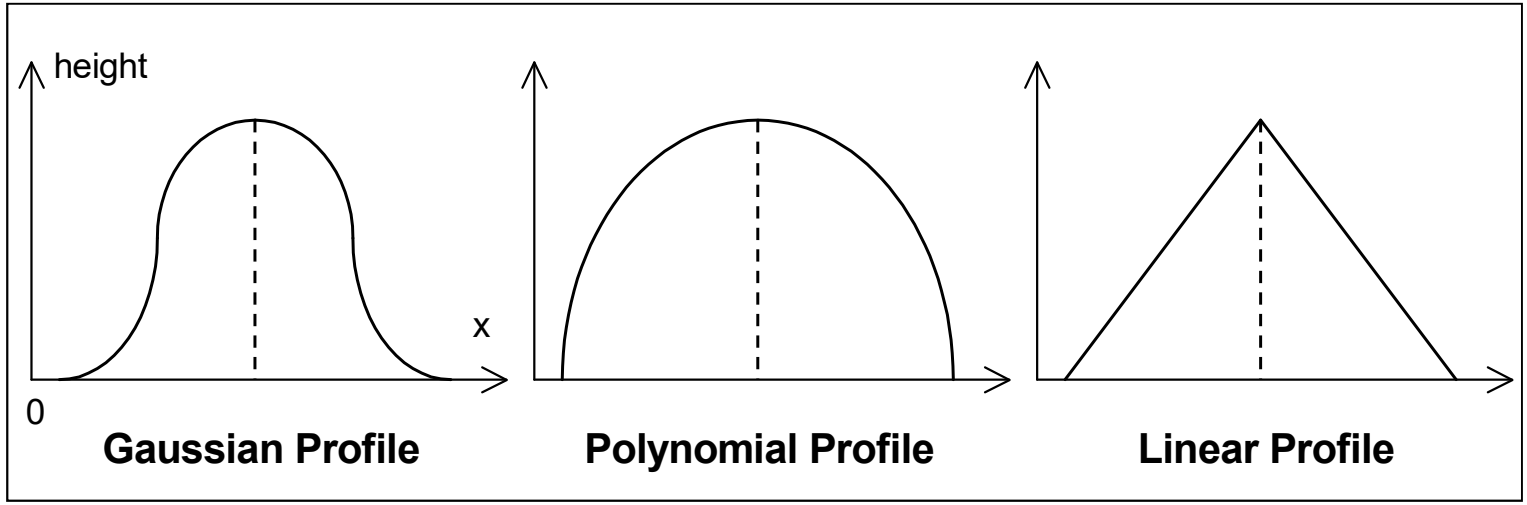


Evaluation of pseudo-haptic textures

Objective : testing ability to simulate bumps and holes

3 experiments

3 different simulation profiles

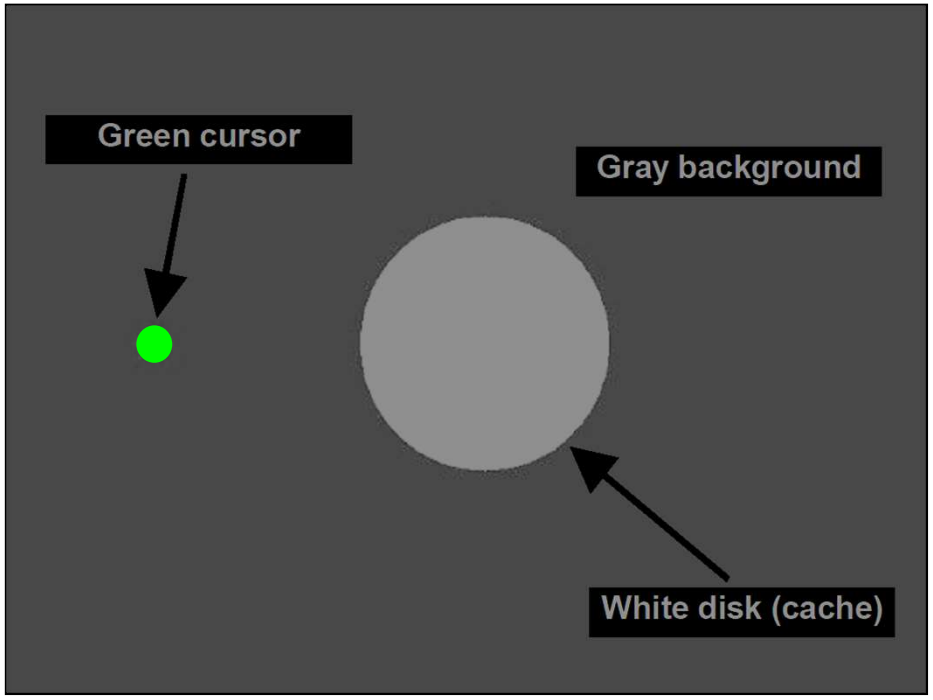


Experiment 1

Can bumps and holes be identified using only 2D visual information?

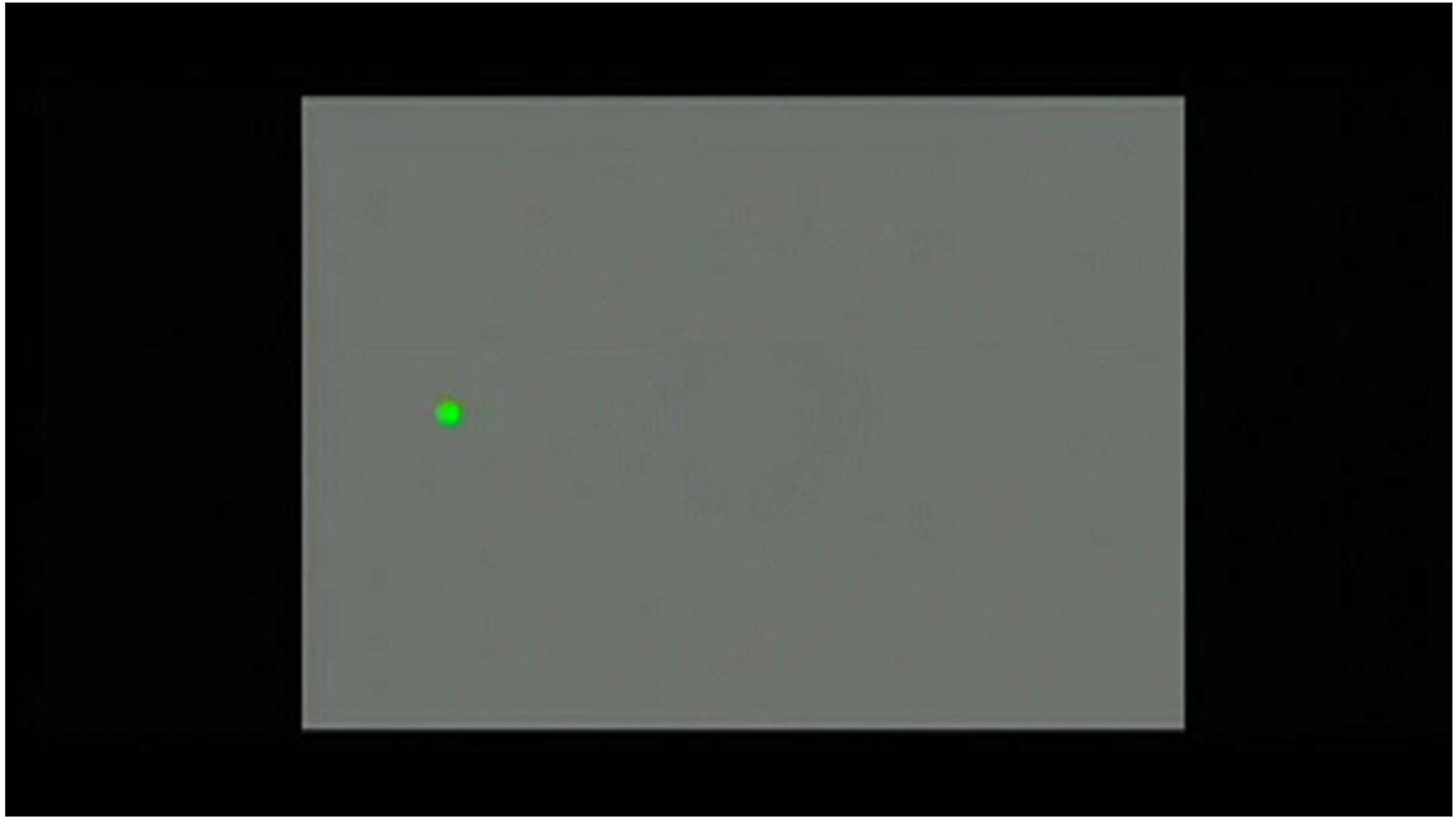
10 Participants

“Identify the target-shape located under a white cache”



Procedure

Video



Results Experiment 1

Conditions : 3 shapes (bump, hole, flat), 3 simulation profiles (linear, Gaussian, polynomial), 3 radiuses, 3 amplitudes (i.e. height or depth)

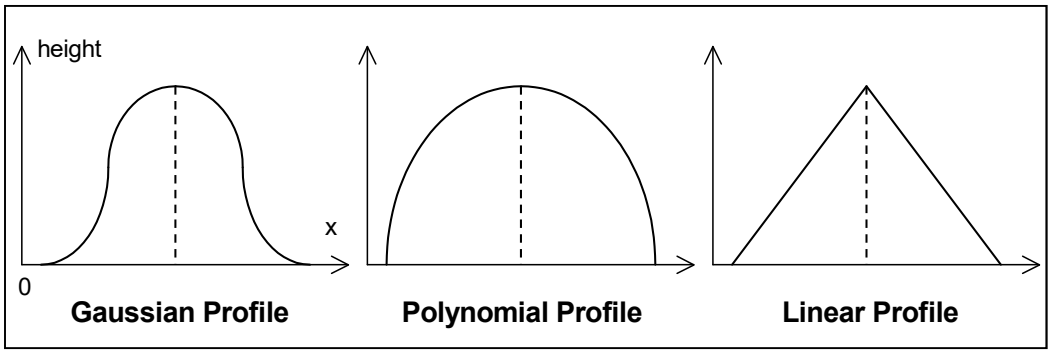
285 tests, 45 minutes

Average percentage of correct responses of : **93%**

“Best Profile”: Polynomial (96%)

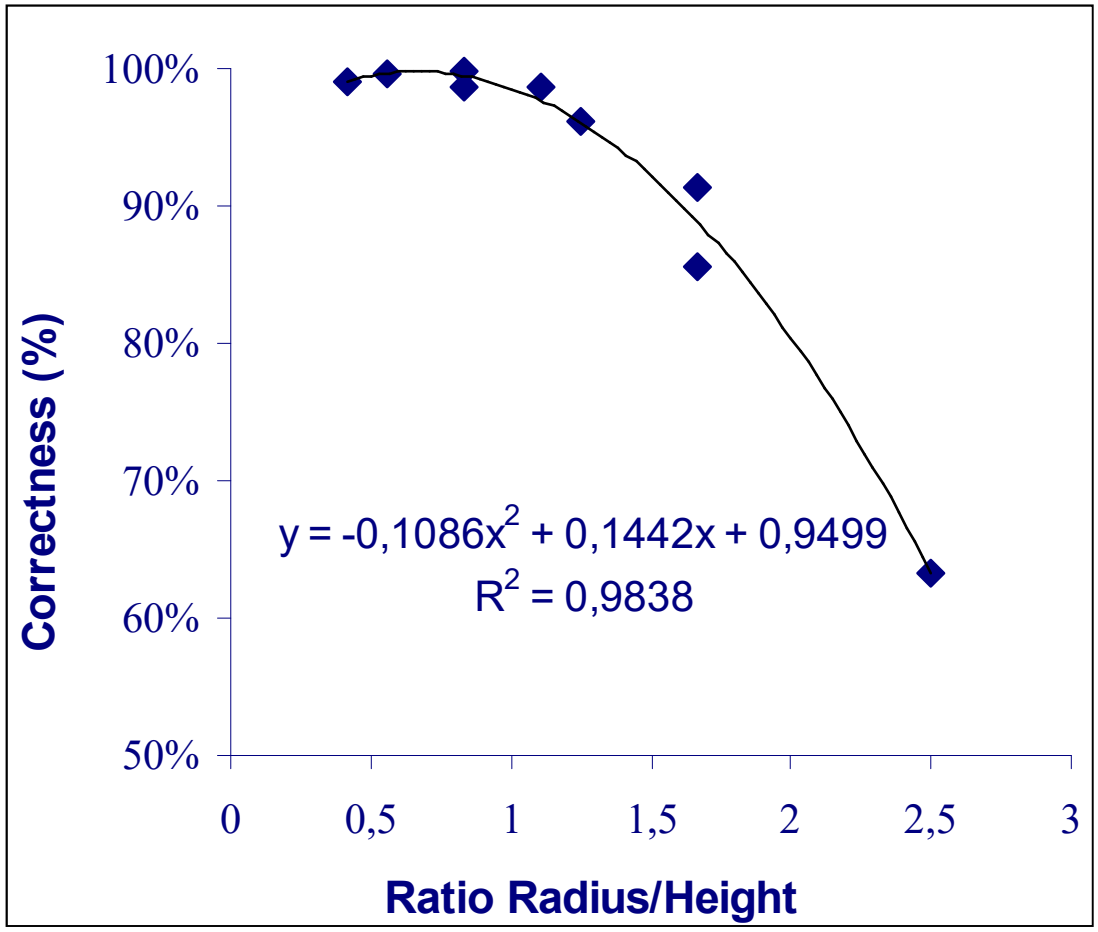
> Gaussian (93%)

> Linear (89%)



Results (cont'd)

Effect of "slope"



But …

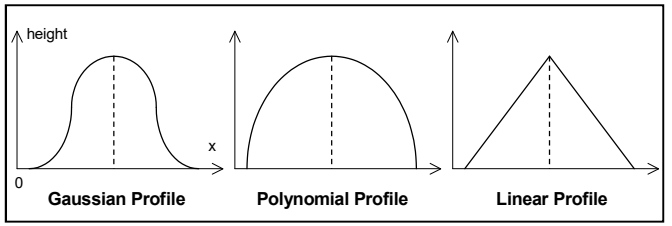
Participants might have used the white cache ?

Experiment 2

Video

Can bumps/holes be identified using the sole motion of the cursor?

Results Experiment 2



10 Participants

Conditions : 3 shapes (bump, hole, flat), 3 simulation profiles (linear, Gaussian, polynomial), 1 radius, 1 amplitude

35 tests, 35 minutes

Average percentage of correct responses : 86%

Still more efficient to identify with Polynomial (90%)

More efficient to localize center with Gaussian, and poor with Polynomial

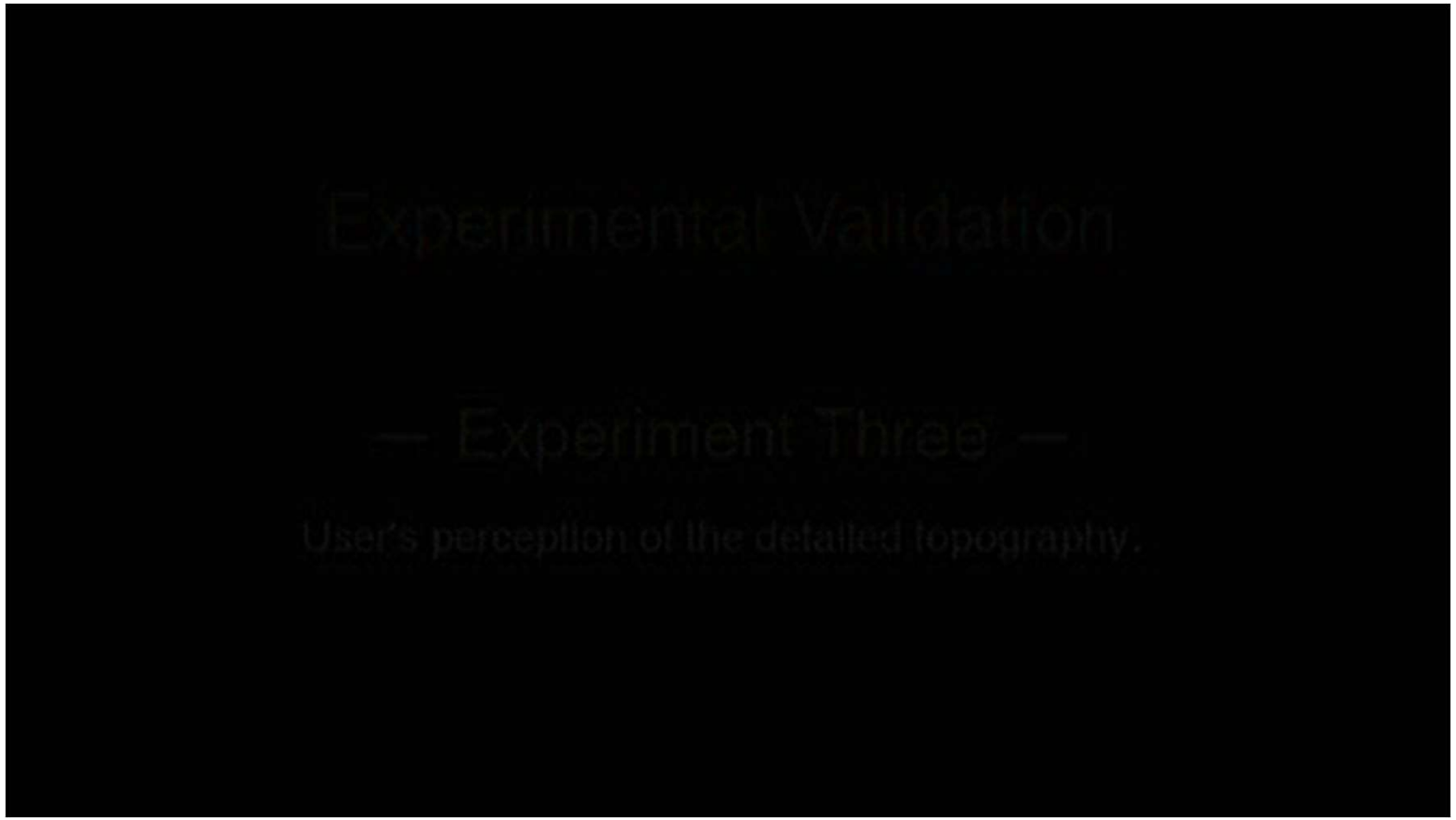
But…

Did participants well conjure a mental image of the topography ?

Experiment 3

Video

User's perception of the detailed topography?

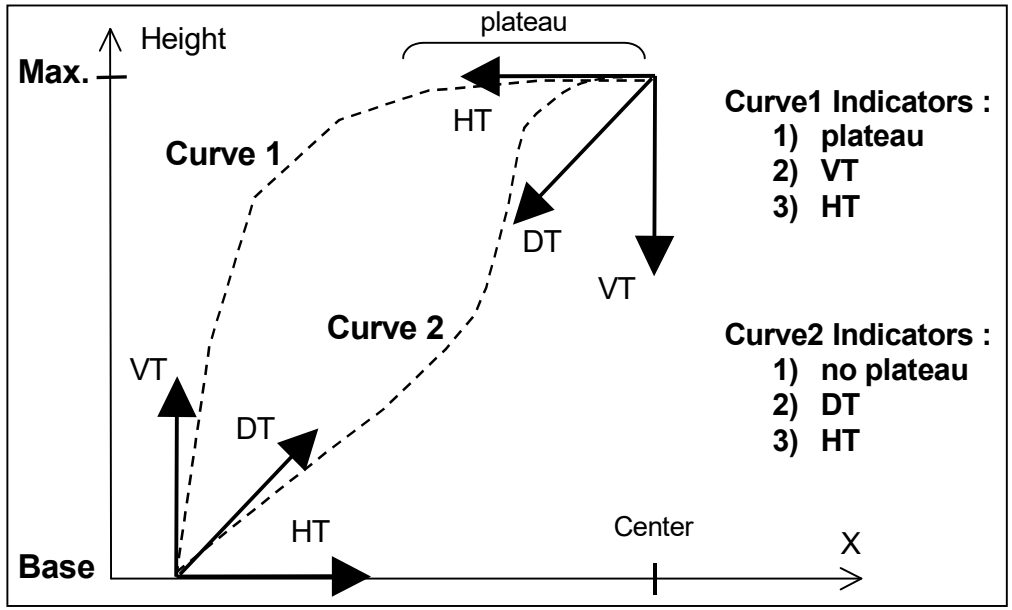


Results Experiment 3

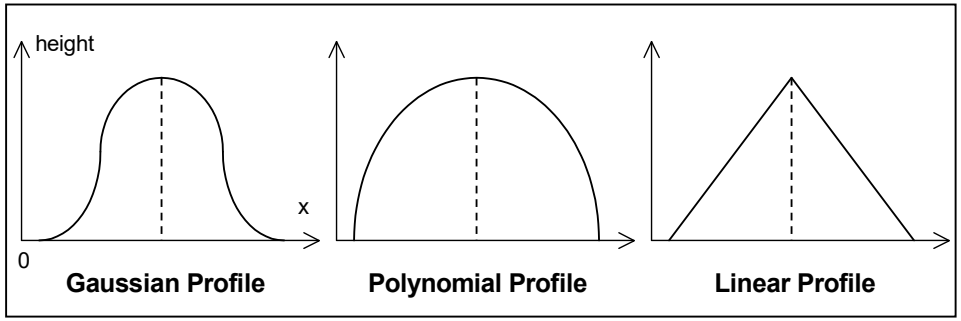
20 Participants, 6 curves, 20mn

Indicators: amplitude at the center, diameter and, more especially:

1. presence of a “plateau”
2. tangent at the base
3. tangent at the extremum



Main results



Gaussian were drawn thinner with horizontal tangents at the base

Polynomial drawn with a plateau and a strong slope at the base

Linear profiles drawn with diagonal tangents

Conclusions Experiment 3 :

Participants accurately perceived differences between the three simulation profiles

Consistent with the actual simulation profiles used

Participants were able to conjure mental representations of the shapes

Conclusions on pseudo-haptic textures

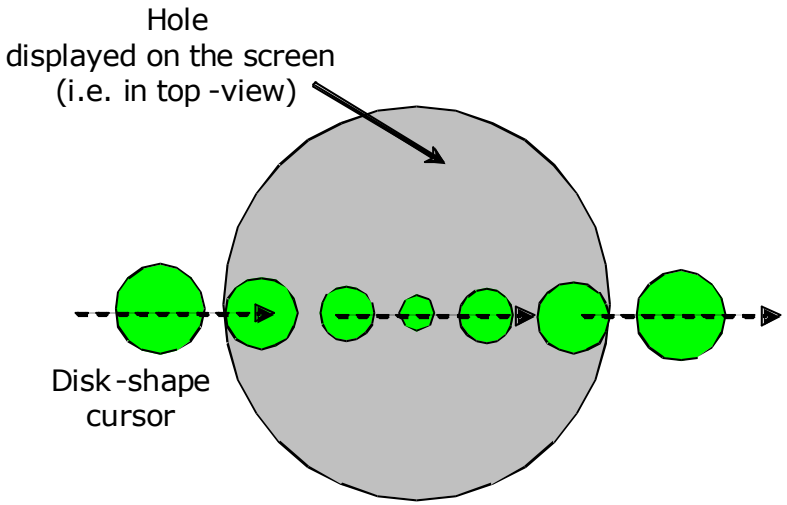
- ✓ Method to simulate relief of images only using cursor motion
- ✓ Participants able to identify bumps and holes using the **sole** variations of cursor motion
- ✓ Participants able to reconstruct (draw) the simulated topography

First follow-up : the “size technique”

Second pseudo-haptic texture technique

Concept : change size of cursor (zoom-in and out) ..

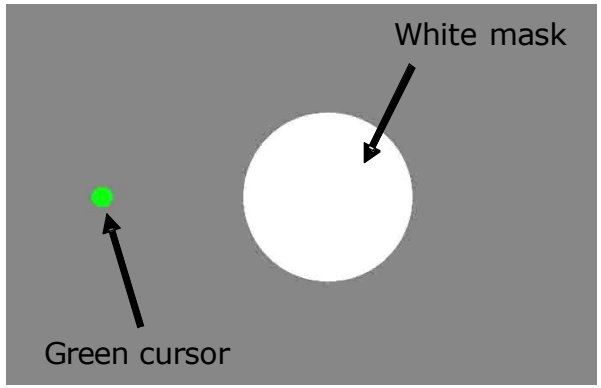
Simulation of a Hole :



Video Bump

(Lécuyer et al., ACM TAP, 2008)

Experimental evaluation



Five experiments (see paper)

Experiments 3 to 5 : Simultaneous use of both techniques

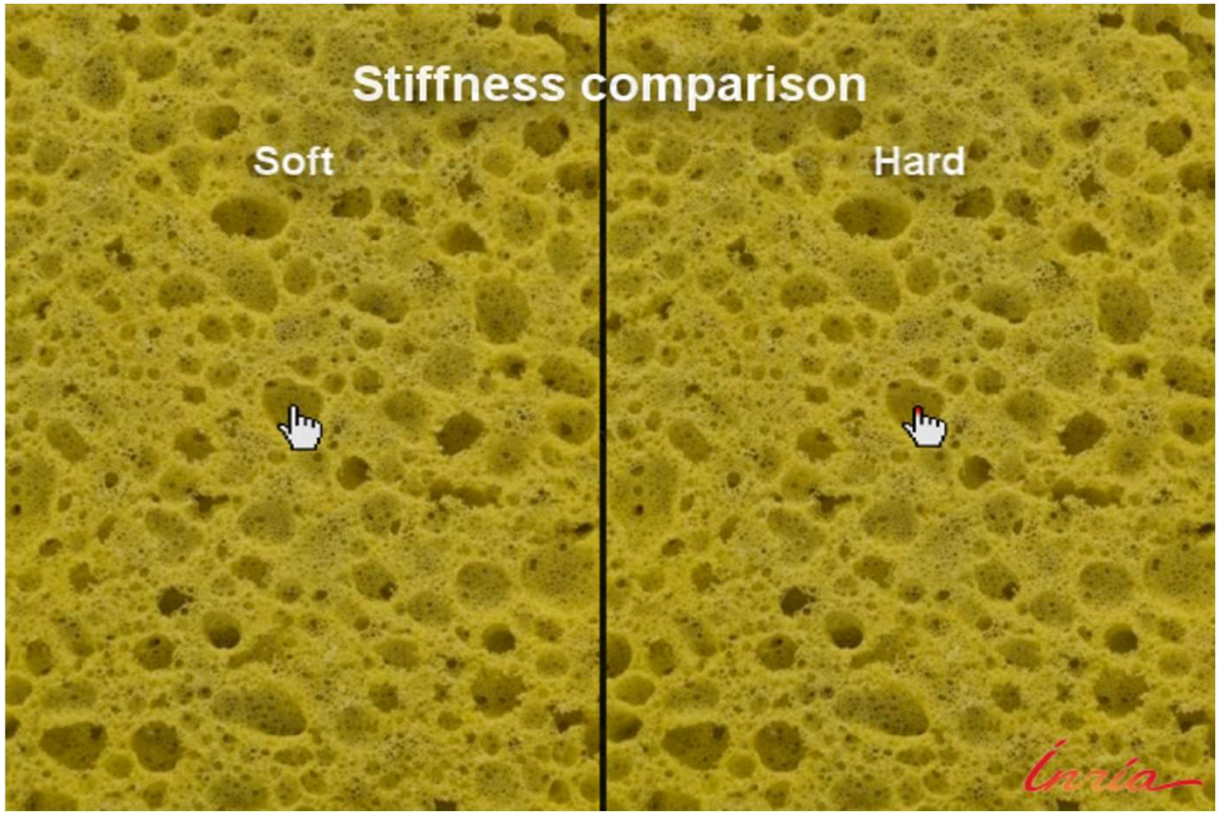
Conflict situation : Bump (Speed technique) and Hole (Size technique) at the same time

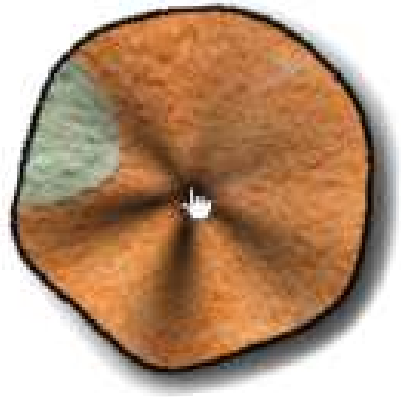
Main results

1. Size technique slightly dominated speed technique
2. The consistent combination of both size and speed technique performs better

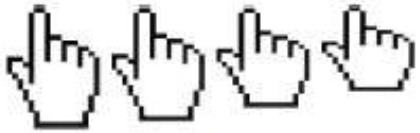
Video conflict

Second follow-up : « Elastic-Images »



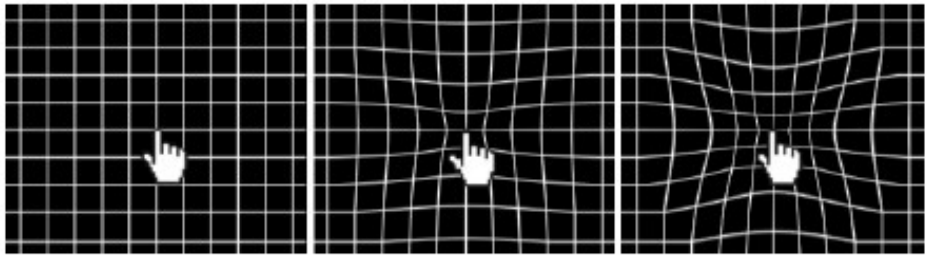


(a)



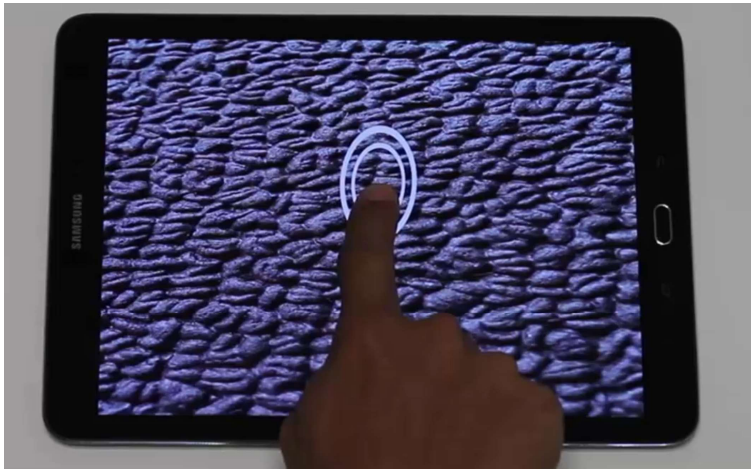
(b)

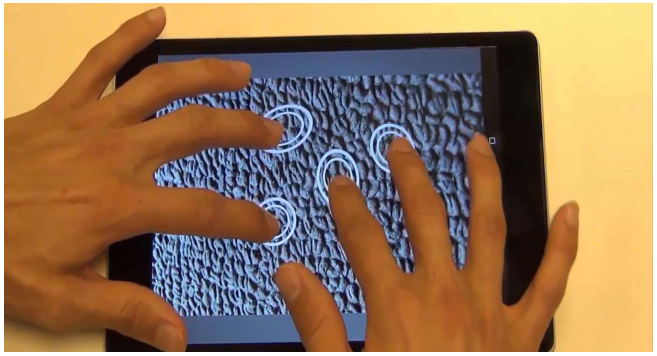
(Argelaguet et al., ACM TAP, 2013)

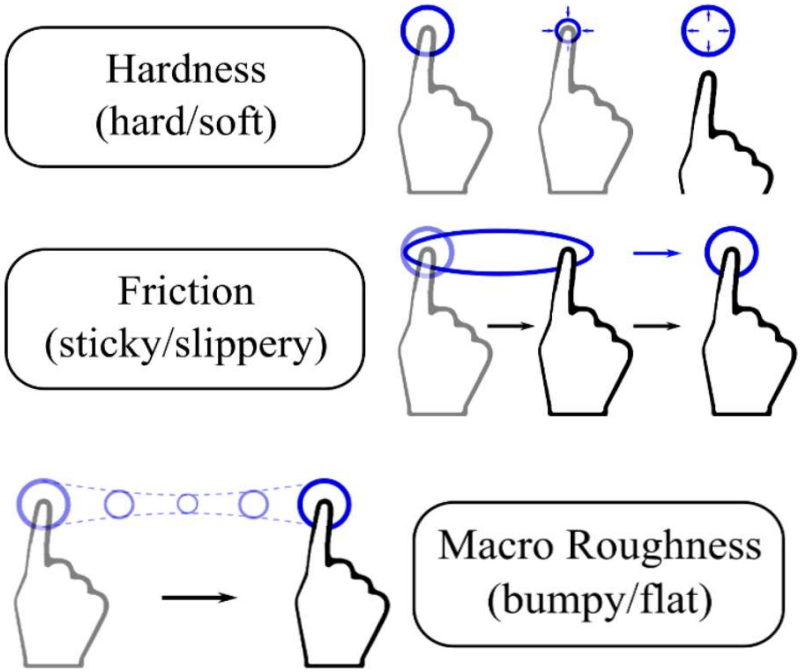


Third Follow-up : « Touchy »

Pseudo-haptics on touchscreens

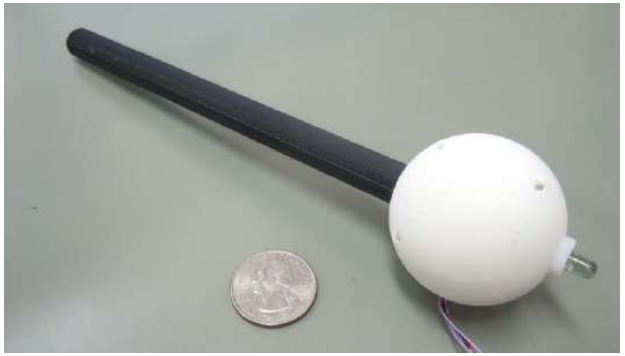






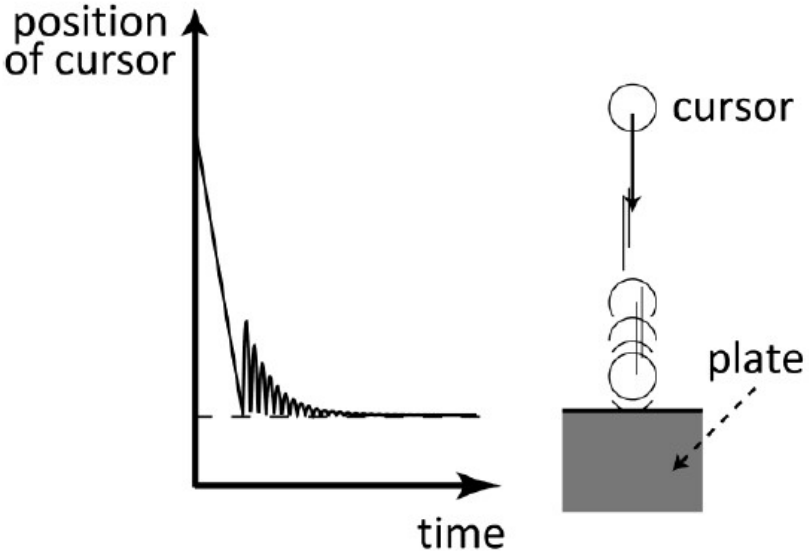
(Costes et al., Frontiers in ICT 2019)

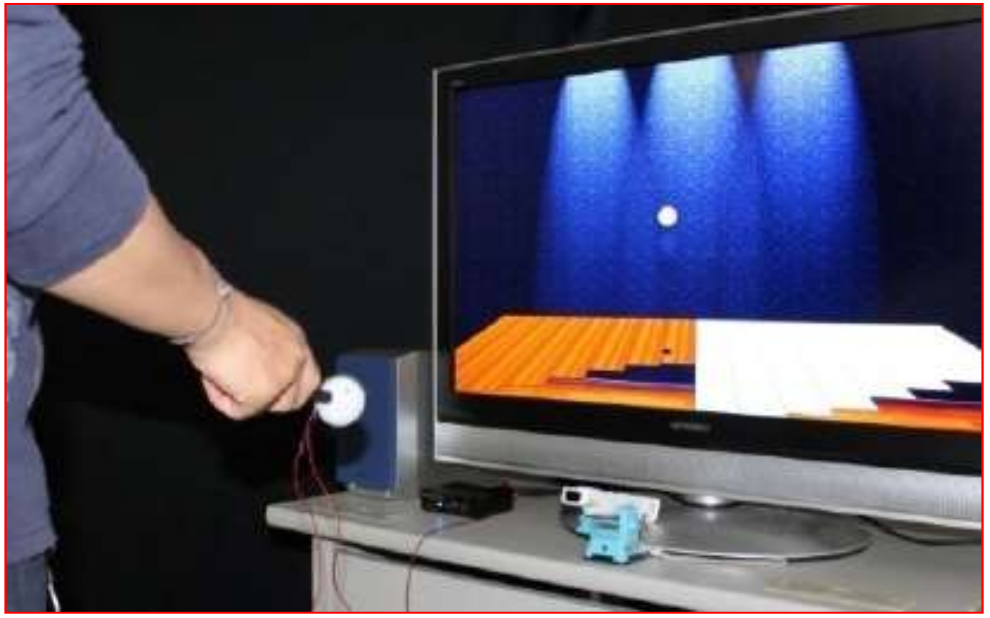
Simulation of material



Visual oscillations of 2D/3D cursor

Successful identification of materials (wood, metal, foam)



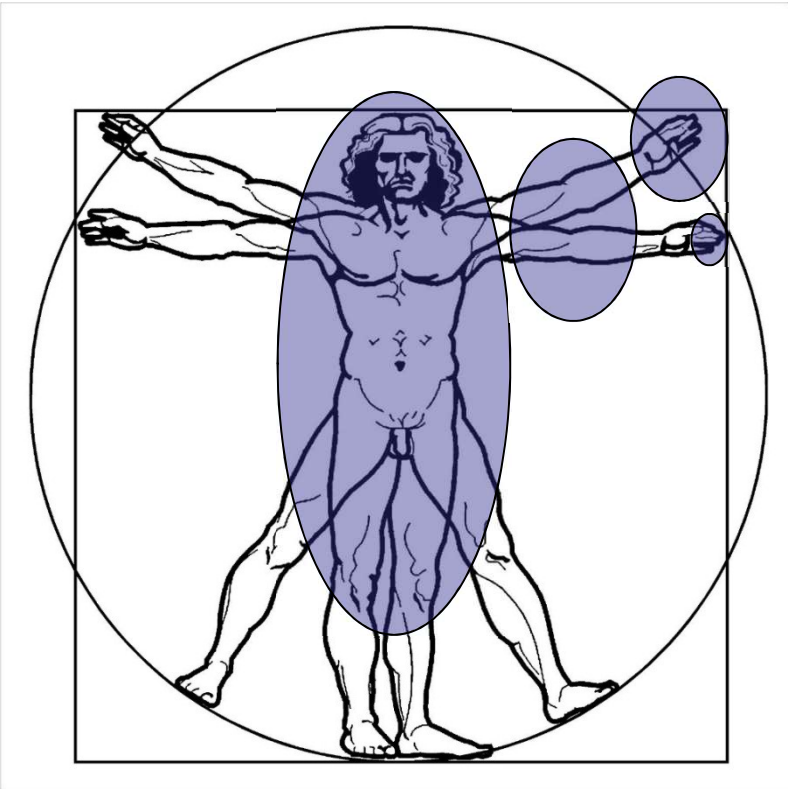


(Hachisu et al., ACE 2011)

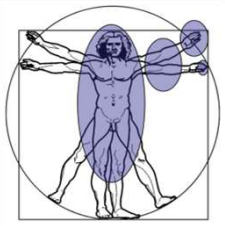
Bringing pseudo-haptic to 3D interaction

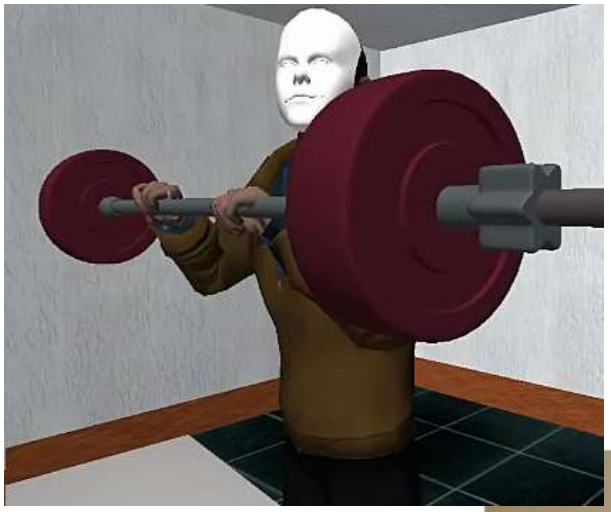
Different interaction schemes depending on body location :

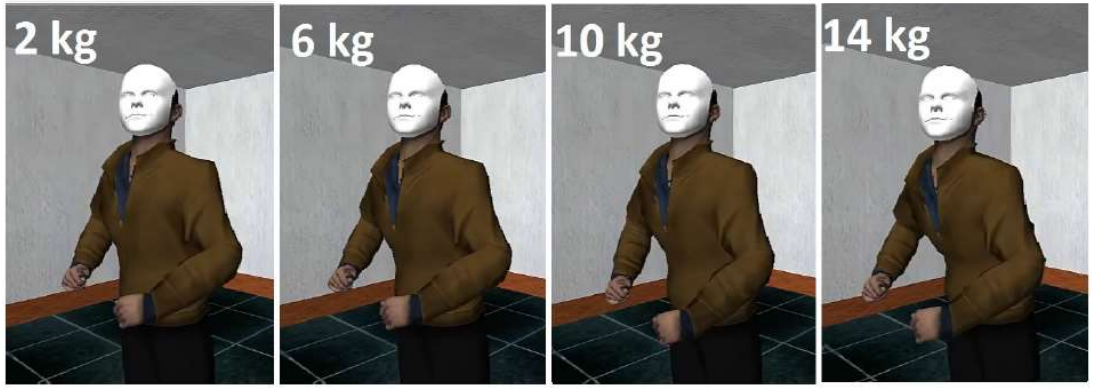
- Body : Pseudo-Haptic Avatars
- Arm : Elastic-Arm
- Hand : Virtual Mitten
- Fingers : FlexiFingers



Pseudo-Haptic Body : the « Pseudo-Haptic Avatars »



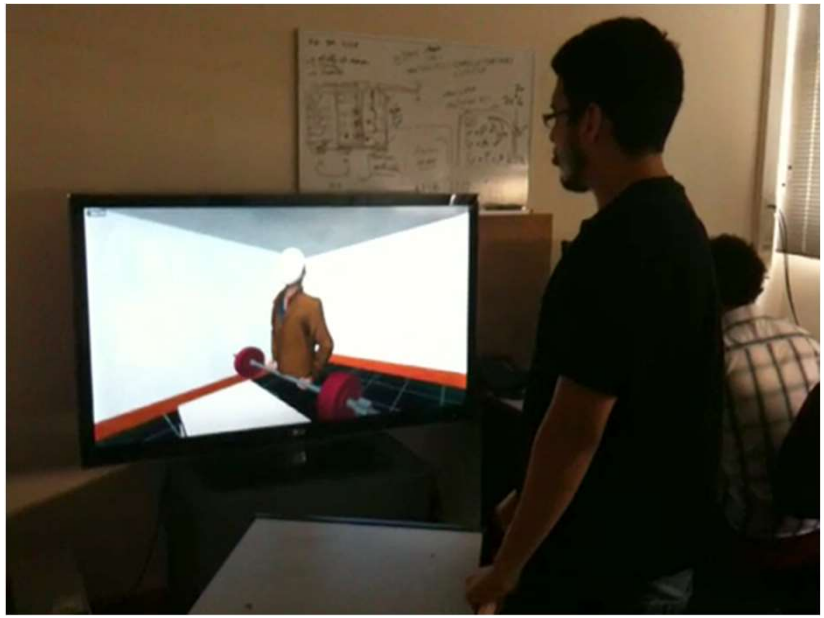




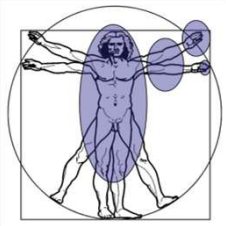
(Gomez et al., IEEE TVCG 2014)

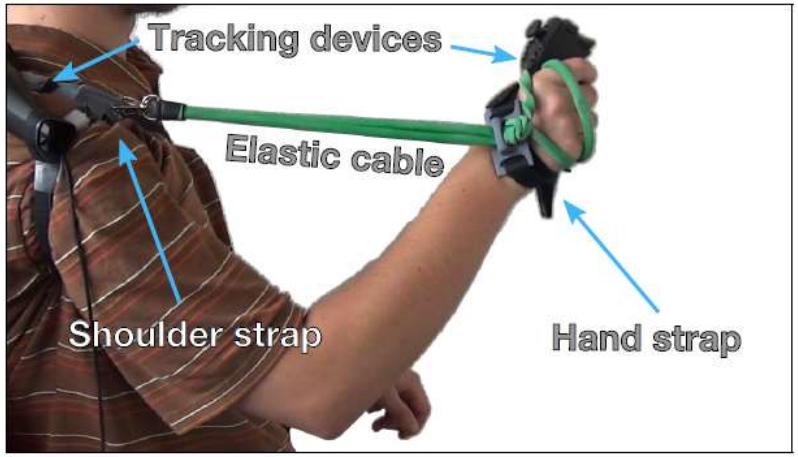
Visual cues :

- Avatar posture
- Dynamic profile
- C/D ratio

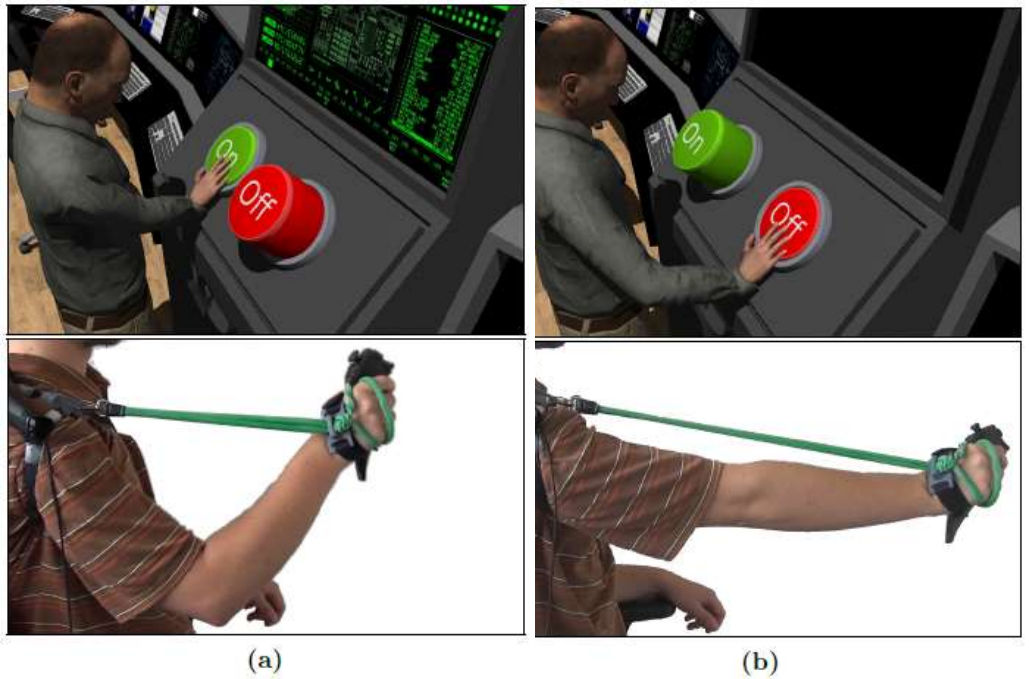


Pseudo-Haptic Arm : the « Elastic-Arm »





(Achibet et al., IEEE VR 2015)

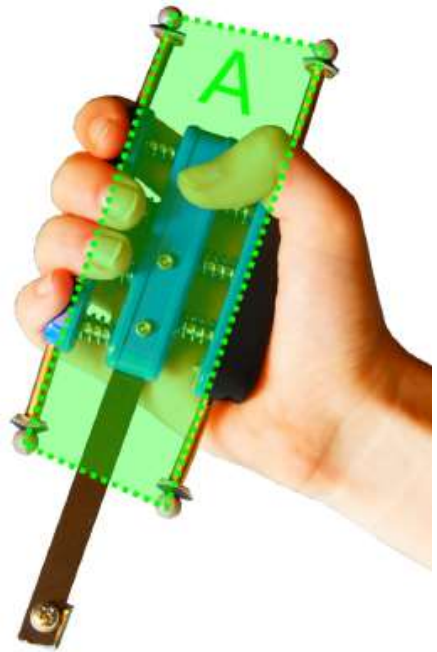


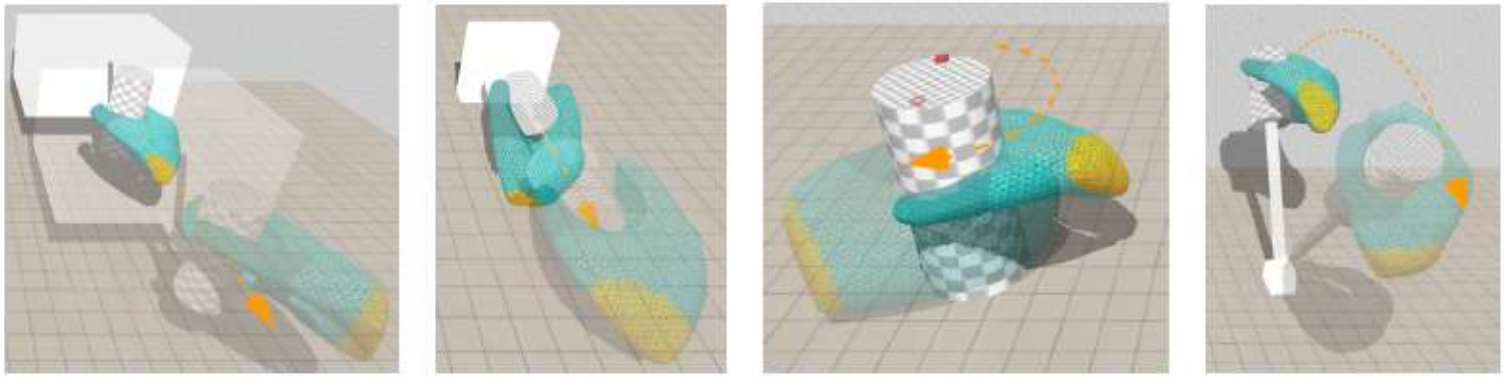
(a) (b)

(a) (b) (c)

Pseudo-Haptic Hand : the « Virtual Mitten »

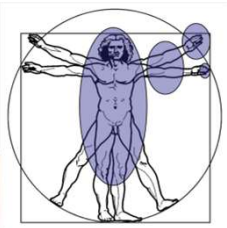
(Achibet et al., 3DUI 2014)

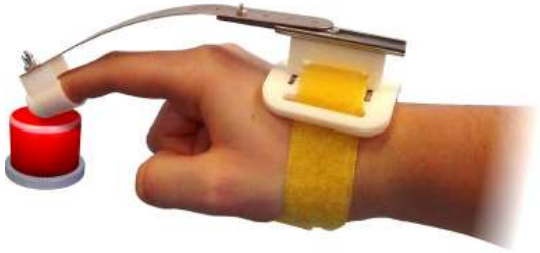


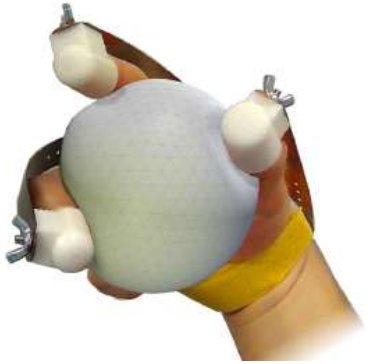


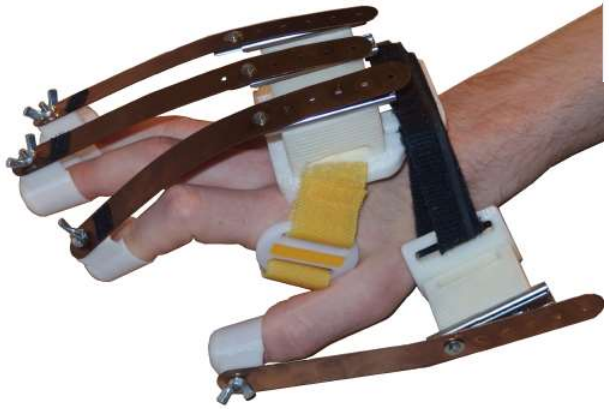
(a) (b) (c) (d)

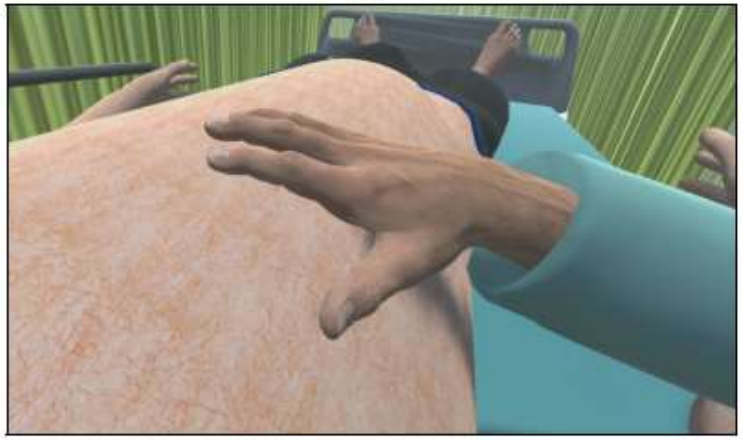
Pseudo-Haptic Fingers : the « Flexi-Fingers »

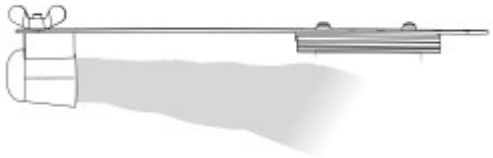


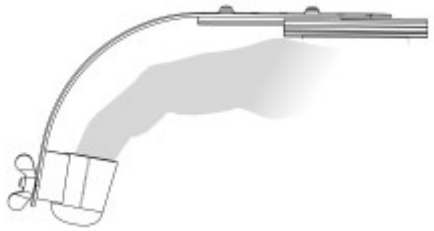








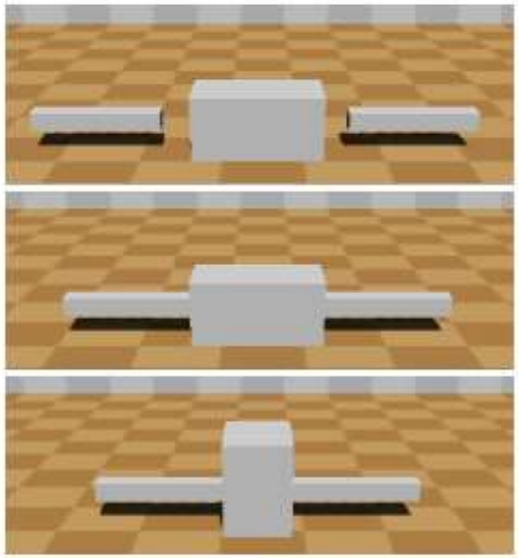


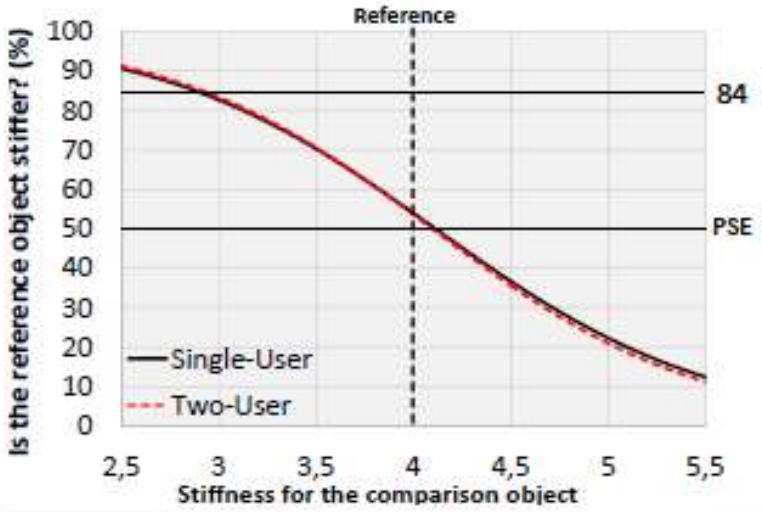


(Achibet et al., IEEE 3DUI 2017)

(Argelaguet et al., Eurohaptics 2014)

Collaborative Pseudo-Haptics



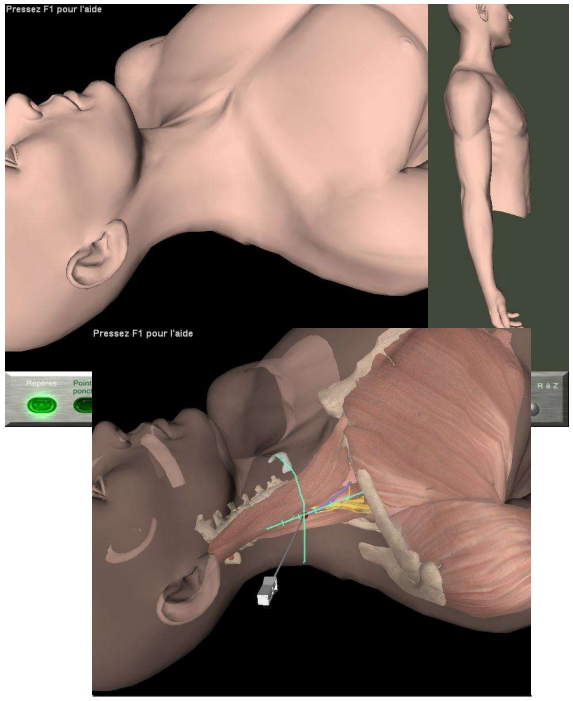


Applications

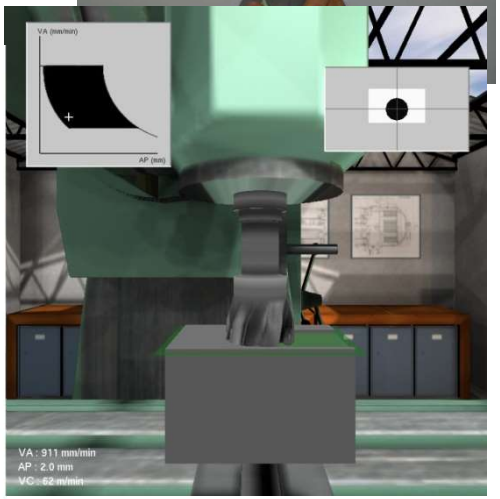
Pseudo-haptic « catalog »

- Vocational training
- Medical training
- Interactive kiosks
- 3D web content
- 2D GUI
- Data Mining
- Museum

(ACM VRST 2008)



(IEEE VR 2005)



(IEEE 3DUI 2013)

video

Internet application

Tactile Images : IFeelPixel

www.ifeelpixel.com

W3D project :

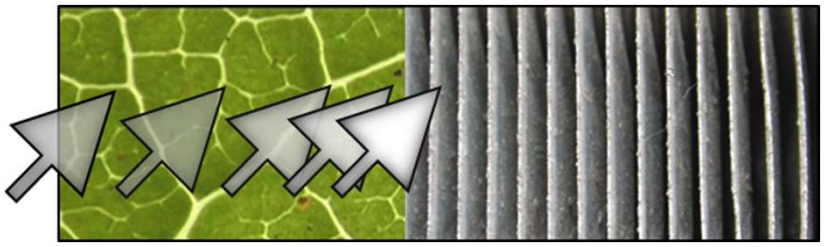
http://w3d.mba-multimedia.com/

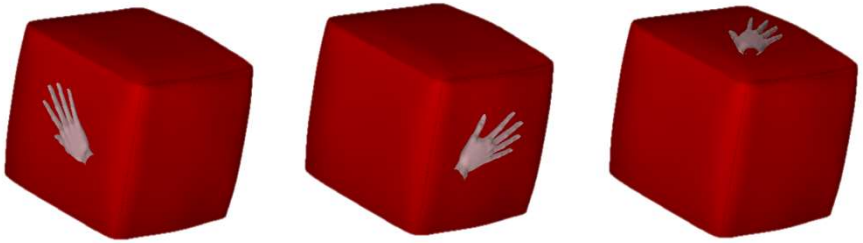
https://team.inria.fr/hybrid/w3d-project/

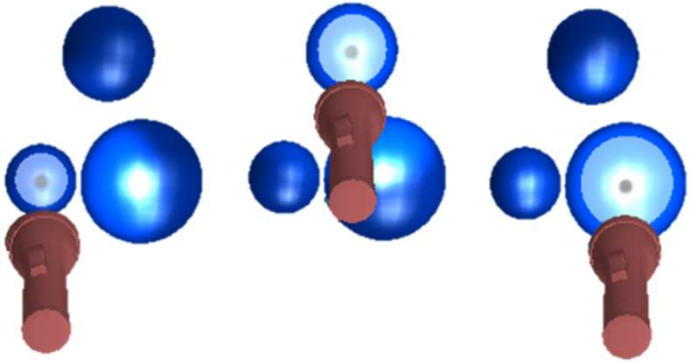
- Partners : Inria, Loustic, Polymorph, MBA
- Objective : improve perception and interaction with 3D web content
- Plug-ins Unity et Wordpress (on-line stores)

3D Cursors

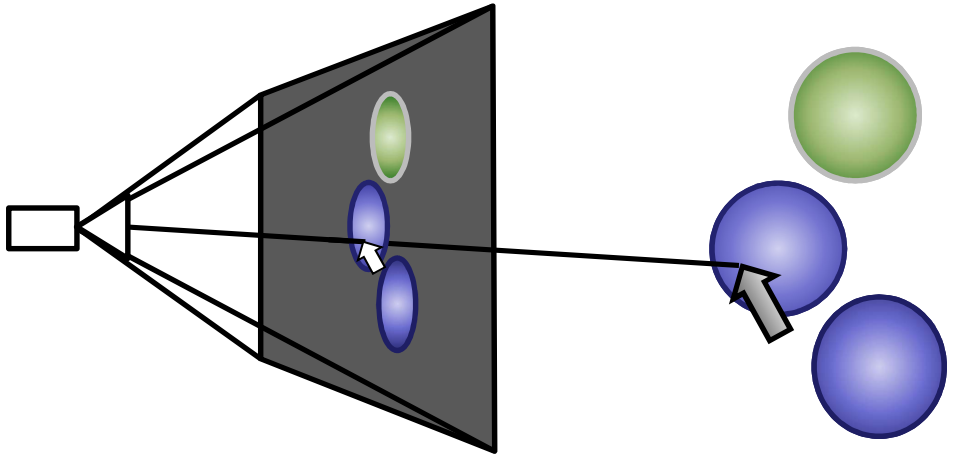
(Gomez et al., IEEE 3DUI 2012)







Cursor	Image-based	Projection-based
Arrow	Yes	No
3D Hand	No	Yes
Torch	Yes	Yes



Lessons learned

- Specificity of pseudo-haptic feedback
  - Different from : « real » haptics, tangible objects, sensory substitution
- Inter-individual variability
  - Necessary tuning and calibration
- Use of input devices
  - Preference for elastic devices vs. isometric vs. isotonic devices ?
- Pseudo-haptic method : use of the C/D gain
  - Sensory-conflict on visual displacement (C/D gain ≠ 1)
  - Visual dominance
  - Re-formatting of haptic percept
  - Strong influence of context (priming, conditioning)

Open questions

Illusions or not?

Neuroimagery

Co-localization

Other modalities : audio

Multi-user systems

Augmented-Reality

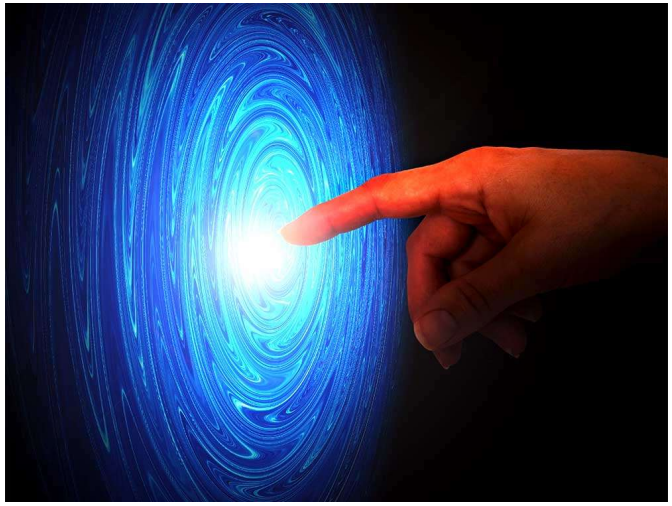
Conclusion

- Alternate technique to simulate haptic properties based on visual feedback and visio-haptic integration
- Successful simulation of haptic properties: friction, stiffness, weight, textures, material, etc
- Transferred into several applications: training, medical, web, etc

Feel free to try it !

Demos at :

www.irisa.fr/tactiles



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Master 2 SIF - Option VRI
Univ Rennes

Interactions en RV:
interfaces cerveau-ordinateur et interfaces haptiques

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