Haptically perceived orientation of a planar surface is altered by tangential forces

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Abstract

We describe an experiment showing that addition of tangential forces can alter the haptically perceived orientation of a flat surface in a systematic fashion. Using a stylus mounted on a Phantom controlled by the GHOST software package, subjects performed single horizontal strokes along vertical surfaces at a number of orientations around the mid-sagittal plane. After each trial, subjects (who could not view their hand) judged whether the surface was rotated around the vertical axis in the clockwise or counter-clockwise direction from the sagittal plane. Psychometric curves for perceived surface orientation were measured in this way for various magnitudes of tangential forces along the stroke direction or in opposition to it. Psychometric curves shifted systematically with varying force magnitude, indicating that resistive forces tilted the perceived surface into the path of motion, while assistive forces tilted it away. More generally, the results show that perception of global surface orientation is not exclusively based on the location of the surface in space, but also on the forces encountered along the surface.

Introduction

In order to haptically determine surface shape through a stylus or similar tool, one could envision a method of sampling contact points in space and performing some kind of interpolation between them. However, there is evidence suggesting that, in humans, the forces encountered during a haptic scan affect the shape percept, suggesting a richer set of perceptual mechanisms. For example, as mentioned in Minsky (1995), lateral assistive forces on a haptic interface create the percept of moving downhill. Morgenbesser & Srinivasan (1996) demonstrated that particular modifications of force vectors on a nominally flat surface ("force shading") were perceived as a bump.

It is unclear, however, whether we have simply learned to associate certain changes in resistance with particular shape features. For example, an increase in resistance followed by a decrease would generally be associated with a bump.

In the experiment described here, we sought to determine whether tangential forces can in fact modify the global perceived orientation of a surface. This was done by measuring the perceived change in orientation of a flat surface as a function of the magnitude of an added tangential force. Specifically, we tested a range of orientations under a number of force conditions, and from the results computed an estimate of the perceived sagittal plane for each condition. This is a form of nulling technique to cancel the perceived change in orientation with a real change in the orientation of the surface.

Estimating the magnitude of a perceptual phenomenon by nulling it with variations in the physical stimulus has been applied to a number of perceptual phenomena in the past (Taylor, 1963; McCourt, 1982; Krauskopf et al, 1986; Sachtler & Zaidi, 1993).

Equipment

Experiments were performed using a Phantom 1.0x fitted with 4000-counts-per-revolution encoders and a standard stylus. Surfaces and tangential force fields were generated using the GHOST software package running on a dual-500 MHz-processor Pentium PC under the Windows NT 4.0 operating system.

Stimuli & Procedure

Stimuli consisted of flat vertical surfaces with a spring constant of 0.8 N/mm and no friction.

Surfaces were presented at a range of orientations, in increments of 6 degrees, around the mid-sagittal plane. A value of zero corresponds to a surface aligned with the mid-sagittal plane. Figure 1 shows a top-down view of a subject's relation to the stimulus. The two subjects whose results are reported here were both right-handed. They were instructed to stroke the surface with the stylus by always moving their right hand towards their body.

Force fields tangential to the surfaces were added along the horizontal direction, that is, parallel to the ground, and were directed either towards or away from the subject. Figure 2 summarizes the sign conventions for force fields at positive and negative surface orientations.

Positive forces were directed towards the subject, assisting motion of the stylus tip along the simulated surface, while negative forces were directed away and thus resisted movement of the stylus.

Seven force conditions were tested with magnitudes of –0.9, -0.6, -0.3, 0.0, 0.3, 0.6, and 0.9 Newton (N). Tangential forces were applied only when the endpoint of the stylus was in contact with the simulated surface.

Figure 3 summarizes the procedure for a single trial, as described in the caption. Subjects, who could not view their hand, were seated at a desk, resting their right elbow on its surface, and used a chin-and-forehead rest to maintain a fixed location with respect to the Phantom throughout the experiment. They were instructed to draw the tip of the stylus along a horizontal path on the vertical surface. Movement and forces were restricted to the horizontal to minimize confounds with gravity. At the end of each trial, subjects indicated via key press with their other hand whether they judged the right side of the surface to be oriented towards or away from them, that is, whether the surface was rotated in the clockwise or counter-clockwise direction from the sagittal plane. They were instructed to guess when unsure.

Seven surface orientations for each of the seven force conditions were randomly interleaved for a total of 49 trials in one block. Eight such individually randomized blocks were run for each subject, providing psychometric curves for perceived surface slant.

The midpoint of each psychometric curve--with equal proportions of clockwise and counter-clockwise orientation judgments--served as an estimate of the perceived sagittal plane. That is, the angle at which a surface was perceived as not tilted. The range of orientations tested for each

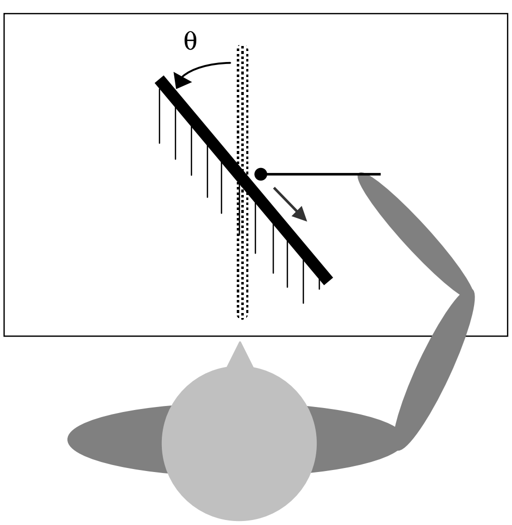


Figure 1: Top-down schematic view of a subject performing a single haptic scan of a simulated surface (solid line) with a Phantom stylus. Surface orientation (θ) is defined with respect to mid-sagittal plane.

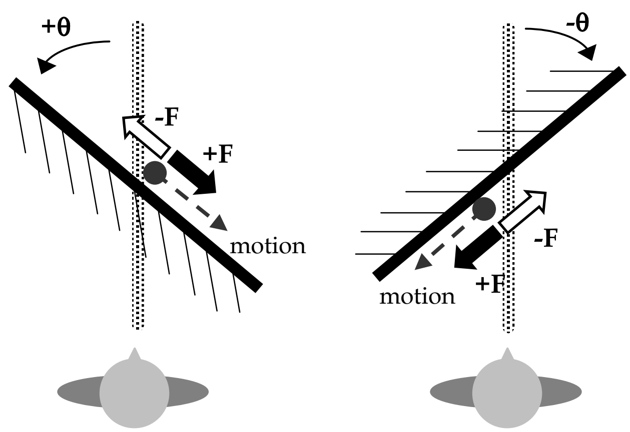


Figure 2: Sign conventions (top-down view). Positive tangent forces are directed towards subject, in alignment with motion of stylus tip along a surface. Positive angles correspond to counterclockwise rotation of the surface with respect to mid-sagittal plane.

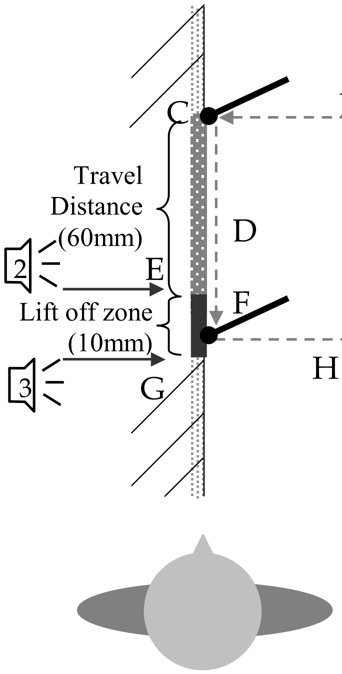


Figure 3: Procedure

A) All trials began from the same starting point. Phantom was constrained under software control.
B) A tone (1) indicated when the constraint was released, and subjects moved the stylus towards the virtual surface.
C) Point of first contact on surface served as reference for distance traveled along the surface.
D) Subjects drew stylus towards their body along the surface.
E) A second tone indicated when desired travel distance from first contact was reached (60mm).
F) Subjects were required to lift stylus off surface within 10mm after travel distance limit or trial was cancelled.
G) A third tone indicated if passed beyond liftoff zone to provide feedback.
H) Subjects lifted stylus off the surface.
I) Subjects responded via key press with free hand while holding stylus in space.
J) Once the response was recorded, the Phantom was pulled to the starting point under software control, and a new trial began.

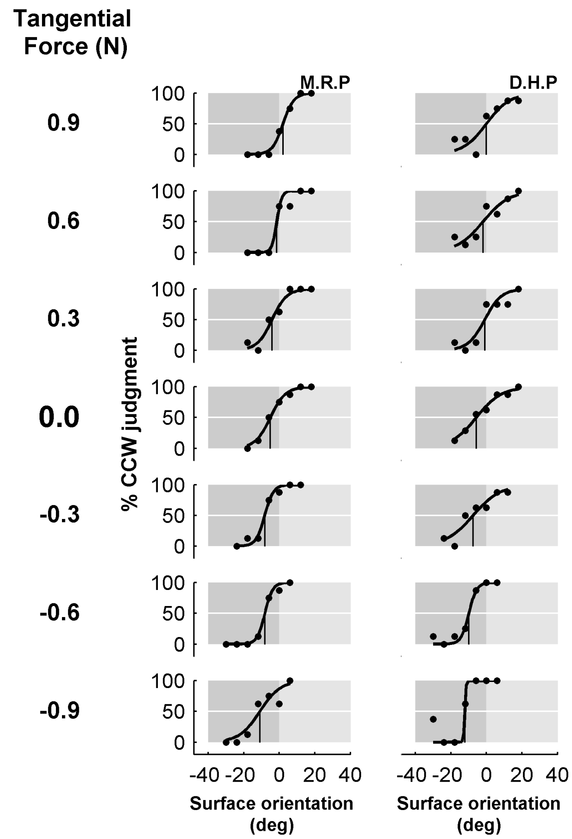


Figure 4: Results for two subjects are shown in separate columns. Each panel shows psychometric curves for perceived surface orientation for different tangential force fields, indicated on the far left. Surface orientation is plotted on the abscissa, while the ordinate shows the proportion of trials in which subjects indicated the surface was rotated counterclockwise (CCW) with respect to the mid-sagittal plane. Solid curve shows the best-fitting logistic function used to estimate the angle at which clockwise and counterclockwise judgments were balanced.

force field was determined in pilot runs.

Two right-handed subjects were tested. DHP was naïve regarding the purpose of the experiment.

Results

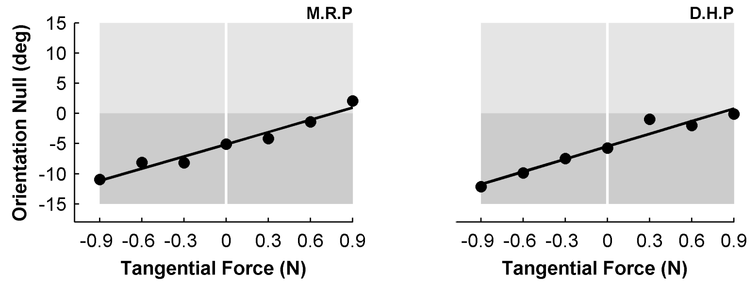
Results for each subject are shown in separate columns in Figure 4. Panels show psychometric curves for perceived surface slant at different force field magnitudes indicated on the left.

Surface orientation is plotted along the abscissa, while the ordinate of each panel indicates the percentage of counter-clockwise judgments (thus, response percentages are high for positive--counter-clockwise--rotations). A value of 50% indicates that the proportion of clockwise and counter-clockwise judgments was the same.

A logistic curve, shown as a solid line, was fit to each data set to estimate the surface orientation at the 50% mark. A thin vertical line in each panel indicates this value, which served as a measure of the angle at which a surface did not appear tilted.

The position of the psychometric curves varied systematically with the applied force field. This is

Figure 5: Orientation of a surface that was perceived as sagittal (not tilted) as a function of tangential force field magnitude. The straight line in each plot shows a linear regression fit, with slopes of 6.7 and 7.0 for MRP and DHP, respectively. Correlation coefficients were 0.98 and 0.97, respectively



shown in different form in Figure 5, where the orientation of a surface that was perceived as sagittal is plotted as a function of force magnitude. That is, applying a particular tangential force to a tilted surface led subjects to report that it was not tilted.

There was a negative bias for both subjects in the perceived orientation of a sagittal surface even in the absence of a force field (bias MRP: -5.1 deg, DHP: -5.5 deg). The angle at which surfaces did not appear tilted increased for positive force fields, and decreased for negative ones.

Summary

Tangential forces systematically altered the haptically perceived orientation of a flat surface.

Results indicate that constant resistive forces tilted the perceived surface into the path of motion, while assistive forces tilted it away.

The linear relationship between tangential force and perceived surface orientation suggests a method by which to scale the lateral forces of 2D force-feedback devices in order to simulate surface features extending in three dimensions.

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