

Effects of Surface Properties on Haptic Perception of the Form of Virtual Objects

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Abstract. The problem studied was the potential effects of surface properties, such as hardness, texture and friction, on haptically perceived form of 3D virtual objects; more specifically, on the precision in judgments of the curvature of a spherical object. It was expected that curvature of a soft surface, as well as of a surface with texture and/or friction, would be more difficult to judge than a hard surface without friction and texture. The difference limen was determined under four conditions with different surface properties. The participants' task was, with the help of a haptic display (a PHANTOM), to judge which of two spherical surfaces was more curved than the other. The result was that only texture had a significant negative effect on the judgments. More textures have to be studied to see how generalized this result can be. Concerning hardness, the participants seemed to adapt their exploratory movements to this property.

1 Introduction

For real objects surface properties, such as hardness, friction and texture, as well as form properties, are important for identification of them. For virtual objects the combination of surface and form properties is optional, and the general problem studied here is if the choice of surface properties has any effect on the perception of form. That this may be the case, is suggested by a study by Robles-De-La-Torres and Hayward [1], where local changes in the distribution of forces within a 2D surface (virtual bumps and holes) counteracted real 3D bumps and holes, and a study by Christou and Wing [2] where friction had an effect on the perception of curvature.

Form is a complex of properties, curvature being an important one. Different aspects of haptic curvature perception have been studied by, e.g., Kappers, Koenderink and Lichtenegger [3], Vogels [4] and Vogels, Kappers and Koenderink [5]. The present study focused on the relation between texture, hardness and friction of a virtual object on one side and the perception of curvature on the other. *Do any of these surface properties have any effect on the perception of the form of a 3D virtual object, more specifically, on the precision in judging the curvature of a spherical object surface?*

It can, for instance, be expected that judgments have lower precision if the surface is soft as such a surface yields more for pressure than a harder surface. The object

may therefore be perceived as deformed. Further, friction and texture may confuse the observer, as these properties can make a continuous exploration of a surface more difficult.

2 Method

2.1 Stimulus surfaces

The observers had their right index finger in the thimble of a PHANToM 1.5A (<http://www.sensable.com>). The software was ENCHANTER developed by Fänger and König [6], a program based on GHOST[®] SDK and allowing rendering of geometric forms with optional surface properties.

Four series of nine stimulus presentations were used. Each presentation consisted of two spherical surfaces to be compared concerning degree of curvature, one with a standard spherical curvature and one with a deviating spherical curvature. The task of the observer was to decide, for each of the stimulus presentations, which one of two object surfaces was most curved. The four series differed concerning surface properties. Condition A (maximum hardness without friction and texture) was the standard condition; B represented a condition with low hardness (without friction and texture); C a condition with texture (a sinusoidal pattern with both amplitude and wavelength 2 mm, maximum hardness and no friction), and D a condition with maximum friction (as well with maximum hardness and no texture).

In ENCHANTER *hardness* can be varied between 1 and 0. However, maximum hardness does not mean, for mechanical reasons, complete hardness at the end of the PHANToM's arm. The exact value has not been measured, but maximum means that the value for hardness in ENCHANTER was set to 1. To render low hardness, the value was set to 0.1, which renders a quite soft surface clearly discriminable from one with maximum hardness.

ENCHANTER allows variation of both static and dynamic *friction* with values varying between 1 and 0. The exact values at the end of the PHANToM's arm were not measured, but the extreme values 1 and 0 were used in both kinds of friction for rendering great variation between maximum and no friction.

Damping was not an experimental variable but was used to add to the differences between the curved and the flat surfaces, the values set to 0 and 5, respectively.

The *curvature* of the surface was defined in terms of the radius of the sphere of which it was a part, its curvature being the reciprocal. The series of curvatures varied in equal radius steps (.005 m) from .025 to .065 m and corresponding curvature measures between 40.0 and 15.4 m⁻¹. The part of each sphere used as stimulus surface was screened off from the rest of the sphere by a horizontal plane with a circular opening of .05 m diameter in the middle, above which the stimulus surfaces protruded¹. This plane was rendered with surface properties contrasting to those of the

¹ This means that the height of the protruding parts unavoidably co-varies with the curvature. However, there were no indications that the participants consciously used this information.

spheres in order to make clear that it did not belong to the stimulus surface. An example of a stimulus scene is given in Fig. 1.

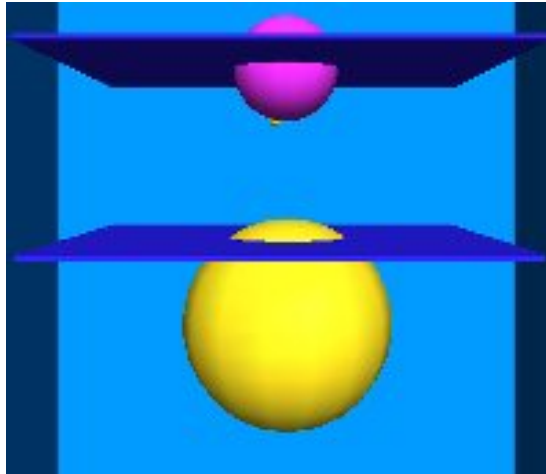


Fig. 1. An example from the visual display of a stimulus scene as a perspective picture of the two spheres, the parts above the restricting planes to be compared by the participants

2.2 Procedure

The participants ($N = 20$, 6 men and 14 women, Mean age = 25 years, $SD = 5$ years) were seated on a chair with their elbows on its armrests at a distance of about 0.35 m from the PHANToM placed on a table. Before the experiment proper the meaning of curvature was explained with drawings showing different degrees of curvature, and the participants were trained in exploration with the device. In order to get only haptic information they were blindfolded and equipped with headphones playing white noise. They had their right index finger in the thimble. The experimenter sat to the right of the participant ready to assist the participant in changing between the two curvatures when they asked her to do so. She measured the exploration time with a stopwatch and made notes of the participants' verbal answer and exploration time. The computer screen showing the stimulus scenes and the participants' exploration was videotaped.

The experiment was organized in four parts, each consisting of one of the experimental condition and presented in randomized order different for each participant. Each condition took about one hour and the conditions were distributed over two days, two each day. The total time for each participant was thus about four hours.

To determine a Difference Limen (DL) the method of limits was used. This means that series of stimulus pairs were prepared, each consisting of a standard stimulus and

a comparison stimulus. The latter were stimuli with stepwise larger or smaller values than the standard stimulus. A number of series for each experimental condition were presented to the participants, and the total means for all participants in each condition were calculated.

The participants had to judge if one of curvatures was more, equally or less curved than the other. No feedback was given. They were allowed to change between the curvatures as many times as they wanted within the maximum time of one minute for each judgment. They were forced to give a judgment and had to guess if uncertain. At the end of each experiment day the participants were asked about comments or questions, which were written down by the experimenter.

3 Results

In Fig. 2 the means of the Difference Limens, in terms of circle radius for the curvatures, are given. An ANOVA showed significant differences between the experimental conditions ($F_{3,57} = 7.426, p < .001$). A contrast test ($\alpha = .016$) showed a significant difference between A and C ($p < .01$), but no significant differences between A and B and between A and D ($p > .05$).

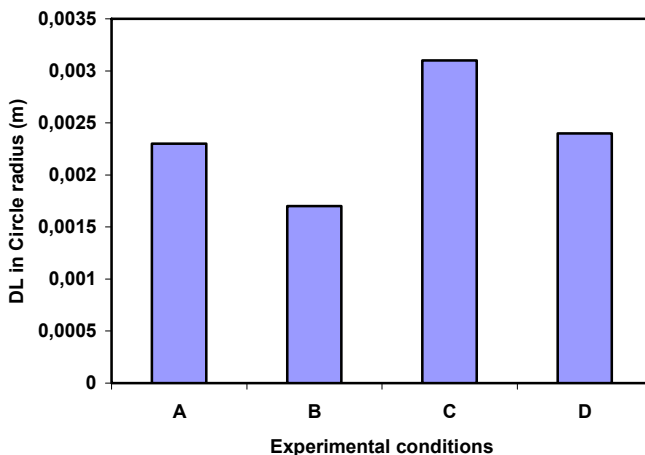


Fig. 2. Difference limens of curvatures in the four conditions: A the standard condition, B the condition with lowered hardness, C the condition with texture, and D the condition with friction.

The numerical result is in accordance with spontaneous comments by the participants after the end of the experiment each day. Most of them said that it was easier to judge form with a smooth than a textured surface, as they felt disturbed by the variation in height by the microstructure.

