The Impact of Unaware Perception on Bodily Interaction in Virtual Reality Environments

Marcos Hilsenrat, Miriam Reiner

The Touchlab – Technion – Israel Institute of Technology

Contact: marcos@tx.technion.ac.il

Abstract

Unaware haptic perception is often inferred but rarely demonstrated empirically. In this paper we present evidence for effects of unaware haptic stimuli on users' motor interaction with virtual objects. Using a 3D hapto-visual virtual reality, we ran a texture-difference-recognition test in which subjects glided a pen-like stylus along a virtual surface with varying roughness. We found that subjects were not aware of changes in texture roughness below a threshold limit, yet the normal force they applied, changed. Subjects didn't recognize on a cognitive level changes in the sensory cues, but behaved as if they did. These results suggest that performance can be affected, through subliminal cues. Based on results from visual perception studies, we also tested the impact of context background conditions on perception of unaware cues. We measured the threshold of awareness to changes in texture for several reference stimuli. We found that indeed, as in visual perception, this threshold for discriminating between the roughness of surfaces increases when texture gets smoother, i.e. sensitivity changes as a function of the background context. Implications are mainly in design of VR especially remote manipulation of objects.

1 Introduction

This study deals with effects of subliminal cues in presence states. We show that haptic cues in a VR, which are so weak that participants are unaware of, affect their interaction with virtual objects. This study tests the nature and boundaries of unaware touch perception and its effect on perception and interaction in a VR.

Among all senses, the human haptic system provides unique and bidirectional communication between humans and interactive systems (Reiner, 2004; Hale & Stanney, 2004). Bidirectional communication has a major role in conceptualization of the environment, performance and manipulation, and has been applied in several problem solving hapto-visual environments. These include molecular docking, nano-material manipulation, surgical training, virtual prototyping, and digital sculpting (Basdogan et al., 2004; Lin & Salisbury, 2004; Jerabkova et al., 2007). All of the above environments include multimodal cues, some on the subliminal level. The role of subliminal cues and their impact on interaction in virtual worlds has not been studied in any of the existing VR haptic applications.

The relevance is beyond 'presence' research, and contributes both to the psychophysics of subliminal cues, and to the design of haptic interfaces and VR environments for remote action. Results provide a model of the effect of unaware perception of objects, especially changes in behavior and action due to subliminal perception. Integration of subliminal cues in virtual environments provides a paradigm for affecting manual behavior, possibly enhancing haptic performance through subliminal cues.

Most existing interfaces allow touching a virtual object via a probe. Still, contact with a surface by means of a probe, a pen or any tool generates considerable information about the texture. For instance, when we stir a bowl with a spoon, we can tell immediately that the food is sticky, without pausing to analyze the pattern of pressure on the fingertips, (Klatzky & Lederman, 2002). Many tasks involve the use of probe-like tools to act on objects, and complete a task. For example, sewing with a needle, and incisions with surgical scalpels. As with studies on the interaction of the bare finger with surfaces (e.g. Lederman, 1974; 1983), investigation of indirect touch of real surfaces is currently focused on the contribution of the geometric features of textured surfaces to object recognition on human exploration strategies (e.g. relative speed, force, and mode of touch: active or passive), and on geometric and physical characteristics of the intermediate tool (such as weight, density, probe diameter), in exploration of object properties (e.g. Klatzky et al., 2003).

Scanning a surface through a probe to obtain information about its texture is an example of a haptic exploration cycle (Reiner, 2004). While writing with a pen we sense the forces exerted on the fingers, palm and arm, caused by friction, the position of the hand in space (kinesthetic), and the texture of the paper felt by the hand (tactile). In addition the users feel the texture of the pen itself: it might be smooth, sticky or heavy. These are all part of the haptic loop. For instance, suppose that while writing, a change in roughness is sensed. The user may interpret the haptic information (function of the cognitive system) and apply the appropriate force on the pen (function of the motor control system) in order to decide whether and how to continue writing (cognitive system). The user's actions generate a new situation, thus new sensory input is received, followed by new interpretations, intentions and actions that generate new sensory input, and so on in an ongoing cycle. We know from visual studies of subliminal cues, that such cues affect behavior. Will this also apply for haptic cues? This paper deals with the motor changes correlated with subliminal cues. The first goal of this study is to examine changes in manual behavior, in terms of applied forces, as a response to change in texture roughness. We tested whether unaware haptic cues affect subjects' interactions with virtual surfaces.

We run a texture-difference-recognition test in which subjects glided a pen-like stylus along a varying rough surface and looked for the threshold change in texture that subjects were aware of. This was defined as the critical just noticeable difference (JND_{crt}) of roughness perception. The actual value of the obtained JND_{crt} is termed as the difference threshold; below this threshold a stimulus is considered to be 'unaware' by the subject. Then, we checked if below the threshold value an unaware change in the applied normal force occurred as it does in the case of aware cues.

The JND_{crt}, is defined as the ratio between the minimal difference in strength between a reference stimulus with a second stimulus that can be discriminated, and the reference stimulus (e.g. Kandel el al., 2000). For several sensory stimuli, the JND_{crt} increases when the reference stimulus approaches the absolute sensory threshold (Gescheider, 1997).

The second goal of this study is to identify the role of reference background in subjects' sensitivity. Research in visual perception suggests that context has a major role in perception. For instance, perception of color changes depending on the background color. We wish to explore the impact of the context, in this case, background roughness, on the users' sensitivity. Thus another goal here is to examine the changes in perceived JND_{crt} as a function of the surface reference texture, and to test whether the sensitivity increases/decreases/does not change when background textures changes.

2 Experiment

We used a 3D hapto-visual Virtual Reality with a haptic interface (The DESKTOP PHANToM from SenseAble Technologies Inc.). The experimental setup is shown in Figure 1.

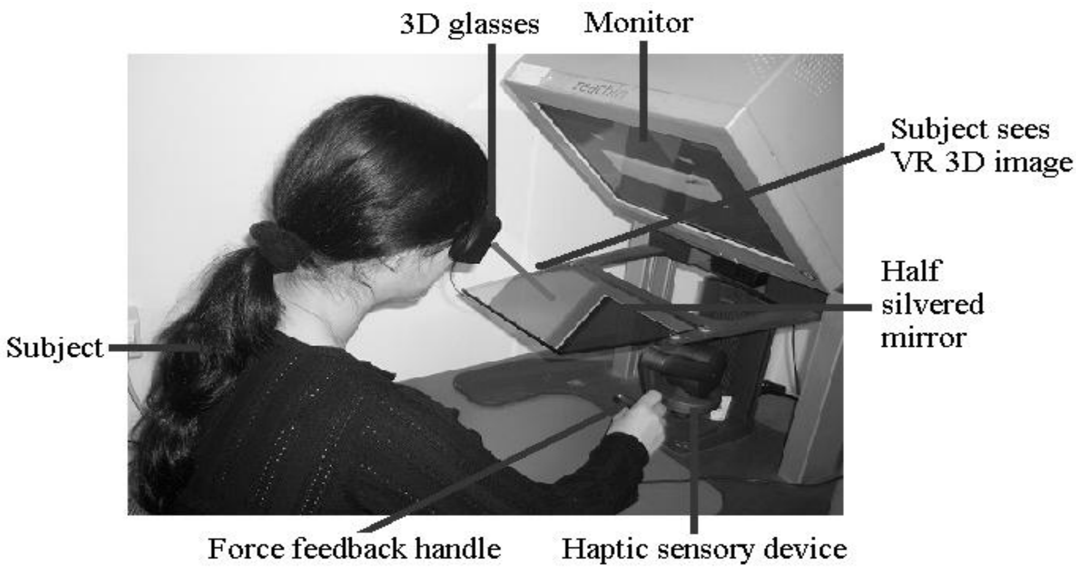

Figure 1: *Experimental array*

We developed 3D VR objects that can be seen, touched, and manipulated, with arbitrary programmable physical properties.

The haptic stimuli we used, was the level of surface roughness. We used the Reachin function that simulates something akin to sand paper (Reachin API 3.2 Programmer's Guide 2003). To simulate the granularity of sand paper, the haptic device's motion is constantly stopped, and a new starting friction value is randomly calculated, using a Gaussian probability distribution with a mean and standard deviation determined by us. The two values that can be altered are the mean and the standard deviation. The input in the mean value is the friction coefficient. The input in the standard deviation allows the randomness to be contained; the standard deviation value was kept constant through all of the experiments.

2.1 Experimental Setup

Figure 2 is the actual view of the environment experienced by subjects in the VR.

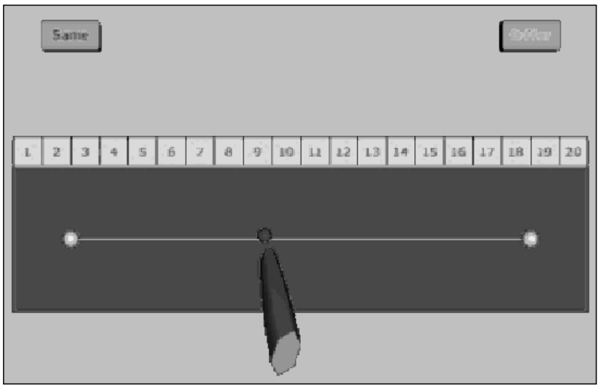

Figure 2: *Experimental setup – actual view*

Figure 3 is a schematic representation of the experimental setup.

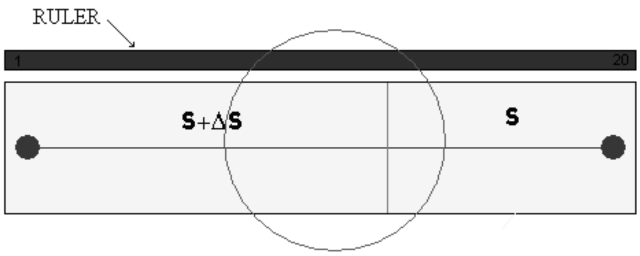

Figure 3: *Experimental setup – schematic representation*

The VR consists of a rectangular shaped surface, twenty centimeters long, positioned in a 3D world with programmable roughness qualities resembling sand paper. The surface is divided into two parts with different friction coefficients. The line that divides the two parts (the vertical line in Figure 3) is randomly located in the rectangle's ten central centimeters for data analysis purposes (see next subsection), and visually undetectable. The line describes the path of touch with the probe. The role of the ruler will become evident in the next subsection.

2.2 Method and Procedures

To experience presence, a subject must perceive the virtual reality with the same sensory-motor contingencies as in the real world (Slater, 2009). Plausibility, the conditional probability that what is being perceived is really happening, given the events that are being observed, determines presence. It is based on the requirement for correlations between the virtual reality and the subjects' activity, e.g. the movement of a virtual stylus across a virtual surface must correlate with the participants' limb movement. Also, the probability of an event in the virtual reality scenario to be 'true' must be high, e.g. if a subject is instructed to glide on a virtual surface with physical properties similar to sand paper, the congruence between the virtual and real sand paper must be high.

The virtual surface in each trial consists of two areas that differ by the friction coefficient. The difference in the value of the friction coefficients covers a wide range of values. For each set of runs, the lower value was kept constant, and it was always on the same side of the rectangle.

Fifteen right handed individuals participated in the experiment (11 females, 4 males) with a mean age of 30.2 years, standard deviation of 6.1 years. The age range was 14 years.

First, participants were instructed to glide gently a pencil on several sheets of physical sand paper with different granularity. Then, they were instructed to do the same on a virtual surface with several degrees of roughness. Before beginning the main part of the experiment, participants reported whether the virtual sand paper feels like real sand paper.

The subjects were then instructed to move the force feedback handle gently along the surface starting at the left circle, ending at the right circle, from the smoother side to the rougher side. Subjects are asked to report, by pressing on the upper left button if he/she felt a roughness change, or on the right button (see Figure 2), if he/she didn't feel changes in roughness. If subjects reported a change in the feel of roughness, they were asked to press on the attached ruler (see Figures 2 and 3) on the point near the zone where in they believe, the change occurred. The distance from the actual point of change was recorded. The normal component of the force applied by the subject on the surface was measured as a function of the distance from the actual point of change in roughness. We set up a length of one centimeter as the maximal distance between the pressing point on the ruler and the actual point of change (in addition to pressing the appropriate button) for accepting the subject's report of sensing the change. This distance was set as appropriate after many test runs. The test runs showed that when the changes in roughness were high, and therefore consciously detectable, the ruler was pressed at a distance that not excided one centimeter from the actual point of change. We recorded the applied normal force for both reported and non reported recognition of changes in roughness, and position as a function of time. Sampling rate was 100 Hz.

We defined $\boldsymbol{S}$ (Figure 3) as the basic value of the friction coefficient. Then we changed the roughness of the second area by multiples of a given value $\boldsymbol{\Delta S}$, and identified the minimal value of change in roughness in which aware perception occurred: $\boldsymbol{\Delta S_{min}}$. Finally, we calculated the critical just noticeable difference (JND_{crt}), defined in the present study as $\boldsymbol{\Delta S_{min} / S}$, for each subject for each value of $\boldsymbol{S}$ applied in this experiment.

We summarized the possible output for every run:

a – Aware perception: The subject reports feeling the change in roughness, and identifies the location of change → subject pointed at the location that is no more than one centimeter away from the correct change in friction.

b – Unaware perception: The subject reports feeling the change in roughness and the distance from the change point is above one centimeter.

c – Unaware perception: The subject doesn't feel the change in roughness.

For every run, a change in the normal applied force was measured. In the case of a given difference in friction coefficient, the subject was aware of the surface change (case *a*) in part of the runs, and in the others he/she didn't (cases *b* or *c*), it was considered as unaware perception when case *b* or *c*, happened in two thirds of the runs for a specific roughness difference.

2.3 Results

All participants reported that gliding on real sand paper and on the virtual programmed surfaces were indistinguishable. None of the participants reported discrepancies between their own movements and the virtual stylus movement, therefore a high correlation between physical and virtual reality was assumed.

The presented results are divided in two steps. In the first step we investigated the change in motor behavior correlated with change in roughness, and in the second step we measured the JND_{crt} for each subject.

We found that changes in friction causes detectable changes in the applied normal force, even if the subject wasn't aware of the change in friction. Figures 4 and 5 are examples of measurements of the applied normal force as a function of the distance from the point of change in roughness, for unaware and aware perception.

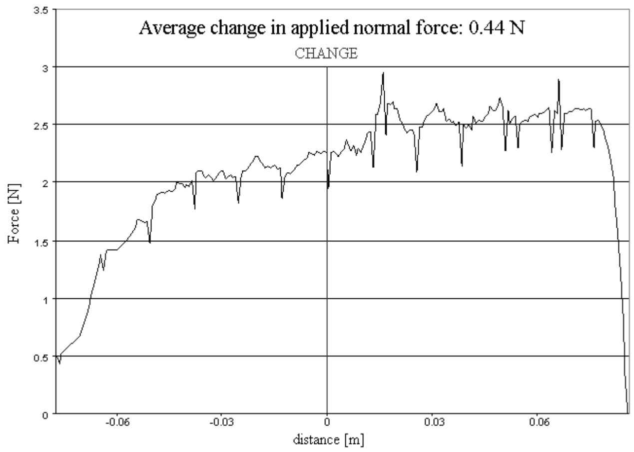

Figure 4: *Change in applied normal force for unaware perception*

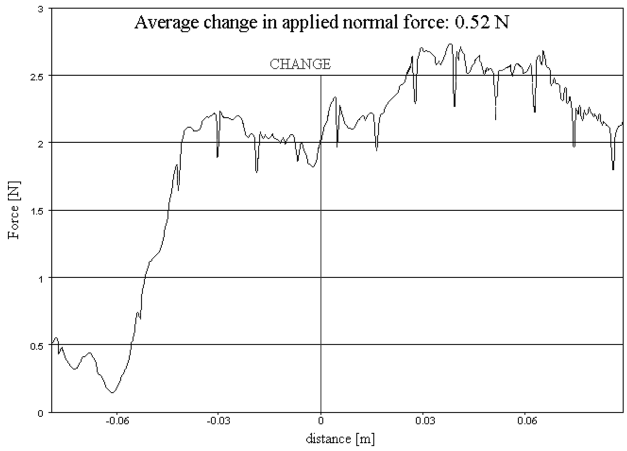

Figure 5: *Change in applied normal force for aware perception*

In Table 1 and in Figures 6 and 7 we present, for each fixed friction coefficient, the number of participants (out of 15) that were unaware of the change in roughness, for each pair of values of the friction coefficient. The three different dimensionless friction coefficients, used as the smoother value in each set of runs (***S*** in Figure 3) were: 0.1, 0.3, and 0.5. Each basic value of ***S*** was compared with nine friction coefficient values. So, for the same values difference, the task was repeated three times.

Table 1: *Number of participant that were unaware of change in roughness for each reference friction coefficient for each difference in roughness*

Ref. μ / ΔS	**0.1**	**0.3**	**0.5**
0.05	15	15	15
0.10	15	12	14
0.15	13	8	8
0.20	10	6	7
0.25	7	6	3
0.30	3	0	0

0.35	2	0	0

Table 1 describes the distribution of threshold for unaware perception of texture among subjects, for each of the background textures. It shows that distribution of sensitivity changes with texture, and that sensitivity is not uniform among subjects. Figure 6 is an example of the distribution among subjects of unaware perception of changes in roughness for one reference texture background.

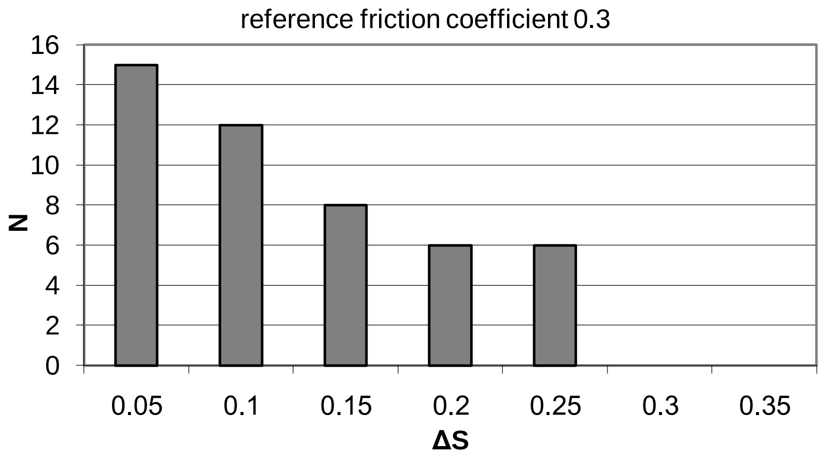

Figure 6: *Number of subjects that were unaware of the change in roughness as a function of the difference in the friction coefficient, for the reference coefficient 0.3*

In Table 2 and Figure 7 we show the average change in the applied normal force for all subjects, when the changes in roughness surface were unaware (ΔS = 0.05), for all three friction coefficients reference values.

Table 2: *Average force change at the awareness limit*

Reference friction coefficient	Average Force change [N]	Standard deviation
0.1	0.21	0.04
0.3	0.17	0.04

0.5	0.18	0.03

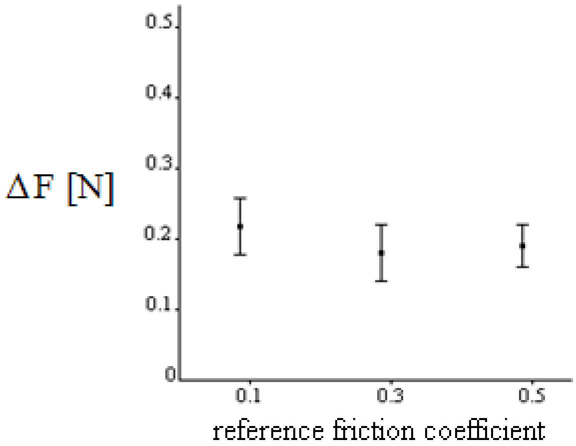

Figure 7: *Average ΔF for unaware perception (ΔS=0.05) as a function of reference friction coefficient*

For purposes of data analysis, the algorithm was written so, that before the point of change in roughness, the distance has negative values and positive values, afterwards. The bumpiness of the measured applied normal force visible in Figures 4 and 5, is due to the randomness in the value of the friction coefficient with a maximal probability near the mean input, due to the Gaussian distribution.

For every run we calculated the average normal force applied, before and after the roughness change, neglecting the edges (start and end of movement). As a standard, we used for analysis the data recorded between four centimeters, before and after roughness change. Statistically we calculated the significant level in force change. Results for all the runs are significant at the level of $p < 0.01$.

In the above examples the average measured force was 2.12 N and 2.56 N for unaware perception, and 2.10 N and 2.62 N for aware perception, before and after the roughness change, respectively. Each subject performed thirty runs for three different basic friction coefficient values (***S*** in Figure 3). An additional ten runs were performed for calibration, that is, null difference in the pair of friction coefficients that implies null difference in the normal applied force. Therefore each subject performed one hundred runs.

Using the described methodology we measured the perceived JND_{crt} for different background reference roughness. Results are presented in Table 3 and Figure 8.

Table 3: *Calculated JND_{crt} for three basic values of the basic friction coefficient*

Basic friction coefficient	Average JND_{crt}	Standard deviation
0.1	2.30	0.44
0.3	0.52	0.19
0.5	0.39	0.14

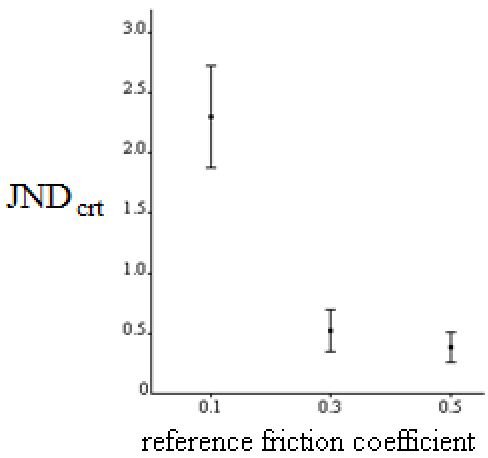

Figure 8: *JND_{crt} as a function of changes in surface friction coefficient*

3 Discussion and Conclusions

Results suggest that participants modified their manual behavior when they were exposed to a haptic stimulus that was below the participants' limit of aware perception. The change in manual motor behavior was assessed by measuring the change in normal force applied to a virtual surface. The applied force changed even when the change in surface roughness was not reported. Furthermore, this change was measured when the change in roughness was well below participants' individual limit of aware perception. Cues are subliminal, in the sense that a cue is considered as such if it is attended but not reportable (Dehaene et al., 2006). This implies that performance can be affected, through cues that are below the threshold of aware perception.

All participants reported that they didn't feel, subjectively, differences between gliding on a real or a virtual surface. The high congruence felt by the subjects between reality and Virtual Reality, and the high correlation between actions in the real world and actions in the virtual world suggest high plausibility that what is being perceived is really happening. Therefore, a high degree of presence can be inferred (Slater, 2009), corroborating the use of Virtual Reality in the study of perception and consciousness (Sanchez-Vives and Slater, 2005). Thus results are valid for interaction in the physical world too.

We found that participants' sensitivity for detecting changes in roughness through a probe, decreases sharply with the intensity of the reference stimulus. The JND_{crt} increases, in accordance with corrected Weber's law (Gescheider, 1997). It has been suggested that this phenomena is related to the operation of sensory systems near threshold. It may represent the amount of sensory noise that exists when the intensity of the stimulus is null (Gescheider, 1997). The large standard deviation for the 0.1 friction coefficient (Figure 8) seems to imply that threshold sensitivity for this stimulus intensity is somewhat individual. However, the average force ΔF, applied in the condition of unaware perception as a function of reference roughness, shows an almost constant force, suggesting that the change in roughness is the major factor in affecting the force applied (Figure 7).

It is worthwhile to note the similar values for the change in the applied normal force at the awareness limit of perception, for all reference friction coefficients, and the relatively narrow standard deviation values, despite the large ones we obtained for JND_{crt}s. The reason might be the smooth and gentle hand movement across the virtual surface, that subjects were instructed to do.

Future work will include the investigation of the influence of haptic subliminal cues on peoples' preferences toward the physical qualities of objects, such as texture and compliance.

Implications are both theoretical and practical. The first, is understanding the psychophysics of subliminal touch, a hardly studied domain. The second relates to design of interaction in VR and in remote, telemanipulation applications. Subliminal cues can be used to affect users' manual motor behavior, on an automatic, fast and effective manner, that requires no increase in cognitive load.

4 References

Basdogan, C., De, S., Kim, J., Manivannan, M., Kim, H., & Srinivasan, M.A. (2004). Haptics in minimally invasive surgical simulation and training. *IEEE Computer Graphics and Applications, 24*(2), 56-64.

Dehaene, S., Changeux, J.P., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: a testable taxonomy. *Trends in Cognitive Sciences, 10*(5), 204-211.

Gaggioli, A. (2003). Using virtual reality in experimental psychology. In G. Riva & C. Galimberti (Eds.), *Toward Cyber Psychology: Mind, Cognitions and Society in the Internet Age, Chapter 9.*

Gescheider, G.A. (1997). *Psychophysics: The Fundamentals*. Lawerence Erlbaum.

Hale, K. S., & Stanney, K. M. (2004). Deriving haptic design guidelines from human physiological, psychophysical, and neurological foundations. *IEEE Computer Graphics and Applications, 24*(2), 33-39.

Jerabkova, L., Jerabek, J., Chudoba, R., & Kuhlen, T. (2007). A stable cutting for finite elements based virtual surgery simulation. *Studies in health technology and informatics, 125*, 200-205.

Klatzky, R.L., & Lederman, S.J. (2002). Perceiving texture through a probe. In M.I. McLughlin, J. Hespanha & G. Sukhatme (Eds.), *Touch in Virtual Environments (pp 180-193),* NY: Pretince Hall.

Klatzky, R.L., & Lederman, S.J. (2003). Haptic Perception. In *Encyclopedia of Cognitive Science.* (pp 508-512).

Kandel, E.R., Schwartz, J.H., & Jessell, T.M. (2000). *Principles of Neural Science*. McGraw Hill.

Klatzky, R.L., Lederman, S.J., Hamilton, C., Grindley, M., & Swendsen, R.H. (2003). Feeling textures through a probe: Effects of probe and surface geometry and exploratory factors. *Perception & Psychophysics, 65*(4), 613-631.

Lederman, S.J. (1974). Tactile roughness of grooved surfaces: The touching process and effects of macro and microsurface structure. *Perception & Psychophysics, 16*, 385-395.

Lederman, S.J. (1983). Tactual roughness perception: Spatial and temporal determinants. *Canadian Journal of Psychology, 37*, 498-511.

Lin, M., & Salisbury, K. (2004). Haptic Rendering – Beyond visual computing. *IEEE Computer Graphics and Applications, 24*(2), 22-23.

Loomis, J.M., Blascovich, J.J., & Beall, A.C. (1999). Immersive virtual environment technology as a basic research tool in psychology. *Behavior Research Method, Instruments & Computers, 31*(4), 557-564.

Reachin API 3.2 Programmer's Guide. (2003).

Reiner, M. (2004). The Role of Haptics in Immersive Telecommunication Environments. *IEEE Circuits and Systems for Video Technology, 14*(3), 392-401.

Salisbury, K., Conti, F., & Barbagli, F. (2004). Haptic rendering: Introductory concepts. *IEEE Computer Graphics and Applications, 24*(2), 24-32.

Sanchez-Vives, M.V., & Slater, M. (2005). From presence to consciousness through virtual reality. *Nature reviews. Neuroscience, 6* (4), 332-339.

Slater, M. (2009). Place Illusion and Plausibility in Immersive Virtual Environments. *Philosophical Transactions of the Royal Society (B),* in press.

List of figure captions