Can a haptic force feedback display provide visually impaired people with useful information about texture roughness and 3D form of virtual objects?

Gunnar Jansson

Department of Psychology, Uppsala University
Box 1225, SE-751 42, Uppsala, SWEDEN

gunnar.jansson@psyk.uu.se

ABSTRACT

The aim was to investigate the usefulness of a haptic force feedback device (the PHANToM) for information without visual guidance. Blind-folded sighted observers judged the roughness of real and virtual sandpapers to be closely the same. The 3D forms of virtual objects could be judged accurately and with short exploration times down to a size of 5 mm. It is concluded that the haptic device can present useful information without vision under the conditions of the experiments. The result can be expected to be similar when observers are severely visually impaired, but this will be controlled in a separate experiment.

1. INTRODUCTION

The most common function expected to be fulfilled by haptic force feedback displays is to enhance the perception of virtual reality scenes rendered by visual and/or auditory displays in medical, entertainment, telerobotic, and military applications (Burdea, 1996). When a haptic display is considered for people with severe visual impairment, the situation is quite different; the lack of visual guidance may decrease the effectivity in utilising the haptic information as vision and haptics normally cooperate (see, for instance, Heller, 1982).

The problems include getting an overview of the display and locate the relevant parts of it, as well as picking up 3D aspects of the display depicted in 2D (cf. Jansson, 1988). If overview and location of parts have to be obtained by haptics alone, very long exploration times may be needed. Concerning getting 3D aspects from 2D haptic depictions, it has been suggested that it is an impossible task (Révész, 1950), and in the applied work with tactile pictures (for an overview, see Edman 1992), 3D aspects of the pictures are not emphasised. On the other hand, there are reports indicating that perspective information may be useful for haptic pick up of 3D aspects (Heller et al., 1996; Holmes et al., in press; Kennedy, 1993). 2D cutaneous information may thus contribute to the perception of 3D objects, but there are many problems left for research on what conditions favour 3D percepts from cutaneous information.

In addition to cutaneous information, information from the movements is available for the observer. The information is provided by sensors in the muscles, tendons and joints. The importance of this information was strongly emphasised in seminal papers by Katz (1925/1989) and Gibson (1962), but the relative contribution of cutaneous and movement information to haptic perception has since then been much discussed. Many authors state that relative motion between skin and object is the important factor pointing to experiments where the performance is the same whether the hand or the object is moving (see, e.g., Lamb, 1983, and Lederman, 1981, 1983). Hughes & Jansson (1994) noted that most of studies of this problem concerned texture perception and that the applicability of the equivalence of movement of observer and of object can not without further evidence be generalised to other types of haptic perception. Vega-Bermudez et al. (1991) got the same result, however, for tactile letter recognition but they studied only patterns smaller than the finger pad. In contrast, Jansson (in press) found significant differences between active exploration and passive reception of cutaneous information when studying larger 2D virtual geometric forms.

The problem of the relative contribution of cutaneous and movement information to haptic perception has direct relevance for the usefulness of force feedback displays for people with severe visual impairment. Force feedback displays emphasise movement information and are much less concerned with cutaneous information. In many cases, including the one to be studied here, the equipment defines only one point at a time for contact between observer and virtual object which is much less than cutaneous information in natural contexts. If movement information can be sufficient this does not decrease the effectivity of the display, but if the cutaneous information also is important the restriction to one point decreases the effectivity. Lederman & Klatzky (in press) made a series of experiment indicating that restriction of cutaneous information to one point substantially impaired the performance. When they applied these results to the design of haptic displays they suggested that there may be significant costs of not providing the fingertips with spatially distributed force patterns, at least for novice operators.

As discussed above, there are both pros and cons concerning the usefulness of presently available haptic force feedback displays. The general aim of the present project, part of which is reported here, is to find to what extent devices of this kind can be useful in spite of their limitations. The most positive aspect in favour of their usefulness is their offer of free exploratory movements in 3D space, the most negative aspect the restricted cutaneous information. A reasonable hypothesis is that the importance of movements increases with the complexity of the depiction, especially when 3D aspects are included. The aspects of the virtual objects to be studied here are texture roughness and 3D form.

2. EQUIPMENT

2.1 Haptic Display

A PHANToM 1.5A from Sensable Technologies, Inc., Cambridge, MA, USA, was used as haptic display. It is a robot driving a two-linked arm the tip of which is freely movable within a 19.5 x 27 x 37.5 cm workspace with a nominal position resolution of .03 mm, maximum exertable force of 8.5 N and enertia (apparent mass at tip) of < 75 g according to Sensable specifications (for more details, see the site http://www.sensable.com). The device was driven by a Scandic Computer equipped with a Pentium Pro 200 MHz and with Windows NT Workstation 4.0.

2.2 Exploration Styluses

The tip of the PHANToM arm was provided with the standard stylus, which means that the point of contact with the virtual object was at the end of this stylus. For the exploration of the real sandpapers a stylus was constructed which was a copy of the one used by the PHANToM but with an additional 50 mm long and 3 mm thick steel tip with a pointed tip corresponding to the stylus used when collecting physical sandpaper data.

3. PERCEIVED ROUGHNESS OF REAL AND VIRTUAL SANDPAPERS

3.1 Problem

Texture is one of the most important properties of an object and a property that haptics readily can pick up. Sandpapers have been used in many studies about texture, one reason being that the physical properties of their texture can be clearly defined and ordered. In order to study how well virtual sandpapers reproduce the texture of sandpapers in a form that is useful for observers, the perception of real and virtual sandpapers were compared. As exploration method may effect the result, the same method was used in both conditions, namely exploration with a stylus.

The experimental problem was thus the following. How well do blind-folded observers' perception of the roughness of real and virtual sandpapers agree when they are explored with a stylus?

3.2 Method

3.2.1 Real Sandpapers. Four Norton Metalite sandpapers with 50, 80, 120 and 220 grit, respectively, were used. (For standard specifications, see http://www.wirecloth.com/howto/convert/ussueve.html.)

3.2.2 Virtual Sandpapers. Virtual sandpapers were presented by the PHANToM with a method developed by Green & Salisbury (1997). The PHANToM is first used to acquire data from a sample of respective sandpapers. A vertical probe with one end attached to the PHANToM arm and the other end resting on the horizontal sandpaper is made to follow a trajectory in the form of a straight line at a constant speed and exerting a constant force. Lateral forces and the z position of the endpoint during the movement are recorded. The collected data are used to calculate the vector of z values and means and standard deviations of the static friction coefficients which are used for the simulation. The virtual surfaces are not exact copies of the real surfaces but the properties used in the simulation are intended to be sufficient for allowing accurate perception of the roughness of the sandpapers.

3.2.3 Procedure. Before using the PHANToM participants were informed about the device and safety aspects of its use (a standard head protective device common in industry was placed on the participant's head) and were allowed to acquaint themselves with it. They were instructed to hold the stylus as vertically as possible close to its lower end and to move it approximately in a straight line back and force applying the same constant force during the whole experiment.

Before exploring the real sandpapers the participants were instructed to hold the specially made stylus as vertically as possible and closely above the steel part of the stylus (about 5 cm from the pointed tip) and keep the hand such that it did not touch the sandpaper. The instructions about movements were the same as those for the virtual sandpapers.

When the participants were ready to start, they were asked to choose hand for the exploration the same hand used for the whole experiment. They were equipped with eye cover and earphones playing white noise and the experiment proper began.

3.2.4 Phychophysical Method. The roughness of the sandpapers were judged with magnitude estimation with 120 grit defined as standard to be given the value of 100; no roughness was defined as 0 and there was no maximum limit. In half the trials the real 120 grit sandpaper was the standard, in the other half corresponding virtual sandpaper. The task of the participants was to judge each presented sandpaper to have a roughness value such that it was related to 100 in the same way as its perceived roughness was related to that of the standard sandpaper.

3.2.5 Design. All participants took part in all the experimental conditions and the trials were arranged in four main blocks: virtual texture with virtual standard, virtual texture with real standard, real texture with virtual standard and real texture with real standard. Each main block consisted of six blocks each containing a presentation of the standard sandpaper followed by the four experimental sandpapers. All orders were randomised for half the participants, and the reverse orders were used for the remaining participants.

3.2.6 Participants. Twelve paid sighted university students (seven women and five men) with a mean age of 25 years (SD = 2.4 years) participated. All with the exception of one man worked with their right hand.

3.3 Results

The data were collected and analysed by Billberger (1998). A fourway ANOVA demonstrated significant effects of roughness and replication ($p < .001$) and interaction between standard and replication ($p < .05$), but no significant effects for stimulus type (real/virtual) and standard ($p > .05$), nor for any other interactions. Fig. 1 demonstrates the effects of physical roughness on perceived roughness for real and virtual sandpapers.

3.4 Discussion

The result indicates that the real and virtual sandpapers are perceived in very much the same way, at least when they are similarly explored. The simulation of these textures can thus be considered as successful. It should be noted, however, that there was a tendency at all levels of roughness of virtual sandpapers to be perceived as somewhat rougher than corresponding real sandpapers. This may mean that a significant difference would show up if the number of participants were larger, but the smallness of the difference means that such a result can not be expected to have any practical importance.

There was hardly any difference between the results when the standard was a real sandpaper and when it was a virtual sandpaper. Any of them can be used in future experiments.

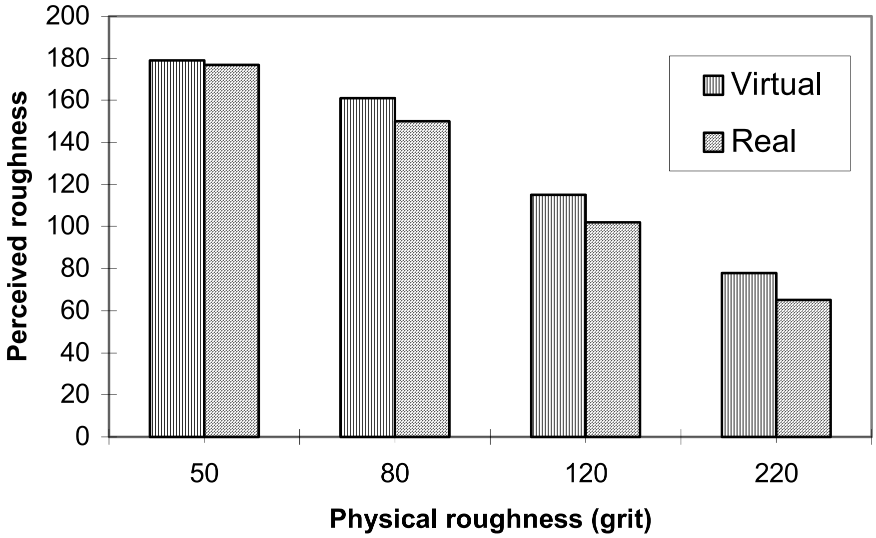

Figure 1. *Perceived roughness as a function of physical roughness and stimulus type.*

4. IDENTIFICATION OF 3D VIRTUAL GEOMETRIC FORMS

4.1 Problem

If any method of rendering virtual objects would be successful, it is important that their 3D form can be identified by the observers. The experimental problem in this part of the investigation was to get a first idea about how well observers can identify differently sized 3D geometric forms rendered by the PHANToM and explored with the stylus.

4.2 Method

4.2.1 Rendering of 3D Geometric Forms. The software, called ENCHANTER, for rendering the experimental forms was developed by Fänger and König (1998) in co-operation with the author. It is based on the software GHOST™ SDK and provides the user with possibilities of easy rendering of 3D geometric forms with several different properties for presentation in experiments.

4.2.2 3D Geometric Forms Studied. Four 3D forms were used, cube, sphere, cylinder and cone, in three different sizes, maximum width and height being 5, 25 and 50 mm, respectively. In order for the 3D forms to be easily localised they were positioned in the middle of a cubical enclosure with dimensions twice those of each 3D form, and for the 3D forms and their enclosure to be certainly discriminated the 3D form surface had no static friction while the inside surfaces of the enclosure had a high such friction.

4.2.3 Procedure. The participants were informed about the PHANToM and the safety aspects and they were allowed to acquaint themselves with the device. The 3D geometric forms to be used were explained for the (sighted) participants with the help of drawings. There were no restrictions on how to use the stylus, but the participants usually kept the stylus similar to a pen. The head protective device and eye cover were applied, and the experiment proper began. (As the PHANToM made very little noise during the exploration of these 3D forms the sound was not masked.)

The participants were presented with the 3D virtual forms one by one and asked to judge their form as fast and accurately as possible (with equal emphasis on both aspects). Maximum 1 min was allowed per 3D form. The verbal responses and the time used for each 3D form was recorded.

4.2.4 Design. All participants took part in all conditions. Each participant was presented three blocks with the 12 3D forms in random order, thus altogether 36 3D forms.

4.2.5 Participants. Ten paid sighted university students (seven women and three men) with a mean age of 22 years (SD = 2 years) took part. All used their right hand for exploration.

4.3 Results

The percentages of correct responses and mean explorations times, both parameters over all participants, are presented in Figs. 2 and 3.

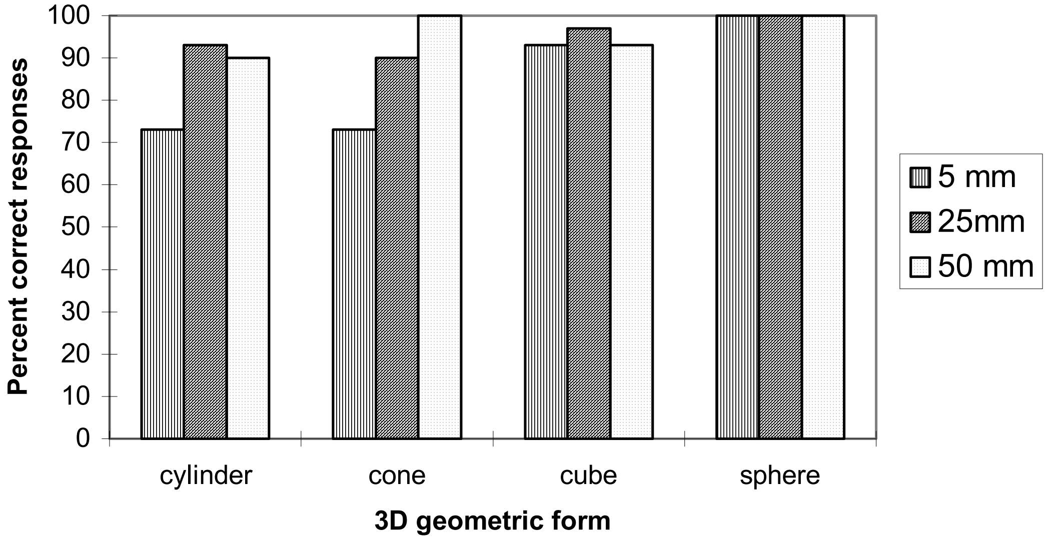

Figure 2. *Percent correct responses for each of the four 3D forms and three sizes.*

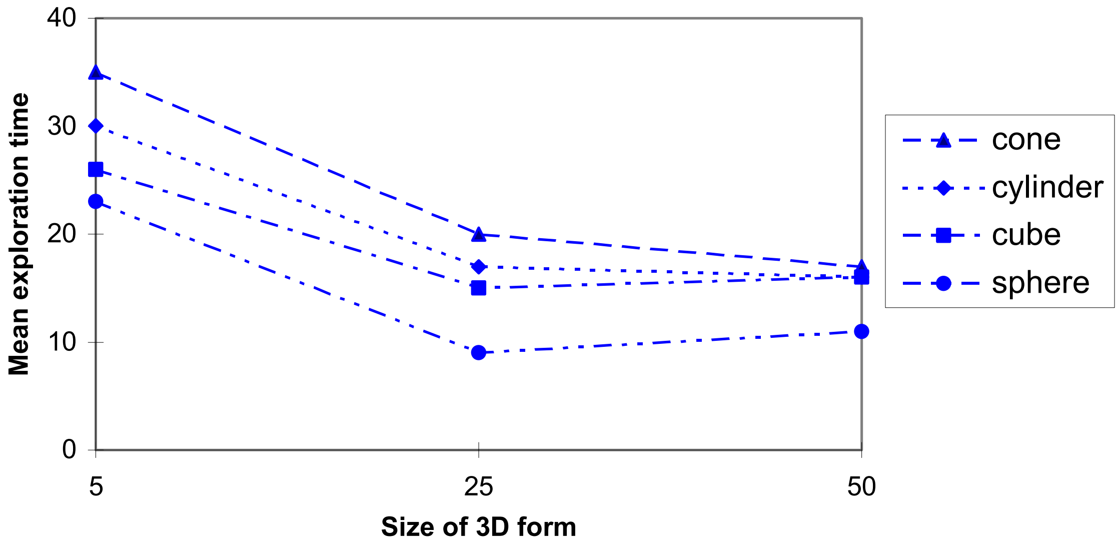

Figure 3. *Mean exploration time (sec.) as a function of 3D form and size (mm).*

4.4 Discussion

The results show clearly that the force feedback device used can provide observers with useful information without vision under the conditions of the experiment. The percent of correct responses is highly above chance level (25 %). In fact, the sphere was correctly identified every time, even in its smallest size. A majority (52 %) of the mistakes for the other 3D forms were made during the first replication. If only the second and third replication had been included the percent correct responses would have been 95 % over all 3D forms and sizes. This demonstrates a quite rapid learning to identify the 3D forms when the identification is not perfect from the start. The size threshold for correct identification is apparently smaller than 5 mm.

Fig. 3 indicates differences in exploration time between the 3D form and sizes. For all the 3D forms the time for the 5 mm size in longer than for the larger sizes. The sphere is not only always correctly identified, but also the time to explore it is shortest for all sizes.

A note should be made about potential effects of sound not being masked. It was assumed before the experiment that the sound could not be used for identification of the 3D forms. Spontaneous comments by some participants indicated, however, that it may have contributed. It can not be excluded that it was used by some participants for the detection of edges. If this was the case, it is not a problem from an applied point of view, as the auditory information is available also for visually impaired people (without hearing loss), but for future experiments about haptics alone it is recommended that sound is always masked.

5. CONCLUSIONS

The investigation demonstrates that the force feedback device studied can present useful information to observers for whom vision is not available. Even if the aspects involved are quite limited they are basic for haptic perception of objects. It is an important result that texture and 3D form can be judged with such accuracy and speed. However, it is evident that the extent to which this can be generalised to other contexts remains to be studied.

In the present study the observers explored the objects via a stylus. That this may not mean a disadvantage compared with other exploration methods is indicated by a theoretical and experimental investigation by Klatzky and Lederman (in press).

The observers were blind-folded sighted people. A study with visually impaired observers would probably not show very large differences, especially not concerning the relations between experimental conditions. Even if the basic haptic capability can thus be expected to be the same for sighted and for visually impaired observers, it is necessary to make specific experiments with visually impaired observers to make sure that the usefulness of the device is similar for them. They have probably more training than sighted people in using haptics which may mean generally better results. On the other hand, especially people with early appearance of severe visual impairment may have less experience of spatial aspects of the environment which may lead to not as good results in general. Therefore, an investigation on related problems with observers having severe visual impairments has started.

Acknowledgements: This study was made possible by grants from the Swedish Council for Research in Humanities and Social Sciences and from the Swedish Transport and Communications Research Board. The author is indebted to Donald Green, Massachusetts Institute of Technology, Cambridge, MA, for making his computer software PALPATE available for this study, to Jens Fänger and Henry König, Universität Magdeburg, Germany, for developing, in co-operation with the author, the computer software ENCHANTER, to Lars-Erik Larsson for technical assistance, and to Katarina Billberger for running the experiments.

6. REFERENCES

K. Billberger (1998), *Haptisk perception av verkliga och virtuella texturer* (Haptic perception of real and virtual textures), Undergraduate thesis, Department of Psychology, Uppsala University, Uppsala, Sweden.

G C Burdea (1996), *Force and touch feedback for virtual reality*, Wiley, New York.

P K Edman (1992), *Tactile graphics*, American Foundation for the Blind, New York.

J Fänger and Henry König (1998), *Entwicklung einer Modellierungs- und Experimentierumgebung für eine Kraftrückskopplungsgerät* (Development of a form production and experiment environment for a force feedback device), Praktikumsdokumentation, Institute for Simulation and Graphics, Magdeburg University, Magdeburg, Germany.

J J Gibson (1962), Observations on active touch, *Psychological Review*, **69**, pp. 477-491.

D F Green and J K Salisbury (1997), Texture sensing and simulation using the PHANToM: Towards remote sensing of soil properties, In *Proceedings of the Second PHANToM Users Group Workshop* (J K Salisbury & N A Srinivasan, Eds), A.I. Technical Report No. 1617 and R.L.E. Technical Report No. 618, Massachusetts Institute of Technology, Cambridge, MA.

M A Heller (1982), Visual and tactual texture perception: Intersensory cooperation, *Perception & Psychophysics*, **3**1, pp. 339-344.

M A Heller, J A Calcaterra, L A Tyler and L L Burson (1996) Production and interpretation of perspective drawings by blind and sighted people, *Perception*, **25**, pp. 321-334.

E Holmes, B Hughes and G Jansson (in press), Haptic perception of texture gradients, *Perception*.

B Hughes and G Jansson (1994), Texture perception via active touch, *Human Movement Science*, **13**, pp. 301-333.

G Jansson (1988). What are the problems with tactual pictures, and what can we do to solve them? In *Man-Machine Interfaces, Graphics and Practical Applications* (C W M Magne'e, F J M Vlaskamp, M Soede, & G Butcher, Eds.), Royal National Institute for the Blind, London, pp. 18-24.

G Jansson (in press). Haptic perception of outline 2D shape: The contributions of information via the skin, the joints and the muscles. In *Proceedings of the Fifth European Workshop on Ecological Psychology (EWEP5),* Pont-à-Mousson, France, July 7-10, 1998.

D Katz (1989), *The world of touch* (L E Krueger, Transl.), Erlbaum, Hillsdale, NJ. Original work published 1925.

J M Kennedy (1993), *Drawing and the Blind*, Yale University Press, New Haven, CT.

G D Lamb (1983), Tactile discrimination of textured surfaces: Psychophysical performance measurements in humans, *Journal of Physiology (London),* **338**, pp. 551-565.

R L Klatzky and S J Lederman (in press), Tactile roughness perception with a rigid link interposed between skin and surface, *Perception & Psychophysics*.

S J Lederman (1981), The perception of surface roughness by active and passive touch, *Bulletin of the Psychonomic Society,* **18**, pp. 253-255.

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

S J Lederman and R L Klatzky (in press), Sensing and displaying spatially distributed fingertip forces in haptic interfaces for teleoperater and virtual environment systems, *Presence*.

G Révész (1950), *Psychology and Art of the Blind*, Longmans, Green and Co, London.

F Vega-Bermudez, K O Johnson & S S Hsiao (1991), Human tactile pattern recognition: Active versus passive touch, velocity effects, and patterns of confusion, *Journal of Neurophysiology*, **65**, pp. 531-546.