ABSTRACT

MENDAT, CHRISTINA COSTANZO. Effects of modality, surface-type and surface-smoothness on the discrimination of texture (Under the direction of SLATER EDMUND NEWMAN and DONALD HARTLAND MERSHON).

This study assessed the performance of participants in haptic and visual discrimination tasks involving the surfaces: abrasive paper and Japanese sharpening water stones. A recent study using abrasive paper surfaces showed that participants' visual discrimination of smooth stimuli was more accurate than the haptic discrimination of those same smooth stimuli (Bozoglu-Sinclair, 2001). These results differed from those of an earlier experiment, which examined visual and haptic performance in the discrimination of Japanese sharpening waterstones and found that participants in the haptic condition performed better than those in the visual condition with smooth stimuli (Heller, 1989, Experiment 2). In both previous experiments, the participants in the haptic and visual conditions performed equivalently with rough stimuli.

The current study employed a 2 (modality) x 2 (smoothness) x 2 (surface) design using Heller's procedure. Data for both accuracy and inspection time were analyzed. Of interest was whether Heller's results for accuracy of performance would be obtained with a different type of surface (i.e., silicon carbide). As in the experiment by Bozoglu-Sinclair, data for inspection time were also analyzed to determine whether, as in that study, visual inspection time would be shorter than haptic inspection time for examination of both rough and smooth stimuli. In addition, optical profilometry was employed to obtain roughness values in microns for each stimulus.

Results for accuracy differed from previous findings in that the haptic and visual conditions were equivalent for both rough and smooth stimuli. Inspection time results, however, showed that participants in the visual and rough conditions made judgments significantly faster than those in the haptic and smooth conditions respectively. Results from optical profilometry indicated that the manufacturer's scale of micron values led to different ranking of the stimuli for the silicon carbide condition and different roughness values for both silicon carbide and Japanese waterstones. Performance measures seemed to be more congruent with the optical profilometry values than with the original scale. These results highlight the desirability of using optical profilometry in evaluating stimulus materials.

EFFECTS OF MODALITY, SURFACE-TYPE AND SURFACE-SMOOTHNESS ON THE DISCRIMINATION OF TEXTURE

by

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BIOGRAPHY

Christina Costanzo Mendat was born in Richmond, Virginia on June 24, 1976. She graduated from Williamston High School in 1994 and entered North Carolina State University that fall. She graduated in 1998 with a Bachelor of Arts in Psychology and a minor in Genetics. For two years, she worked in genetics at a bio-scientific company in the area of Fluorescent-in-situ-Hybridization and advanced the research in Pre-Implantation Genetic Diagnosis.

Realizing her passion for psychology, she entered the graduate program in Experimental Psychology at North Carolina State University at Raleigh in the fall of 2000. Since then, she has been active in her research, her teaching of various courses, and her recent marriage.

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INTRODUCTION

This study examined the effects of modality, surface-smoothness, and surface-type on the discrimination of texture. More specifically, this experiment sought to determine whether the effects obtained by Heller in 1989 (i.e., equivalent performance between Vision and Haptic groups for rough stimuli, but better performance by the Haptic group for smooth stimuli) would be replicated, not only with the same type of surface used by Heller (waterstones) but also with an apparently similar surface (i.e., silicon carbide abrasive paper). A recent experiment (Bozoglu-Sinclair, 2001) using silicon carbide abrasive paper replicated Heller's results with rough, but not smooth, stimuli.

The study of touch has been pursued for over 150 years. One of the earliest investigators was E. H. Weber whose major works in touch were published in 1834 and 1846. E. H. Weber, David Katz, and J. J. Gibson were among those who made major contributions. Most relevant to the experiment described in this paper are: a) Weber's proposal that "...the shape and texture of ...objects is not discovered by touch, unless the finger is deliberately moved over the surface of the touched object" (Ross & Murray, 1996, p.5); b) Katz's (1925) experiment on texture discrimination and his proposal that the hand and not its receptors or skin surface is the organ of touch; and c) Gibson's (1962) statement of a similar position and his demonstration that the perception of objects is done more effectively by active touch (touching) than by passive touch (being touched).

The remainder of this introduction is divided into two main sections: haptic vs. visual discrimination of texture and the discrimination of texture as a function of surface-type. Since the literature on tactile perception is quite broad, the studies presented below are limited to those which are most closely related to the current research topic.

Throughout this introduction the terms, “haptic”, “tactile” and “touch” will be used in accord with the usage in the various studies. Regardless of which of these terms was used by the various experimenters, each term refers to “active” touch in which there is exploration of the stimulus by the hand.

Haptic versus Visual Discrimination of Texture

A number of different positions on the roles of vision and touch have been proposed. Some have speculated that the hand teaches the eye (Zincheko & Lomov, 1960), while others believe that texture is processed by vision and touch in different ways depending on the task (Lederman, Thorne, & Jones, 1986). In that vein, Freides (1974) stated that individuals rely on the sense which is more adept for the given stimulus. Katz (1925) also speculated that touch surpasses vision in judgments of thickness and micro-texture, and Heller (1989) has provided support for the position that touch surpasses vision in the judgment of smooth textures. In contrast, Loomis (1981) asserted that touch works as a “low-pass filter,” similar to that of blurred vision whereby touch is inferior to sight.

There have been a number of studies comparing visual and haptic modalities and the usual finding is that people do better with vision than touch when the task is the perception of objects (Jones, 1981). The same is true when the task is to learn the names of a set of Braille symbols (Newman, Hall, Foster, & Gupta, 1984).

There has been little research, however, in which visual and haptic discrimination of texture have been compared (Bjorkman, 1967; Bozoglu-Sinclair, 2001; Heller, 1982, 1989; Jones and O'Neal, 1985). Their results show that for rough stimuli the visual and haptic groups perform equivalently, but for smooth stimuli the results are equivocal (Heller, 1989, Experiment 2; Bozoglu-Sinclair, 2001). These experiments are summarized below.

The purpose of Bjorkman's study (1967) was to compare intramodal and crossmodal variability in accuracy using the following four conditions: Vision-Vision, Touch-Touch, Vision-Touch, and Touch-Vision (these indicate the modality for examining the first and second stimuli of the pairs). The stimuli were 3-Mite abrasive papers with 17 grit values: 24, 30, 36, 40, 50, 60, 80, 100, 120, 150, 180, 220, 240, 280, 320, 400, and 500. ["Grit value" refers to the number of openings per inch in a screen that is used to sort abrasives (Stevens & Harris, 1962). The grit values increasing in numerical value represent a progression from rougher to smoother surfaces.]. Values of the standard stimuli were 36, 50, 80, 120, 180, 240, and 320. Participants were presented either 175 stimulus pairs or 295 stimulus pairs and were instructed to indicate whether the two stimuli in each pair were "equal" or "different." Results indicated that accuracy was less variable in the intramodal conditions than in the crossmodal conditions and less variable in the Vision-Vision condition than in the Touch-Touch condition.

Jones and O’Neal (1985) compared the two modalities and examined the effects of using the left and right hand (indicative of the role of the right and left hemispheres in right-handed individuals) in the discrimination of texture. Their first experiment had five different conditions: Vision Only, Touch with the Left Hand Only, Touch with the Right Hand Only, Vision and Touch with the Left Hand, and Vision and Touch with the Right Hand.

The stimuli used in this study (Jones & O’Neal, 1985) were 3 x 3 cm squares of abrasive paper with the following grit values: 80, 100, 120, 150, 180, 220, 240, 280, 320, and 400. Participants were presented pairs of these stimuli and were instructed to indicate which was “rougher.” The items of each pair differed from one another by no more than three steps in the scale of grit values. The finding of most relevance to the present experiment is that there were no significant differences in accuracy between the two Touch Only conditions and the Vision Only condition. However, participants took less time to respond in the Vision Only condition.

In a second experiment the conditions were the same as in Experiment 1. This time participants were instructed to indicate whether the stimuli of each pair were the “same” or “different.” The same grit values were used as in Experiment 1. Results from this experiment were similar to those found in Experiment 1 in that the Vision Only and Touch Only conditions did not differ significantly in number of correct responses. However, the latencies were shorter for the Vision Only than for the Touch Only condition. Thus, in both experiments, accuracy was the same under the Vision and Touch conditions independent of the type of judgment required, “rougher” in Experiment 1 and “same” or “different” in Experiment 2.

Heller (1982) examined the effect of multimodal input on texture perception. In each of three experiments, sandpapers (aluminum-oxide abrasive papers) were used as the stimuli. Each of the three experiments used the same set of stimuli with the exception of three values in Experiments 2 and 3. The stimuli were 5-cm^2 aluminum-oxide abrasive papers. The grit values used in each of the experiments were 80, 100, 120, 150, 180, 220, 240, 280, 320, and 400 (220, 240, and 280 were not used in Experiments 2 & 3). Participants in Experiment 1 were assigned to one of three conditions: Bimodal (haptic + vision), Vision Only and Haptic Only. In each condition, the stimuli were presented simultaneously in three adjacent 16.5 x 7.5 cm panels. During the experimental sessions, participants were asked to indicate which of the three stimuli presented was the smoothest. In all conditions, participants were allowed to examine the stimuli for as long as they needed in order to make an informed decision. To control for any confounding textural cues in all of the conditions, participants wore a pair of industrial gloves. For those in the haptic conditions, the index finger of the glove for the preferred hand was partially cut out, so that the tip of the index finger could freely examine the stimuli.

In the Vision Only condition, participants were allowed to examine the stimuli from all angles without touching the stimuli. However, due to differences in the hues of the sandpapers, participants were asked to refrain from making smoothness judgments based on the color of the stimuli (There was no report as to whether participants followed instructions or not). For the Bimodal and Haptic Only conditions, participants were allowed to handle the stimuli with their non-preferred hand and to feel the surface with the preferred hand. For half the judgments, the intertrial interval was 0 seconds and for the rest 1 second.

Results from Experiment 1 showed that the Bimodal (haptic + vision) condition was superior to the Haptic Only and the Vision Only conditions, which did not significantly differ from one another, although the Haptic Only condition did slightly outperform the Vision Only condition. Intertrial interval had no effect.

Experiment 2 was similar to Experiment 1 but with a few minor changes. The haptic and auditory modalities were thought possibly to affect the smoothness judgments of the participants. Therefore, Heller had participants in the three original conditions wear earmuffs, but not those in a fourth condition (Vision + Haptic + Audition). As indicated previously, the set of grit values in this experiment was identical to that of the first experiment with the exception that the grit values 220, 240, and 280 were not used. During the 28 trials, for half of the participants in the three haptic conditions the stimuli were stationary for the first 14 trials and participants handled the stimuli for the last 14 trials. For the rest of the participants in each of the three haptic conditions, the handling condition came first. This time, there was no intertrial interval. In addition, different orders of the stimuli (28 trials in total) were administered to the participants than in the first experiment. In all other respects the procedure was the same as in Experiment 1.

The two multimodal groups were more accurate than the two unimodal groups, but did not differ in accuracy from one another. The Vision Only and Haptic Only groups were also equally accurate. However, it was not possible to identify in the Bimodal condition whether vision and touch contributed equally to performance. The accuracy for the stationary and handling conditions was equivalent.

In the third experiment, Heller attempted to determine whether vision and touch contributed equally to performance in the bimodal condition. As a result of this experiment, he concluded that touch contributed more to the judgment of texture than did vision. In this experiment, there were no separate Touch and Vision groups.

The results from the previous experiments indicate that under a variety of conditions, accuracy in the discrimination of texture did not differ whether the stimuli were examined by touch or by vision. However, since 500 had been the smoothest grit value employed, another experiment (Heller, 1989, Experiment 2) examined whether the results would be the same if much smoother stimuli were used. Thus, Japanese sharpening waterstones were used which permitted the inclusion of very smooth stimuli (grit values up to 6000).

Again, vision and touch were compared. Thus, the conditions were Vision-Vision and Haptic-Haptic. A within-subjects design was used in which each participant was tested with both rough and smooth pairs. Each participant was exposed to six different pairs (each stimulus of a pair had a surface area of 4 x 6 cm) presented by the experimenter and was asked to indicate which of the two, in the pair, was "smoother." The pairs were 220/250, 250/800, 800/1000 for the "rougher" stimuli and 1000/1200, 1200/4000, and 4000/6000 for the "smoother" stimuli.

The two stimuli in each pair were presented to the participants simultaneously. Participants were not given any time constraints for their examination and were instructed to feel each stimulus with their preferred index finger. As in the previous study, participants in the Haptic condition wore auditory-isolating earmuffs to reduce exposure to auditory stimulation and cotton work gloves to reduce exposure to extraneous texture cues. (Participants in the Vision condition also wore cotton work gloves.) In the Vision condition, participants were instructed to point to the "smoother" surface; in the Haptic condition, participants were to tap the "smoother" surface.

For the rougher stimuli, Vision and Haptic groups performed equivalently, thus replicating the results of previous experiments. For the smoother stimuli, however, performance was better in the Haptic condition than in the Vision condition. Heller thus concluded that touch is the superior modality in the judging of very smooth textures.

An experiment by Bozoglu-Sinclair (2001) also compared visual and haptic presentation for rough and smooth stimuli, using two crossmodal conditions (Vision-Haptic and Haptic-Vision) as well as the two intramodal conditions (Vision-Vision and Haptic-Haptic). In addition, the effect of instructions was examined. Thus, half of those in each treatment were instructed to select the smoother of the two stimuli, and the others the rougher of the two stimuli. A 2 x 2 x 4 between-participants design was employed with the following independent variables: Instructions (Rougher, Smoother), Grit Value (Rough, Smooth) and Modality (Vision-Vision, Haptic-Haptic, Vision-Haptic, Haptic-Vision).

The stimuli in this experiment were 7 x 7.5 cm pieces of silicon-carbide sandpaper[1] with the following grit values: 60, 80, 100, 120, 150, 180 (rough values) and 800, 1000, 1200, 1500, 2000, 2500 (smooth values). Participants were presented with 40 pairs of stimuli (4 sets of 10 stimulus-pairs). Each stimulus was paired with its adjacent grit values (e.g., 60-80 and 80-100). The two stimuli of each pair were presented successively.

Most relevant to the experiment proposed here are the Haptic-Haptic and Vision-Vision conditions. Participants in the Haptic-Haptic condition examined each stimulus with the right index finger. For each pair they called out whether the second stimulus was rougher (or smoother) than the first. Participants were given as much time as needed to examine each stimulus.

For the Vision-Vision condition, participants were treated in the same way except that they examined each stimulus visually rather than haptically. For these participants, haptic examination was precluded. The main dependent variables were accuracy and inspection time. Results showed that for rough stimuli, accuracy was the same for the Vision-Vision and Haptic-Haptic conditions. For the smooth stimuli, however, the Vision-Vision group was the more accurate. Inspection time was less in the Vision-Vision condition than in the Haptic-Haptic condition. Overall, it made no difference whether participants were to pick the "smoother" or "rougher" of the pair. Bozoglu-Sinclair proposed that the between-experiment difference in outcomes for the smooth stimuli between her experiment and that of Heller might be attributable to the difference between experiments in the type of surface, waterstone and sandpaper.

[1] Silicon carbide is another type of abrasive paper used for sanding purposes. It is also categorized as wet-dry sandpaper. Research prior to Bozoglu-Sinclair's study used aluminum-oxide abrasive papers as stimuli. Silicon carbide is coated with a water resistant substance which is not applied to aluminum-oxide surfaces.

Of the experiments summarized above, especially interesting is that difference between the results of Heller's (1989, Experiment 2) and Bozoglu-Sinclair's (2001) experiments. The results for the rough stimuli replicated those of previous research in that there was no difference in accuracy of performance between the visual and haptic groups in both experiments. For the smoother stimuli, however, the results from the two experiments were markedly different. Heller found touch to be superior, whereas Bozoglu-Sinclair found vision to be superior.

What might account for this difference in outcome between the Heller and Bozoglu-Sinclair experiments? There were several differences in materials and procedures. Most notable among these are the following (in each case, the Heller characteristic is mentioned first): type of surface (Japanese waterstones; sandpaper), range of grit values (220-1000 and 1000-6000; 60-180 and 1000-2500), area of stimulus exposure (4 x 6 cm; 7 x 7.5 cm), instructions about color (disregard color; no mention of color), type of presentation (simultaneous; successive), type of response (tap or point; vocal), type of design (within-participants for smoothness; between-participants for smoothness), and range of color (larger; smaller).

Thus, the difference in outcome between these experiments may have been due to any one or combination of these factors. The current study examined whether (as proposed by Bozoglu-Sinclair) type of surface may have been a contributing factor by determining whether the results obtained by Heller would be replicated using both his type of surface and that employed by Bozoglu-Sinclair. This experiment also provides information about inspection time for pairs examined under each of its eight conditions.

<u>Discrimination of Texture as a Function of Surface-Type</u>

Several other surface-types in addition to those considered above (sandpaper and waterstones) have been used in experiments on texture discrimination, including wool fibers, gratings, dot patterns, smooth surfaces bearing a single tiny dot varying in height and diameter, curved surfaces, and spatially complex patterns such as Braille dots and embossed letters (see Sathian, 1989). Some authors (Grant, Thiagarajah, and Sathian, 2000; Heller, 1989; Miyaoka, Mano, and Ohka, 1999) have used different surfaces in different experiments reported in the same paper and Katz (1925) investigated the effects of several variables using various grades of paper in individual experiments.

In two of their experiments, Miyaoka, et al. (1999) aimed to measure the discriminability of fine-surface textures. Their study categorized the abrasive stimuli (sandpaper) on the basis of a micron scale. [This scale refers to the average size of each particle on the abrasive surface. A micron is defined as "a unit of length equal to one millionth of a meter" (Merriam-Webster, 1993). The usual symbol for micron is μ.] Participants were instructed to make "rougher" discriminations when presented pairs of abrasive stimuli. Results from Experiment 1 revealed that participants judged the 3-μ comparison stimulus to be "rougher" than the 1-μ stimulus with a probability of 95%, indicating that individuals can discriminate fine-surface textures very effectively by touch. In a subsequent experiment using stimuli with various "ridge-height" stimuli, Miyaoka and colleagues again found that when using the haptic modality participants were very accurate in discriminating small ridge-differences (.95 to 2.0-μ).

In a study of blind Braille readers, Grant, Thiagarajah, and Sathian (2000) were interested in whether blind individuals were superior to sighted individuals with regard to tactile sensitivity. In this study, two different types of stimuli were used, dot patterns and gratings. In the first experiment of the study, results showed that the blind participants were more accurate on the dot-pattern task than were the sighted participants. With respect to the gratings used in the second experiment, the blind participants did not outperform the sighted participants. The results from these two experiments supported the position that blind participants perform better on dot patterns due both to the similarity of the patterns to Braille and the greater experience they have had with Braille as compared to that of the sighted participants.

Heller (1989) conducted a study in which he used two different types of surfaces (sandpaper, Experiment 1, and waterstones, Experiment 2). The initial interest in this study was in whether visual imagery was needed by participants to discriminate texture. Participants were blind and sighted adults in the first experiment. Results indicated that there was no significant difference between groups in the discrimination of texture. In the second experiment, as indicated earlier, sighted adults discriminated differences in the smoothness of waterstones. They found that participants were more accurate with rougher than with smoother stimuli. However, as in the studies mentioned above, there was no attempt to compare the differences in performance as a function of the between-experiment difference in type of surface.

Finally, as mentioned earlier, Katz (1925) carried out several experiments on the discrimination of texture. He used 14 grades of paper as stimuli and participants were usually asked to indicate whether the two stimuli were different. (Unfortunately, there were no pairs where the stimuli were the same.)

METHOD

The current research replicated the second experiment of Heller's 1989 study and also used the type of surface employed by Bozoglu-Sinclair (2001). Like Heller, this study used Japanese waterstones for half the participants and like Bozoglu-Sinclair, silicon carbide was used for the other half of the participants. The other minor differences between Heller's experiment and the current experiment will be indicated in a later section.

Participants

Undergraduate students (N = 64) enrolled in an introductory psychology course at North Carolina State University participated in this experiment, as one way of fulfilling a research requirement for the course. Participants ranged in age from 18-25 years. [Stevens and Patterson (1995) have reported that tactile acuity of adults diminishes by one-percent each year after the age of 20]. Participants used the index finger of the preferred hand in the haptic conditions, so there was no handedness requirement. Women and men were separately assigned to conditions using a balanced Latin square. The data from one participant were not used due to a lack of sensation in his index finger. An additional three participants did not pass a preliminary visual examination and were not used. Participants signed up for the experiment electronically.

Stimuli and Apparatus

A test of visual acuity was administered to the participants at the beginning of the session to verify 20/20 vision using a Keystone telebinocular apparatus and the Snellen Visual Acuity measure for near vision. Data are included only from those participants who had normal or corrected-to-normal vision.

Each condition included four different grit values. For the Japanese sharpening waterstones, the “rough” grit values were 220, 250, 800, and 1000 and the “smooth” grit values were 1000, 1200, 4000, and 6,000. For the silicon carbide sandpapers, the “rough” grit values were 180, 320, 400, and 600 and the “smooth” grit values 600, 800, 4000, and 6000. Values were chosen in an attempt to achieve approximate matches between the two type of stimuli. Micron equivalents for the respective grit values for both surfaces are given in Appendix B. The rest of this paper will refer to the silicon carbide stimuli as sandpaper and to the Japanese sharpening waterstones as waterstones.

The stimuli were covered by a white poster board with a 4 X 6 cm opening. The surfaces were presented in an open area of the apparatus which allowed “simultaneous” exploration of both stimuli. A 75-watt incandescent light was used to provide adequate lighting for examination in the vision condition. In the haptic condition, a black curtain was used both to block sight of the actual stimuli and of the participants’ hand movements.

In each condition, four sets of random arrangements (i.e., six possible pairs within rough or smooth; see Appendix C) were established, so that each participant was exposed to 24 trials, each set consisting of an arrangement of the six stimulus pairs [When Heller was contacted, he was unable to provide information as to the orders he used (personal communication, December 15, 2001).] Each of the 24 pairs of waterstones was equivalent in smoothness *differences* to the pair of sandpapers in the same ordinal position. Order B in all conditions was the reverse of Order A. For each pair in each set, each stimulus appeared twice on each side (right or left). Since the sandpapers could lose some of their grit during use, they were replaced after each 8th participant in the haptic sandpaper condition. Waterstones keep their grit very well and did not need replacement.

To reduce possible extraneous textural cues, participants in the haptic and visual conditions wore a pair of cotton work gloves on their hands. However, in the haptic condition, participants wore gloves having the distal area of the preferred index finger cut off so that the participants could haptically explore the stimuli. In addition, participants in the haptic condition wore auditory isolating earmuffs to reduce the number of auditory cues that could be heard by participants from their contact with the various stimuli.

Procedure

Upon entering the experimental laboratory, participants were presented with an informed-consent form and were notified of their rights and responsibilities as a participant (see Appendix G). At that time, participants were administered a near-distance visual acuity test. Upon passing the visual examination, the participants were seated before the wooden apparatus and given a brief introduction to the experiment and the equipment involved. Instructions for the task were read to each participant (see Appendix F). These instructions asked participants to determine which stimulus of each pair was the "smoother." To indicate their choice, participants in the haptic condition were instructed to tap the smoother stimulus with their preferred index finger; in the visual condition they were asked to point to (but not touch) the smoother surface.

As indicated previously, there were four sets of six comparisons (24 trials in all). Each set was composed of a random arrangement of the six comparison pairs. Before each trial set, in the haptic conditions, participants wiped the tip of their exposed index-finger region on a cloth dampened with alcohol and then wiped the fingertip dry. This was done to help prevent any residue buildup and to reduce fingertip insensitivity which might affect item discriminability.

For each stimulus pair, the surfaces were presented simultaneously and adjacently in the open area of the device. The time during which a stimulus pair was examined was determined by the participant (during the instructions, they were told to take the time needed to make an informed decision). However, the experimenter did control the inter-pair time by allowing approximately five seconds from each participant's response to the presentation of the next pair, so that the experimenter could change pairs. A rest period of two minutes occurred after the first half of the set. In order to obtain the inspection time for each pair, the experimenter pressed a key on a response pad when the pair was presented and when the participant had responded. The Super Lab Program was used to record the inspection times and the responses with an accompanying response pad. This program allowed for an accuracy of +/- 1 millisecond.

In general, visual-condition participants engaged in the same tasks as participants in the haptic condition, except that they were able to see the stimuli. As in the haptic condition, participants discriminated which of the two presented stimuli was smoother.

The instructions prior to the experimental session also instructed the participants to disregard the color of each stimulus. The colors of the stimulus materials are presented in Appendix E. Participants were instructed to look as closely at the stimuli as desired and at any angle without actually touching the stimuli. As in the haptic condition, the participants determined the examination time for each pair, and the time between pairs (approximately 5 seconds) was controlled by the experimenter.

Following the last trial, participants were asked several questions about the task (see Appendix G). The experimenter then answered any questions the participants had. Each participant was informed about the purpose of the experiment and dismissed.

Although I replicated as closely as possible the methodology of Experiment 2 in Heller (1989), there are a few differences between the current study and Heller's. The most noticeable difference between the two studies is the introduction of an additional surface, sandpaper, with the same grit values as those used by Heller. In the present experiment, intertrial intervals were controlled at five seconds whereas in Heller's experiment this time was not controlled. There is also a possibility that the orders used in the current experiment differed from those used by Heller, but it is impossible to confirm this one way or the other. It seems unlikely, however, that any of these between-experiment differences would result in a difference in outcome between this experiment and that of Heller.

<u>Experimental Design</u>

A 2 (modality – vision or touch) X 2 (surface – waterstone or sandpaper)X 2 (smoothness – smooth or rough) X 6 (stimulus pairs – 1*2, 2*3, 3*4, 4*5, 5*6, and 6*7) mixed design was employed with modality and surface varied between participants, and smoothness and stimulus pairs varied within participants. The dependent measures in this experiment were the number of correct responses for each pair given by each participant in each smoothness condition and the average inspection time for each "smoothness" condition. The maximum number of correct responses in each condition was 24 (4 for each pair). A mixed-analysis of variance was applied to the data for each dependent variable.

Table 1.

Experimental Design

	Modality			
	Visual		Haptic	
Surface Type	Smooth→Rough	Rough→Smooth	Smooth→Rough	Rough→Smooth
Waterstone	8	8	8	8
Sandpaper	8	8	8	8

Of interest, also, was the consistency and accuracy of the manufacturers' scales which were used to identify stimulus pairs' smoothness values. Therefore, a technique of optical profilometry was employed to obtain a smoothness value (expressed as micron equivalent) for each stimulus.

Predictions

If the accuracy results for both Heller and Bozoglu-Sinclair's studies are replicated, then there will be a three-way interaction of modality, surface and smoothness. This outcome would be in accord with Bozoglu-Sinclair's speculation that differences in surface were, at least in part, a contributing factor to the difference in outcomes.

Because the experiment is being carried out following Heller's procedure for both types of surface, it is perhaps more likely, however, that Heller's results would occur for both surfaces. In that case, a major finding would be that a first-order interaction involving modality and smoothness would occur, so that for rough stimuli no difference in accuracy would be observed between modalities, but for smooth stimuli, performance would be better for the haptic than for the visual modality.

If Bozoglu-Sinclair's results for inspection time are replicated not only for the sandpapers but also for waterstones, then there should be a significant effect for modality with the means for vision being substantially lower than the means for touch. For previous experiments in which inspection time has been examined (Bozoglu-Sinclair, 2001; Jones & O'Neal, 1985), either accuracy was equivalent for the two modalities (with rough stimuli) or the visual means were lower than the haptic means. It will be interesting to see whether, for the smoother stimuli, the previously-observed differences in inspection time hold (i.e., inspection-time being longer in the haptic condition than in the visual condition).

RESULTS

This section is divided into five parts. The first part presents the results for the analysis of variance on the dependent measure for accuracy. The second part provides the results on the dependent measure for inspection time. The third section presents the results for the optical profilometry. The fourth section provides data for the comparisons of the manufacturer scales to the measure obtained by optical profilometry and the final section presents data related to the effect of color on participants' judgments in the visual condition. An alpha level of .05 was employed in evaluating the results of each statistical test.

Accuracy as the Dependent Measure

Although the primary focus in this research was on the effects of the three variables (modality, surface and smoothness), there was also an interest in whether accuracy in judging stimulus pairs with the same micron values would be the same across treatments. Hence, the data[2] were subjected to a 2 X 2 X 2 X 6 mixed-analysis of variance with modality and type of surface as the between-participants variables and smoothness and stimulus pairs as the within-participants variables with stimulus pairs nested within smoothness.

The ANOVA revealed no significant main effects for modality, type of surface or smoothness. In addition, there were no significant interactions among these three variables. The means for each condition appear in Table 2. Note that there is little variation among the eight means.

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[2] Results have been modified to reflect data obtained from optical profilometry. More specifically, 180 was ranked as smoother than 320 and 600 was ranked as smoother than 800. Only the responses for these two pairs in the sandpaper condition were reversed. This will be discussed in further detail in a later section.

Table 2.

Mean Number Correct for Each Condition (maximum = 12)

	Modality			
	Visual		Haptic	
Surface Type	Smooth	Rough	Smooth	Rough
Waterstone	9.01 (.33)	10.20 (.61)	9.38 (.30)	10.19 (.34)
Sandpaper	9.50 (.46)	9.19 (.33)	9.25 (.57)	9.81 (.38)

Note. Values in parentheses are standard errors.

Including the pair variable in the analysis resulted in several statistically significant effects. These were the main effect for stimulus pair within smoothness $F(4,240) = 8.13$, $p<.0001$; two two-way interactions and a three-way interaction: modality X pair within smoothness $F(4,240) = 2.97$, $p<.05$; type X pair within smoothness $F(4,240) = 15.17$, $p<.0001$; and type X modality X pair within smoothness $F(4,240) = 6.87$, $p<.0001$. Table 3 presents the means for each of the main treatment conditions for each pair. The ANOVA summary table can be found in Table 4. Examination of the data in Table 3 indicates that for any of the three main independent variables considered, there is little consistency in accuracy. This is reflected in the fact that the greatest accuracy does not occur for one pair across all conditions nor is any particular pair the least accurate among all conditions.

Table 3.

Mean Number Correct for Each Pair in Each Condition (maximum = 12)

	Stimulus	Waterstone		Sandpaper	
Smoothness	Pair	Haptic	Visual	Haptic	Visual
Rough	1-2	3.69	3.44	2.31	2.50
Rough	2-3	3.50	3.88	3.56	3.06
Rough	3-4	3.00	2.88	3.94	3.63
Smooth	4-5	3.38	2.13	2.31	3.00
Smooth	5-6	4.00	3.63	3.38	2.94
Smooth	6-7	2.00	3.25	3.56	3.56

Table 4.

Analysis of Variance for Number Correct for Each Pair

Source	DF	F	Pr>F
Modality	1	0.25	0.6172
Type	1	0.45	0.5055
Type X Modality	1	0.00	1.0000
Error	60	(0.0873)	
Smoothness	1	3.51	0.0659
Modality X Smoothness	1	0.17	0.6787
Type X Smoothness	1	2.12	0.1503
Type X Modality X Smoothness	1	1.08	0.3029
Error	60	(0.0271)	
Pair(Smoothness)	4	8.13	<.0001
Modality X Pair(Smoothness)	4	2.97	0.0202
Type X Pair(Smoothness)	4	15.17	<.0001
Type X Modality X Pair(Smth)	4	6.87	<.0001
Error	240	(0.3735)	

Note. Values enclosed in parentheses represent error terms. Residual error = 0.5068.

<u>Inspection time as the dependent measure</u>

The results for inspection time were consistent with those from past research (Bozoglu-Sinclair, 2001; Jones & O'Neal, 1985) and previous speculation that there would be a significant main effect for modality. The only significant effects were for modality *F*(1,60) = 9.30 and smoothness *F*(1,60) = 7.26. Participants in the visual condition took less time to inspect the stimuli than those in the haptic condition. Also, rough pairs were examined more quickly than smooth pairs. No significant interactions were found between these three variables. The means for each condition are given in Table 5.

Table 5.

Inspection Time: Mean for Each Condition (in seconds)

	Modality			
	Visual		Haptic	
Surface Type	Smooth	Rough	Smooth	Rough
Waterstone	8.96 (1.00)	7.26 (3.89)	11.59 (0.99)	9.88 (2.37)
Sandpaper	7.33 (0.94)	5.96 (0.70)	10.26 (1.00)	10.97 (1.19)

Note. Values in parentheses are standard errors.

For the part of the analysis of variance that included the pairs, there were several statistically significant effects. These were the main effect for stimulus pair within smoothness *F*(4,240) = 8.34; two first-order interactions and one second-order interaction: modality X pair within smoothness *F*(4,240) = 6.64; type X pair within smoothness *F*(4,240) = 24.32; and type X modality X pair within smoothness *F*(4,240) = 6.20. Table 6 presents the means for each pair in each condition. The ANOVA summary table appears in Table 7. Again, there is little consistency in inspection-time among the three main variables. Also, there was no pair for which inspection-time was longest across all four conditions nor was there any pair for which it was the shortest.

Table 6.

Inspection Time: Mean for Stimulus Pairs in Each Condition (in seconds)

	Stimulus	Waterstone		Sandpaper	
Smoothness	Pair	Haptic	Visual	Haptic	Visual
Rough	1-2	2.6	2.8	4.8	2.2
Rough	2-3	3.4	1.6	3.8	2.1
Rough	3-4	3.9	2.9	2.3	1.6
Smooth	4-5	4.4	3.5	4.2	2.4
Smooth	5-6	2.3	1.9	2.9	3.4
Smooth	6-7	5.0	3.5	3.2	1.5

Table 7.

Analysis of Variance for Inspection Time for Each Pair

Source	DF	F	Pr>F
Modality	1	9.30	0.0034*
Type	1	0.53	0.4679
Type X Modality	1	0.40	0.5317
Error	60	(1.83E8)	
Smoothness	1	7.26	0.0091*
Modality X Smoothness	1	1.91	0.1717
Type X Smoothness	1	3.32	0.0733
Type X Modality X Smoothness	1	1.98	0.1647
Error	60	(9.41E6)	
Pair(Smoothness)	4	8.34	<.0001
Modality X Pair(Smoothness)	4	6.64	<.0001
Type X Pair(Smoothness)	4	24.32	<.0001
Type X Modality X Pair(Smth)	4	6.20	0.0001
Error	240	(1.21E8)	

Note. Values enclosed in parentheses represent error terms. Residual error = 2.00.
*$p < .05$.

Optical Profilometry

A Burleigh Horizon Non-Contact Optical Profilometer was used to measure the topography (discussed in more detail later) of each of the fourteen samples (7 sandpaper samples and 7 waterstone samples). The samples used for scanning were not those used in the experiment. However, the sandpaper samples were taken from the same sheets from which the experimental sections were taken. The optical profilometry provided a micron value for each of the samples (see Tables 8 & 9).

The manufacturer's ordering of the waterstone samples was consistent with the profilometry results, although the actual micron values given by the profilometry procedure differed from those provided by the manufacturer. For the sandpaper samples, the values provided by the manufacturer were again different from the profilometry values for each of the stimuli. However, there were also important differences in the ordering of the stimuli by the two measures (see Table 9).

Table 8.

Waterstone (JIS) Scale in Microns Compared with Optical Profilometry Scale

Grit Value (JIS)	Micron Equivalent[a]	Ra (roughness)[b]
220	~60	16.534
250	~30	14.138
800	~18	11.353
1000	~15	10.948
1200	~12	9.441
4000	~3	4.089
6000	~2	1.605

Note. [a] Micron equivalent refers to the original micron scale obtained from the manufacturers.
[b] Roughness values in microns based on optical profilometry.

Table 9.

Silicon Carbide (FEPA) Scale in Microns Compared with Optical Profilometry Scale

Grit Value (FEPA)	Micron Equivalent[a]	Ra (roughness)[b]
180	~60	15.063
320	~30	22.048
400	~18	17.313
600	~15	15.707
800	~12	21.021
4000	~3	12.519
6000	~2	6.638

Note. [a] Micron equivalent refers to the original micron scale obtained from the manufacturers.
[b] Roughness values in microns based on optical profilometry.

Comparison of OP Scale with Manufacturer Scale

Additional analyses were conducted to determine how well accuracy and inspection time were each predicted by the rankings from the manufacturer and from optical profilometry. A rank-order correlation was conducted between accuracy and each scale and likewise for inspection time. Table 10 presents the rank-order correlations for each condition and scale type. The rank-order correlations for the waterstones indicate that participants' rankings for accuracy and inspection time were positively correlated with the rankings provided by both the manufacturer and OP. In contrast, negative correlations were obtained for each of the sandpaper conditions. Since there were few degrees of freedom (i.e., 4), none of these correlations reached the $r = .90$ required for significance at the .05 level. However, there was consistency within type of surface in that participants in the waterstone condition were more accurate with rougher pairs while participants in the sandpaper condition were more accurate with the smoother pairs.

Table 10.

Rank-Order Correlations between the Manufacturer and Optical Profilometry Scales for Accuracy and Inspection-Time

Scale	Waterstone				Sandpaper			
	Haptic		Visual		Haptic		Visual	
	Accuracy	Time	Accuracy	Time	Accuracy	Time	Accuracy	Time
Manufacturer	.81	.81	.64	.73	-.34	-.47	-.67	-.44
Optical Profilometry	.54	.49	.83	.66	-.63	-.34	-.77	-.67

An additional rank-order correlation was conducted between accuracy and inspection time for each of the four main treatment conditions. Each of the correlations was positive, with two of the four reaching significance. Thus, inspection-time was greater for pairs judged accurately than for those judged inaccurately. Table 11 presents the rank-order correlations for each condition.

Table 11.

Rank-Order Correlations between Accuracy and Inspection Time for each Condition

Surface Type	Haptic	Visual
Waterstone	.94*	.94*
Sandpaper	.80	.77

Note. * significant at .05 level.

As mentioned previously and shown in Table 9, for two of the sandpaper pairs, 180-320 and 600-800, the relationship of the micron values as provided by the manufacturer was opposite to the relationship indicated by optical profilometry. To determine whether performance for each pair in each condition was better predicted by one of these scales or the other, t-tests were done. Each of the four t-tests was significant. In each case, the OP scale was a better predictor of accuracy for each of the pairs. For the haptic condition, the results are as follows: Pair 180-320, $t(14) = 3.50$, and Pair 600-800, $t(14) = 3.50$. For the visual condition: Pair 180-320, $t(14) = 5.59$, and Pair 600-800, $t(14) = 11.19$. The means for each condition using both optical profilometry ordering and manufacturer ordering for sandpaper appear in Table 12.

Table 12.

Mean for Stimulus Pairs in each Silicon Carbide Condition for the Manufacturer and OP Scales

	Haptic		Visual	
Scale	180-320	600-800	180-320	600-800
Manufacturer	1.69	1.69	1.50	1.00
Optical Profilometry	2.31	2.31	2.50	3.00

Note. Maximum score is 4. These values are mutually constrained. “Incorrect” answers were reversed to be “correct” for the second analysis of each pair.

Relationship Between Color and Smoothness Judgments

As pointed out earlier, the waterstones employed in this experiment differed in color as did the sandpaper stimuli (see Appendix E). Each participant in the visual conditions was instructed to disregard the color of the surfaces and make smoothness judgments based solely on texture. At the completion of the experiment, each visual participant was asked if the color of the surfaces affected their judgments of the surfaces (Question 4). Twenty-one participants (65%) indicated that color did affect their judgments while 11 indicated that color had no effect on their judgments.

DISCUSSION

This experiment was done to determine whether, as proposed by Bozoglu-Sinclair (2001), the difference in outcome between her experiment and that of Heller (1989, Experiment 2) may have been attributable, at least in part, to differences in the type of surface used in the two experiments. Heller provided evidence that, for waterstone surfaces, individuals performed better with touch than with vision in the discrimination of smooth surfaces. With rough surfaces, vision and touch were equally accurate. Bozoglu-Sinclair found, however, that individuals performed better with vision in the discrimination of smooth surfaces, and equally well with touch and vision for rough surfaces.

This discussion will focus on those parts of the analyses that deal with the three main independent variables, modality, smoothness, and type of surface. This study's results differed from those of Heller (1989, Experiment 2) and of Bozoglu-Sinclair (2001) in that, with respect to accuracy, performance was equivalent for touch and vision, independent of both the type and the smoothness of the surface. Thus, neither the results of Heller nor of Bozoglu-Sinclair for smooth stimuli were replicated, nor did the findings support Bozoglu-Sinclair's speculation that the difference in outcomes between the two studies may have been at least partly attributable to the difference in the type of surfaces employed in the two experiments. It should be mentioned, however, that the equivalence in accuracy between vision and touch for the rough stimuli replicates the findings of Heller and of Bozoglu-Sinclair, as well as those of other experiments (Heller, 1982; Jones and O'Neal, 1985). It is not clear why the results for smooth stimuli in this experiment differed from those of the other two, especially from Heller's whose procedure was substantially replicated. The only differences between the procedure for this experiment, for the waterstone condition, and that used by Heller are that there was a standard 5-second interval between pairs, whereas that interval was not controlled by Heller. The orders used in this experiment may have also differed from those employed by Heller. It does not seem likely, however, that these small differences (either individually or in combination) would have contributed to the difference in outcomes for the smooth pairs.

How is it, then, that I substantially replicated what Heller did but did not find the same results? As mentioned previously, examination of the accuracy means for each study indicates that the largest discrepancy between the two studies is in the Visual/Smooth waterstone condition. In that condition, my participants out-performed Heller's; in other conditions they performed comparably. In contrast, Heller's participants in the Visual/Smooth condition performed slightly below chance level and much below the performance of those in the other conditions. Therefore, the answer to this question could lie within this cell. One suggestion would be to look at the questions asked of each participant in the visual condition to assess who indicated that they were or were not affected by color. As mentioned earlier, this type of post-experimental analysis was used in this study. However, there was no difference in accuracy between those who said they were affected by color and those who did not, either overall or, more specifically, for this cell. This does not appear to have been a factor contributing to the between-experiment difference in outcomes in the Visual/Smooth waterstone condition.

Bozoglu-Sinclair's findings, however, were replicated with respect to inspection time, for both smooth and rough stimuli for the sandpaper pairs. Those in the visual condition spent less time examining these pairs than did those in the haptic condition. Results were the same for the waterstone pairs. Also, inspection time was less for rough pairs than for smooth pairs. This may be due to the greater micron differences between the rough than the smooth pairs.

There were, of course, many more methodological differences between the present experiment and that of Bozoglu-Sinclair (2001). As mentioned previously, these were: 1) type of surface, 2) range of grit values, 3) area of stimulus exposure, 4) range of colors, 5) instructions about color, 6) type of presentation, 7) type of response, and 8) experimental design. Whether any one or combination of these differences contributed to the results of this experiment and those of Bozoglu-Sinclair in accuracy judgments of smooth sandpaper pairs might, of course, be examined in additional research.

Some Methodological Concerns

A review of the literature comparing vision and touch on texture discrimination combined with the optical profilometry results suggest one major concern. In addition to the micron equivalents that are available for stimuli from scales provided by the manufacturers of abrasive papers and waterstones, information about roughness is available through optical profilometry. The average roughness value (Ra) is the scale used in this study since it appeared to be similar to the manufacturer's scale in that it was measurable in microns. However, further examination of the two micron scales indicated that whereas the manufacturers' micron scales refer to the actual size of the particle, our

OP micron scale refers to the average distance in microns between particles. Tables 8 and 9 present the micron values for the stimuli used in this experiment as determined by the manufacturers and by optical profilometry.

There are several items to be noted in these tables:

1) Items from the two manufacturers' scales which have the same micron equivalents (e.g., 40-μ) differ both in grit value (e.g., 180 FEPA; 220 JIS) and in roughness (e.g., Ra = 15.063 and 16.534). This is the case for all seven of the stimuli used in this experiment.
2) The range in optical profilometry roughness values (6.638-22.048 for FEPA-scale stimuli, and 1.605-16.534 for JIS-scale stimuli) is noticeably shorter than the range of micron equivalents for these stimuli provided by the manufacturer (i.e., ~2 - ~60).
3) As grit values increase on the JIS scale, micron equivalents and roughness values decrease. For the FEPA scale, there is again a negative relationship with micron equivalents, but not with roughness. There are two pair-wise reversals, one involving 180 and 320 and the other involving 600 and 800. In addition to these two pair-wise reversals, as a sequence of values, there were much greater inconsistencies present.

Items 2 and 3 suggest that the micron equivalents determined by OP reflect a different characteristic of the stimuli than do the scales used by the manufacturer. Also important to note is that the micron equivalents provided by the manufacturer do not take into account a number of other aspects of the stimuli. For instance, the micron equivalent does not reflect any other characteristic but the average height or width of the particles. The micron equivalent does not refer to the actual distribution of the particles on the surface or to any other compounds that may be added to the surface (i.e., adhesives, side resins, or anti-loading agents), which may affect the perceived roughness of the surface (D. Billig, personal communication, August 1, 2002). Optical profilometry, however, does take these other characteristics of the surfaces into account for roughness measures. Consider the case of the 180 sandpaper being smoother in roughness value than the 320 paper. This reversal was actually due to another compound, Zinc Stearate, which is applied to very coarse surfaces to enhance sanding. The OP identified this difference whereas the manufacturer's scale did not.

When the data for accuracy are based on OP, results change. An initial ANOVA was conducted on the data before the scanning of the stimuli and as pointed out earlier, this scan revealed that two of the pairs in the sandpaper condition were in fact assigned different micron values. Fortunately, the scans revealed this anomaly so that the data set could be changed to examine the participants' judgments of those pairs in relation to the OP order. When this was done, a different effect with respect to type of surface emerged. In the initial ANOVA, the results showed that there was a significant main effect for type of surface $F(1,60) = 14.65$, $p <. 001$. After correction, the main effect for type of surface was not significant $F(1,60) = .45$, $p >.05$. This difference in outcomes illustrates the importance of scanning to assess the surfaces used in tactile research. If scanning had not been done, the conclusions of this study would have been different.

There is one additional implication of these profilometry results. If the pairs had been established using the OP ordering, then the rough sandpaper pairs would have been 320-400, 400-600 and 600-180 and the smooth sandpaper pairs would have been 800-600, 600-4000 and 4000-6000. Thus, had OP been conducted prior to the experiment, different pairs would have been chosen since the true adjacent stimuli would have been different , yielding perhaps a different set of results

Concerns About Scaling Based on Scans

It is important to recognize some of the limitations of optical profilometry. In some instances where surfaces may be grossly irregular (e.g., small cracks or deep holes in the surface), the roughness value for two seemingly different surfaces could have the same Ra value. This would be due, in part, to the fact that the Ra of a surface is not sensitive to the spatial distribution of surface heights (Michigan Metrology, LLC, 2002). The surfaces in this study, however, appeared to me to be uniformly distributed (see Appendix H).

The issue of measurement difficulties relates to a more general concern that must be addressed when scanning surface texture and that is the reliability of the scans. Therefore, each surface was scanned twice (two different areas of the same ½ x ½-in section) to test the reliability of the scans. For each section, the results for the second scan were comparable to those of the initial scan (Additional scans were not possible due to lack of funding.) For the four sandpaper values in question, a third scan was done on the same surface but in a different area of the same section to validate the first two. The additional scan supported the findings for each of the four surfaces. Examination of Table 13 reveals the roughness value for each of the two scans conducted on each section and the additional scan conducted on the four surfaces in question. Note the high agreement of the three scans for these four surfaces.

Table 13.

Roughness Values Obtained from Optical Profilometry for Each Stimulus

Sandpaper	Ra Value			Waterstone	Ra Value	
	(1)	(2)	(3)		(1)	(2)
180	15.06	15.32	14.32	220	16.53	16.52
320	22.05	22.04	21.76	250	14.04	14.73
400	17.31	17.41		800	11.35	11.73
600	15.71	14.90	15.36	1000	10.95	9.89
800	21.02	22.05	21.51	1200	9.44	9.06
4000	12.52	13.01		4000	4.09	4.97
6000	6.64	6.12		6000	1.61	1.96

Note. Parenthetical values refer to the first, second, and third OP scans.

Another concern about scaling based on scans is similar to the first in that the actual sandpaper sections used throughout the experiment could not be scanned to obtain roughness values, because there were two exchanges of stimulus materials in the sandpaper conditions. The waterstones used in this study, on the other hand, could not be placed directly under the microscope. Instead, a flat surface had to be chipped off the corner of each stone to obtain a roughness value. Thus, for both stimuli, the actual stimuli examined visually or haptically were not scanned by OP. In fact, the roughness (Ra) values from optical profilometry presented in this study were obtained from a different area of the stimulus paper and waterstone than those examined by the participants, limiting our OP roughness values to just a ½ x ½-in square taken from each stimulus.

One final note is that the difference in microns between 800 and 1000 is equal to that between 1000 and 1200 for the JIS scale, whereas for the OP results, the 1000-1200 difference is greater than the 800-1000 difference. The same is true for equivalent scale values in the sandpaper condition. This may call into question the accuracy of the OP values with respect to these four pairs. However, since the two scales are measuring two different aspects of the surface, this difference may be attributable to the difference in type of measure.

Limitations of the Present Study

This study has some limitations. First, when participants rubbed the index finger against the abrasive surfaces, it is likely that some material was deposited (e.g., dirt, oil, epithelial cells, etc.) onto the surfaces. Although the surfaces were changed after every 8^{th} participant in the sandpaper condition, some material would have probably collected over time. A scan of each surface at various points in the experiment would have been desirable and might have indicated changes in roughness of the surfaces with usage, since changes in the surface Ra value could have occurred due to the additional rubbing of a surface. If so, this could have affected haptic discrimination more than visual discrimination.

Another limitation to this study is that, as in previous research, the stimuli varied in color. Unfortunately, the waterstones were of several colors, as were the sandpapers. Examination of Tables E1 and E2 indicates that although the sandpaper stimuli varied less in color than the waterstones, the variation in both is still apparent. Although participants in the visual condition were instructed not to attend to the colors of the stimuli, many indicated that they did. Future research would benefit if stimuli with exactly the same colors could be identified and incorporated into the research.

Future Research

This study was conducted to assess the performance of vision and touch with both smooth and rough surfaces of two different types, waterstone and sandpaper. The results replicated the finding of earlier studies (Bozoglu-Sinclair, 2001; Heller, 1982; 1989; Jones and O'Neal, 1985) that found that participants in vision and touch conditions performed equally well with rough stimuli. With smooth stimuli, however, the results were the same as with the rough stimuli, thus replicating neither the better performance for touch (Heller, 1989, Experiment 2) with the waterstone pairs nor the better performance for vision (Bozoglu-Sinclair, 2001) with the sandpaper pairs. The results from this study appear to be more consistent with Loomis' (1981) spatial-filtering hypothesis than with Katz's (1925) position that touch surpasses vision in judgments of smoother surfaces, in that the two modalities performed equivalently for both smooth and rough surfaces.

When optical profilometry was done, there were two important consequences: 1) for both surface types, there was a big difference in magnitude between micron equivalents as determined by OP and by the manufacturer, especially for the rough stimuli; 2) with respect to sandpaper, the OP revealed a different rank position for four of the stimuli, two rough and two smooth, than was provided by the manufacturer. Nevertheless, results were consistent with past research for rough stimuli before and after correction.

Research on the influence of color on texture judgments is another direction that may help explain the differences in outcome between this experiment and those of Bozoglu-Sinclair (2001) and of Heller (1989, Experiment 2). For instance, it would be of interest to observe whether if each stimulus were coated in the same color, the results from this experiment or from either of the others would be replicated. Furthermore, would coating the stimuli affect the measurements obtained from optical profilometry? It would be desirable, also, to conduct a study which employs a surface that is uniform in color, adhesive, backing, and other characteristics which have been found possibly to affect texture perception. We have recently been informed about such a surface (D. Billig, personal communication, August 1, 2002), a lapping film, which sounds as though it would be an ideal surface for such research.

If, however, such a surface is not available, then it would be desirable to examine the effect of the type of instructions relevant to the use of color. Such an experiment could have four groups. One group would be instructed only to attend to texture while another group would be instructed to attend only to color. A third group would be instructed to use both color and texture and the fourth group would not be given instructions about either characteristic.

Concluding Statement

Results of this experiment did little to help explain the difference in outcome between the experiments of Heller (1989, Experiment 2) and Bozoglu-Sinclair (2001). Accuracy was not affected by the main independent variables (modality, smoothness, and type of surface). Inspection time, however, was affected by smoothness of the surface and by modality in that participants in the haptic and rough conditions took less time to examine the stimuli than did those in the haptic and smooth conditions, respectively. Likewise, participants in the Visual/Rough conditions took less time to examine the stimuli than those in the Visual/Smooth conditions. Of particular interest in this study was the use of optical profilometry which appears to show some promise in evaluation of stimuli for use in further tactile research.

It is not clear if participants' performance in the Visual/Smooth waterstone condition was facilitated by color. If so, then the difference in outcome between those participants and Heller's in that condition might be explained. Unfortunately, Heller did not report if his participants were affected by color. In addition, it may be that the illumination conditions in his experiment may have resulted in the color's being less salient than in our experiment. These results present a strong case for seeking abrasive materials which vary only in texture, if such stimuli are to be used in texture-discrimination experiments in which there is a visual condition.

The present experiment provides the following new information: 1) inspection time is shorter in the haptic condition for rough than smooth stimuli, perhaps due to the greater micron difference among the rough than among the smooth stimuli used in this experiment, 2) there was no difference in accuracy or inspection-time for rough or smooth haptically-examined stimuli between the two types of surfaces, 3) accuracy in texture discrimination is sometimes better predicted by optical profilometry roughness values than by a manufacturer's scale of particle size, and 4) that accuracy and inspection time were positively correlated in that as accuracy increased so did inspection time and, of course, as inspection time increased so did accuracy.

The texture of materials is affected by a number of physical characteristics (e.g., side resin, adhesive, particle size, particle shape, particle distribution) which in turn may affect haptic and visual discrimination. The effects of these various characteristics have been little studied and the need for future research is indicated.

References

Bjorkman, M. (1967). Relations between intra-modal and cross-modal matching. *Scandinavian Journal of Psychology, 8,* 65-76.

Bozoglu-Sinclair, B. (2001). *Effects of stimulus characteristics and instructions on intramodal and crossmodal discrimination of texture.* Unpublished doctoral dissertation, North Carolina State University, Raleigh.

Freides, D. (1974). Human information processing and sensory modality: Cross-modal functions, information complexity, memory and deficit. *Psychological Bulletin, 81,* 284-310.

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

Grant, A. C., Thiagarajah, M. C., & Sathian, K. (2000). Tactile perception in blind braille readers: A psychophysical study of acuity and hyperacuity using gratings and dot patterns. *Perception and Psychophysics, 62,* 301-312.

Heller, M. A. (1982). Visual and tactual texture perception: Intersensory cooperation. *Perception and Psychophysics, 31,* 339-344.

Heller, M. A. (1989). Texture perception in sighted and blind observers. *Perception and Psychophysics, 45,* 49-54.

Japan Woodworker. (2001, March). Abrasive-Grade Comparison Chart.

Jones, B. (1981). The developmental significance of cross-modal matching. In. R. D. Walk & H. L. Pick, Jr. (Eds.), *Intersensory Perception and Sensory Integration* (pp. 109-136). New York: Plenum Press.

Jones, B., & O'Neal, S. (1985). Combining vision and touch in texture perception. *Perception and Psychophysics, 37,* 66-72.

Katz, D. (1989). *The world of touch.* (L. E. Krueger, Ed. and Trans.). New Jersey: Lawrence Erlbaum Associates (Original work published 1925).

Lederman, S. J., Thorne, G., & Jones, B. (1986). Perception of texture by vision and touch: Multidimensionality and intersensory integration. *Journal of Experimental Psychology: Human Perception and Performance, 12,* 169-180.

Loomis, J. M., (1981). Tactile pattern perception. *Perception, 10,* 5-27.

Merriam-Webster's Collegiate Dictionary (10^{th} ed.). (1993). Springfield, MA: Merriam-Webster.

Michigan Metrology, LLC (2002, May 15). 3D Surface texture parameters. Retrieved from http://www.michmet.com/3d_surface_texture_parameters.htm.

Miyaoka, T., Mano, T., & Ohka, M. (1999). Mechanisms of fine-surface-texture discrimination in human tactile sensation. *Journal of the Acoustical Society of America, 105,* 2485-2492.

Newman, S. E., Hall, A. D., Foster, D. L., & Gupta, V. G. (1984). Learning as a function of haptic discriminability among items. *American Journal of Psychology, 97*, 359-372.

Ross, H. E., & Murray, D. J. (1996). Preface. In H. E. Ross & D. J. Murray (Ed. and Trans.), E.H. Weber on the Tactile Senses. United Kingdom: Erlbaum (UK) Taylor & Francis. (Original work published 1878).

Sathian, K. (1989). Tactile sensing of surface features. *Trends in Neuroscience, 12,* 513-519.

Stevens, J. C., & Patterson, M. Q. (1995). Dimensions of spatial acuity in the touch sense: Changes over the life span. *Somatosensory and Motor Research, 12,* 29-47.

3M, Superabrasives & Microfinishing Systems (2001, August). Abrasive-Grade Comparison Chart.

Zinchenko, V. P., & Lomov, B. F. (1960). The functions of hand and eye movements in the process of perception. *Problems of Psychology, 1,* 12-26.

Appendix A

Scores on Each Dependent Variable for Each Participant

Participant	Gender	Modality	Order	Type	Smooth	Rough	Total Correct	Mean Time (ms)
1	Female	Vision	B	Paper	4	8	12	9850
2	Male	Haptic	B	Stone	10	12	22	13369
3	Female	Haptic	B	Paper	10	12	22	6352
4	Male	Haptic	B	Paper	11	11	22	15338
5	Male	Haptic	A	Stone	11	11	22	10613
6	Female	Vision	B	Stone	10	9	19	5347
7	Female	Haptic	B	Stone	10	10	20	6726
8	Male	Haptic	A	Stone	10	12	22	10149
9	Female	Haptic	B	Stone	9	11	20	7119
10	Female	Vision	A	Stone	9	12	21	2844
11	Female	Haptic	B	Paper	8	10	18	12360
12	Male	Vision	A	Paper	11	9	20	5230
13	Female	Haptic	A	Paper	9	10	19	18548
14	Male	Vision	B	Paper	11	10	21	7712
15	Male	Haptic	B	Paper	10	12	22	6329
16	Male	Vision	A	Stone	9	11	20	12166
17	Female	Vision	A	Paper	6	10	16	3634
18	Female	Haptic	A	Paper	11	11	22	9772
19	Male	Vision	B	Stone	11	12	23	12823
20	Male	Haptic	A	Paper	2	6	8	6391
21	Male	Vision	B	Stone	12	10	22	6261
22	Male	Vision	A	Stone	9	12	21	3683
23	Female	Vision	A	Paper	9	6	15	2089
24	Male	Vision	B	Paper	12	11	23	1980
25	Male	Haptic	B	Stone	10	9	19	5855
26	Male	Vision	A	Paper	4	9	13	9610
27	Female	Haptic	A	Stone	10	9	19	10944
28	Female	Vision	B	Paper	9	11	20	9962
29	Female	Haptic	A	Stone	8	11	19	11181
30	Female	Vision	A	Stone	10	11	21	9329
31	Female	Vision	B	Stone	8	11	19	5093
32	Male	Haptic	A	Paper	8	10	18	10786
33	Female	Haptic	B	Stone	7	8	15	9914
34	Female	Vision	B	Paper	10	6	16	3299
35	Male	Haptic	A	Stone	9	10	19	8637
36	Female	Vision	B	Stone	10	3	13	13380
37	Female	Vision	B	Paper	12	12	24	3422

38	Female	Haptic	B	Paper	11	8	19	5898
39	Male	Vision	A	Paper	12	11	23	2021
40	Female	Vision	A	Stone	9	8	17	6514
41	Male	Vision	B	Paper	11	5	16	2885
42	Female	Haptic	A	Stone	8	10	18	3756
43	Male	Haptic	A	Paper	9	10	19	6131
44	Female	Haptic	B	Paper	10	8	18	7431
45	Male	Vision	A	Stone	7	11	18	7539
46	Male	Vision	B	Paper	12	8	20	2122
47	Female	Haptic	A	Paper	8	11	19	3847
48	Male	Haptic	A	Paper	12	9	20	8383
49	Female	Vision	A	Paper	8	10	18	8111
50	Male	Haptic	B	Stone	10	9	19	4773
51	Female	Haptic	A	Stone	10	10	20	10483
52	Female	Vision	A	Paper	10	9	19	6597
53	Male	Vision	B	Stone	10	10	20	3315
54	Female	Vision	B	Stone	11	10	21	8256
55	Female	Vision	A	Stone	9	8	17	3364
56	Male	Vision	A	Stone	11	10	21	3993
57	Male	Haptic	B	Paper	10	10	20	13625
58	Male	Haptic	A	Stone	9	10	19	5510
59	Male	Haptic	B	Stone	10	11	21	16285
60	Female	Haptic	B	Stone	12	7	19	7480
61	Female	Haptic	A	Paper	9	10	19	3242
62	Male	Vision	A	Paper	11	12	23	9978
63	Male	Haptic	B	Paper	10	9	19	7160
64	Male	Vision	B	Stone	8	6	14	4243

Appendix B

Grit Values and Their Micron Equivalents Provided by the Manufacturer

Table B1

Micron Equivalents of Silicon Carbide and Japanese Waterstones based on Manufacturer Scales

Abrasive Paper Value (FEPA)[a]	Micron Equivalent	JIS Value (waterstone)[b]
180	~60	220
320	~30	250
400	~18	800
600	~15	1000
800	~12	1200
4000	~3	4000
6000	~2	6000

Note. [a]Sandpaper values and micron equivalents obtained from 3M, Superabrasives & Microfinishing Systems Abrasive-Grade Comparison Chart (8/2001)

[b]JIS values and micron equivalents obtained from Japan Woodworker Abrasive-Grade Comparison Chart (3/2001).

Appendix C

Stimulus Pairs for Waterstones and Silicon Carbide Abrasive Paper

Table C1

Waterstone Stimulus-Pairs

Smooth	Rough
1000-1200	220-250
1200-4000	250-800
4000-6000	800-1000
1200-1000	250-220
4000-1200	800-250
6000-4000	1000-800

Table C2

Sandpaper Stimulus-Pairs

Smooth	Rough
600-800	180-320
800-4000	320-400
4000-6000	400-600
800-600	320-180
4000-800	400-320
6000-4000	600-400

Appendix D

Stimulus-Pair Orders for Waterstones and Silicon Carbide Abrasive Paper

Table D1

Visual and Haptic Stimulus-Pair Orders for Japanese Waterstone Condition (220-6000)

Order A	Order B
1. 4000-1200	1. 220-250
2. 4000-6000	2. 800-1000
3. 1200-1000	3. 250-800
4. 1200-4000	4. 250-220
5. 6000-4000	5. 1000-800
6. 1000-1200	6. 800-250
7. 1200-4000	7. 800-1000
8. 6000-4000	8. 250-220
9. 4000-1200	9. 250-800
10. 1000-1200	10. 1000-800
11. 4000-6000	11. 800-250
12. 1200-1000	12. 220-250
13. 220-250	13. 1200-1000
14. 800-250	14. 4000-6000
15. 1000-800	15. 1000-1200
16. 250-800	16. 4000-1200
17. 250-220	17. 6000-4000
18. 800-1000	18. 1200-4000
19. 800-250	19. 1000-1200
20. 1000-800	20. 6000-4000
21. 250-220	21. 1200-4000
22. 250-800	22. 1200-1000
23. 800-1000	23. 4000-6000
24. 220-250	24. 4000-1200

Table D2

Visual and Haptic Stimulus-Pair Orders for Silicon Carbide Condition (180-6000)

Order A	Order B
1. 4000-800	1. 180-320
2. 4000-6000	2. 400-600
3. 800-600	3. 320-400
4. 800-4000	4. 320-180
5. 6000-4000	5. 600-400
6. 600-800	6. 400-320
7. 800-4000	7. 400-600
8. 6000-4000	8. 320-180
9. 4000-800	9. 320-400
10. 600-800	10. 600-400
11. 4000-6000	11. 400-320
12. 800-600	12. 180-320
13. 180-320	13. 800-600
14. 400-320	14. 4000-6000
15. 600-400	15. 600-800
16. 320-400	16. 4000-800
17. 320-180	17. 6000-4000
18. 400-600	18. 800-4000
19. 400-320	19. 600-800
20. 600-400	20. 6000-4000
21. 320-180	21. 800-4000
22. 320-400	22. 800-600
23. 400-600	23. 4000-6000
24. 180-320	24. 4000-800

Appendix E

Stimulus Colors for Waterstones and Silicon Carbide Abrasive Paper

Table E1

Japanese Waterstone Colors

Waterstone Grit Value	Corresponding Color
220	Green
250	Blue-Green
800	Brown
1000	Medium Brown
1200	Dark Brown
4000	Gray
6000	Yellow-Brown

Table E2

Silicon Carbide Colors

Sandpaper Grit Value	Corresponding Color
180	Blue-Gray
320	Charcoal
400	Black
600	Charcoal
800	Charcoal
4000	Dark Gray
6000	Gray

Appendix F

Informed Consent Forms for Each Condition

North Carolina State University
INFORMED CONSENT FORM

Effects of Type and Smoothness of Surface and of Modality on Discrimination of Texture

<u>Christina Costanzo Mendat</u> <u>Slater E. Newman, Ph.D.</u>

You are invited to participate in a research study. The purpose of this study is to examine the effects of different types of surfaces on the perception of texture.

INFORMATION
(Vision Condition)
In this experiment, you are going to be comparing different surfaces. You will be able to see the surfaces and look as closely as you need to. You will not, however, be able to touch the surfaces. The surfaces will be presented to you side-by-side and you will be asked which of the two is smoother. There will be a total of 24 pairs of surfaces. This experiment should take between 30-40 minutes.

(Haptic Condition)
In this experiment, you are going to be comparing different surfaces. You will be able to touch the surfaces as long as you need to. You will not, however, be able to look at the surfaces. The surfaces will be presented to you side-by-side and you will be asked to feel each of them and to indicate which of the two is smoother. There will be a total of 24 pairs of surfaces. This experiment should take between 30-40 minutes.

RISKS
(Vision Condition)
We do not foresee any risks associated with this experiment. If you feel uncomfortable at any time, please let me know.

(Haptic Condition)
We do not foresee any risks associated with this experiment. If you feel uncomfortable at any time, please let me know.

BENEFITS
We are interested in the way in which individuals are able to perceive and discriminate various textures. This study includes surfaces that have not been used a great deal in the examination of texture perception. We hope to contribute new knowledge to the research in tactile perception. As a participant, we hope that you will learn how psychology experiments are carried out on texture discrimination.

CONFIDENTIALITY
The information in the study records will be kept strictly confidential. Data will be stored securely and will be made available only to persons conducting the study unless you specifically give permission in writing to do otherwise. No reference will be made in oral or written reports which could link you to the study.

COMPENSATION
For participating in this study you will receive 2 research credits. Other ways to earn the same amount of credit are writing a relevant paper in psychology or participating in other research studies. If you withdraw from the study prior to its completion, you will receive credit for the time you have participated.

CONTACT

If you have questions at any time about the study or the procedures, you may contact the researcher, Christina Costanzo Mendat, at 209 Twin Oaks Place Cary, NC 27511, or 513-3417 If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Dr. Matthew Zingraff, Chair of the NCSU IRB for the Use of Human Subjects in Research Committee, Box 7514, NCSU Campus (919/513-1834) or Mr. Matthew Ronning, Assistant Vice Chancellor, Research Administration, Box 7514, NCSU Campus (919/513-2148)

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be returned to you or destroyed.

CONSENT

I have read and understand the above information. I have received a copy of this form. I agree to participate in this study.

Subject's signature____ **Date** _________________

Investigator's signature___________________________________ **Date** _________________

Appendix G

Experimental Instructions for Each Condition

Vision Instructions – Experiment 1 February 2002

Informed Consent Form

Please read this Informed Consent Form. It will tell you about this experiment and your rights and responsibilities as a participant. If you decide to participate in this study, please sign at the bottom of the form.

Information

Before we begin I need to get some information from you. Please take a few moments now to complete this index card with the following information:

Name ***Date of Birth*** ***Psy 200 Section***

Introduction

Hello! My name is Christina Costanzo Mendat and I am a graduate student in Psychology here at State. I am going to read these instructions to you to make sure that I say everything I need to say.

The experiment you are going to serve in today is aimed at studying the role of vision/touch in the discrimination of surface-texture with Japanese Waterstones and Silicon Carbide abrasive paper. In your case, you will be in the vision condition.

The Psychology Department here sponsors this study at State. The results will be kept confidential and will in no way affect your status here at State or later on.

In accord with the ethical principles of the American Psychological Association, I am informing you that you are free to leave this experiment at any time without penalty.

You may have noticed that a fan is operating in the room today. The purpose of the fan is to help mask any unwanted noise, which may occur.

Overview

In this experiment, you will be presented with pairs of textured surfaces. Your job will be to tell me which of the two surfaces is "smoother."

Before I tell you how we are going to proceed, I would like to tell you briefly about the materials we will be using today. Behind this device I have some blocks. On each of these blocks is one abrasive surface. With the aid of this device (point to it) each pair will be presented to you side-by-side in this area (point to the area).

Procedure

Now here is how we are going to proceed. You will be examining a total of 24 pairs of surfaces. The surfaces will be presented side-by-side in the open area of this device. You will be able to see the surfaces in this area. Each pair will be presented to you in this same area. (Point to it for 5 seconds) You can look at each surface without contacting them.

When the first pair is presented I will say "Pair One." At that time a pair of surfaces will be presented and you should look and compare the surfaces. You can visually examine both of the surfaces as long as you wish. When you think you know which of the two surfaces in the pair is smoother, you will point (without touching) the one you believe is smoother. Make sure you point to the surface and look at me when you have decided which one is smoother. I will say, "OK," and you can rest until I say "Pair Two," and you will visually examine the next pair to see which of the two is smoother and so on. We will proceed in this way until we finish the first 12 pairs and we will have a rest period for about 2 minutes. After the rest period, we will proceed in the same way until we have finished up the last 12 pairs. I want to let you know that when you are choosing which surface is smoother, there is no penalty for guessing. So, even if you can't tell which one is smoother, please make an educated guess.

During this experiment, I want you to wear these gloves on your hands.

I also want to inform you that the surfaces in the pairs you will be presented will vary in color. I would like you to disregard the color of those surfaces and base your judgment solely on the texture of each surface.

OK. Do you have any questions before we start the actual experiment? If you do, please ask them now because I am not able to answer any questions once the experiment has started. Please make sure you are comfortable in your chair. Do you have any questions at all?

OK. Let's Begin......"Pair One, OK."...............

Wrap-up:

Thank you very much for your time. Now, before you leave there are a few questions I would like to ask you.

1) Was there any particular method you used in choosing the smoother surface?
2) Do you know of any reasons that you may have had difficulty in examining the surfaces?
3) Did you notice any difference in color of the surfaces?
4) Did the color of the surfaces affect you in determining which was the smoother surface of the pair?
5) With which hand do you write?
6) With which hand do you throw a ball?

Before you leave, there are a couple of items I would like to mention. First, The purpose of this experiment is to examine the effects of touch, vision, and smoothness on the perception of texture. In your condition, you were able only to see the surfaces while others are able only to feel the surfaces. You examined both smooth and rough surface textures that each group is exposed to.

Also, I would like to ask you to not mention this experiment to anyone else once you leave here today. The reason is that someone you know may participate in this experiment. As you might guess, if anyone knows about the experiment before they come, it may bias the results of the experiment. We would appreciate it, then, if you said nothing about this experiment to anyone else, OK? Thank you again for your time!

Haptic Instructions – Experiment 1 February 2002

Informed Consent Form

Please read this Informed Consent Form. It will tell you about this experiment and your rights and responsibilities as a participant. If you decide to participate in this study, please sign at the bottom of the form.

Information

Before we begin I need to get some information from you. Please take a few moments now to complete this index card with the following information:

Name ***Date of Birth*** ***Psy 200 Section***

Introduction

Hello! My name is Christina Costanzo Mendat and I am a graduate student in Psychology here at State. I am going to read these instructions to you to make sure that I say everything I need to say.

The experiment you are going to serve in today is aimed at studying the role of vision/touch in the discrimination of surface-texture with Japanese Waterstones and Silicon Carbide abrasive paper. In your case, you will be in the touch condition.

The Psychology Department here sponsors this study at State. The results will be kept confidential and will in no way affect your status here at State or later on.

In accord with the ethical principles of the American Psychological Association, I am informing you that you are free to leave this experiment at any time without penalty.

You may have noticed that a fan is operating in the room today. The purpose of the fan is to help mask any unwanted noise, which may occur.

Overview

In this experiment, you will be presented with pairs of textured surfaces. Your job will be to tell me which of the two surfaces is "smoother."

Before I tell you how we are going to proceed, I would like to tell you briefly about the materials we will be using today. Behind this device I have some blocks. On each of these blocks is one abrasive surface. With the aid of this device (point to it) each pair will be presented to you side-by-side in this area (point to the area).

Procedure

Now here is how we are going to proceed. You will be examining a total of 24 pairs of surfaces. The surfaces will be presented side-by-side in the open area of this device. Your hand will be rested in front of the device. Each pair will be presented to you in this same area. (Point to it for 5 seconds) Please put your hand in the device and find the surfaces. You should feel each surface with your right index finger like this (demonstrate). You should feel each surface with the flat part of your index finger; do not use your fingernail. Also, you should make sure to feel both of the surfaces in the pair.

When the first pair is presented I will say "Pair One." At that time a pair of surfaces will be presented and you should examine it with your index finger. You can feel both of the surfaces as long as you wish with your index finger. When you think you know which of the two surfaces in the pair is smoother, you will tap the one you believe is smoother. Make sure you tap the surface and look at me when you have decided which one is smoother. I will say, “OK,” and you can remove your hand from the device until I say “Pair Two,” and you will examine the next pair to see which of the two is smoother and so on. We will proceed in this way until we finish the first 12 pairs and we will have a rest period for about 2 minutes. After the rest period, we will proceed in the same way until we have finished up the last 12 pairs. I want to let you know that when you are choosing which surface is smoother, there is no penalty for guessing. So, even if you can’t tell which one is smoother, please just make an educated guess.

During this experiment, I want you to wear these gloves on your hands. You will notice that the tip of the index finger is cut out so that you can feel the surfaces. This is just a reminder that you can only use your index finger in feeling the surfaces. I will also need you to wear these earmuffs while you examine the surfaces. I will speak loud enough so that you are able to hear me present the pairs even though you have earmuffs on.

Also, before we begin I am going to clean the tip of your finger with rubbing alcohol. This is just to clean up any residue you may have on your finger. I will do this before we begin and then during the break before we start the last set of 12 pairs.

Do you have any questions so far? If you do, please ask them now because I am not able to answer any questions once the experiment has started. Please make sure you are comfortable in your chair. I am going to clean your index finger now. You have your gloves on and earmuffs, we are ready to proceed. Do you have any questions at all?

OK. Let’s begin......”Pair One, OK.”...............

Wrap-up:

Thank you very much for your time. Now, before you leave there are a few questions I would like to ask you.

1)Was there any particular method you used in choosing the smoother surface?
2)Do you know of any reasons that you may have had difficulty in examining the surfaces (i.e. dry skin, calluses, sores, etc)?
3)With which hand do you write?
4)With which hand do you throw a ball?

Before you leave, there are a couple of items I would like to mention. First, The purpose of this experiment is to examine the effects of touch, vision, and smoothness on the perception of texture. In your condition, you were able only to feel the surfaces while others are able only to see the surfaces. You felt both smooth and rough surface textures that each group is exposed to.

Also, I would like to ask you to not mention this experiment to anyone else once you leave here today. The reason is that someone you know may participate in this experiment. As you might guess, if anyone knows about the experiment before they come, it may bias the results of the experiment. We would appreciate, then, it if you said nothing about this experiment to anyone else, OK?

Thank you again for your time!

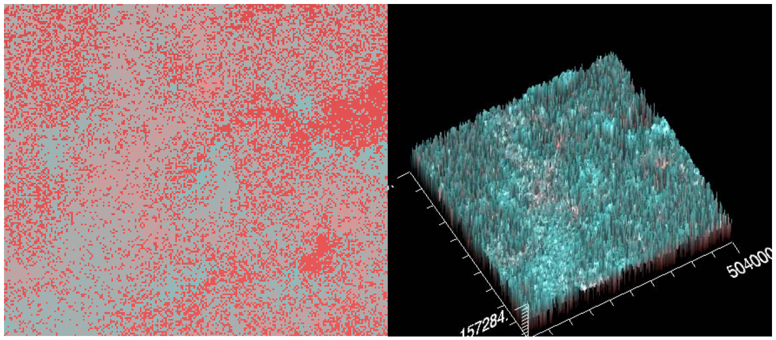
Appendix H

2D and 3D Images of Stimulus

Scans with Corresponding Grit- and Micron Values

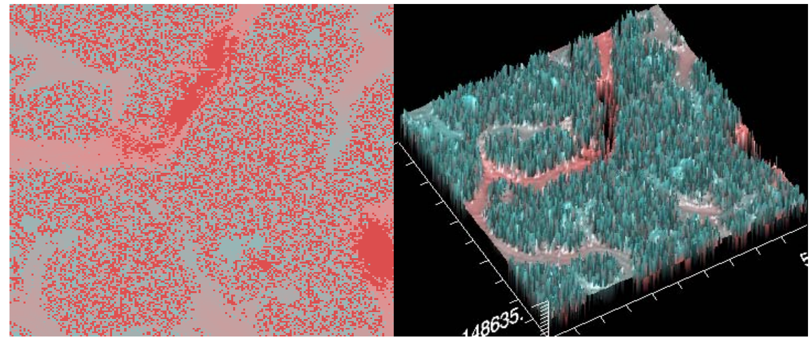
Sandpaper (Rough Values)

2D 3D

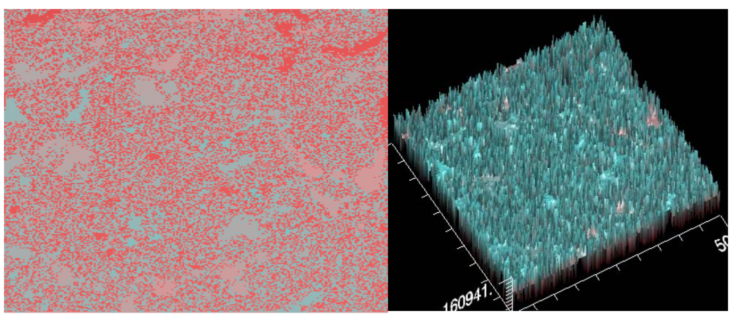


180 (15.063μ)

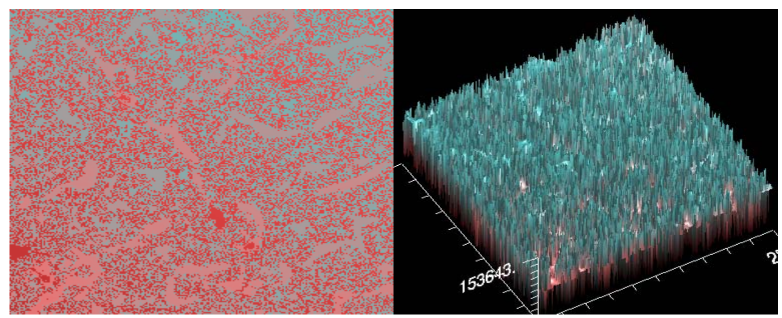
2D 3D



320 (22.048μ)



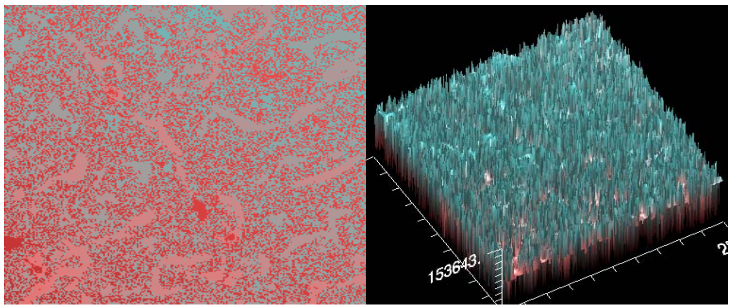
400 (17.313μ)



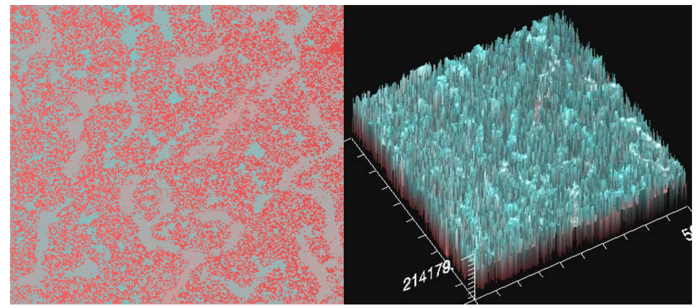
600 (15.707μ)

Sandpaper (Smooth Values)

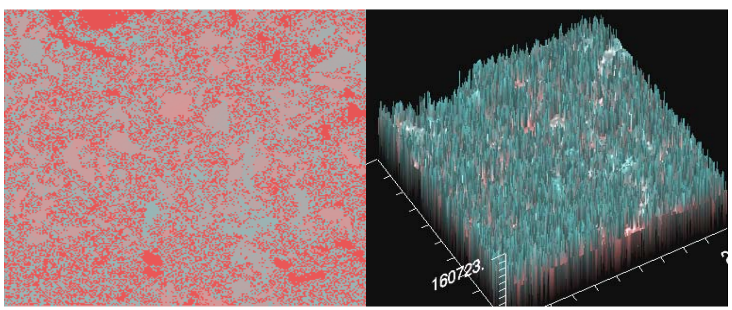
2D 3D 2D 3D



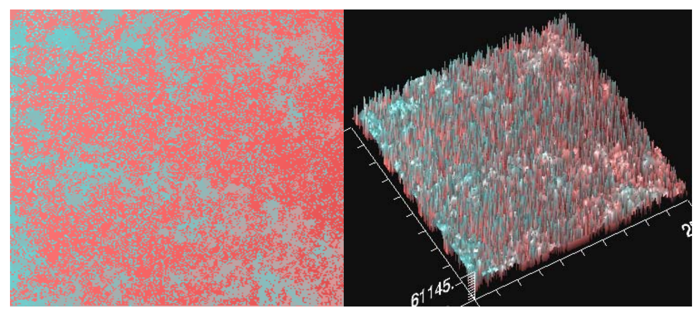
600 (15.707μ)



800 (21.021μ)



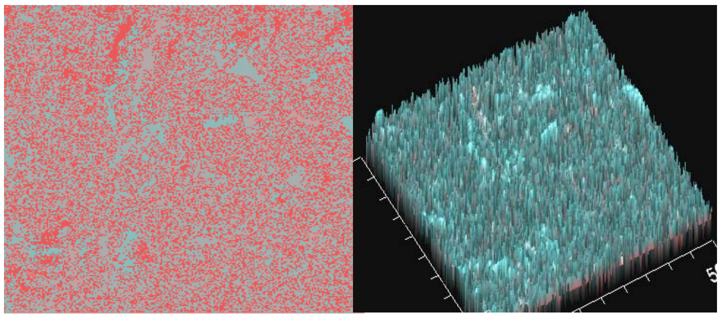
4000 (12.519μ)



6000 (6.638μ)

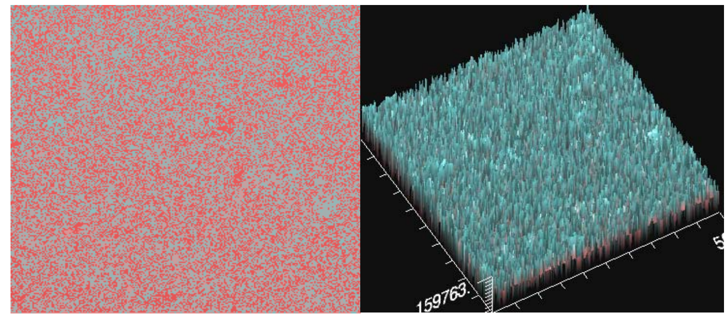
Waterstone (Rough Values)

2D 3D

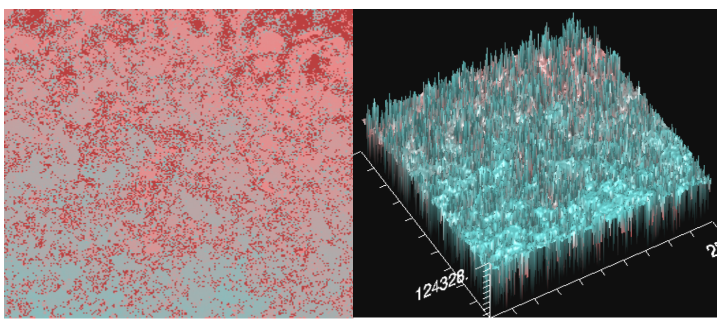


220 (16.534μ)

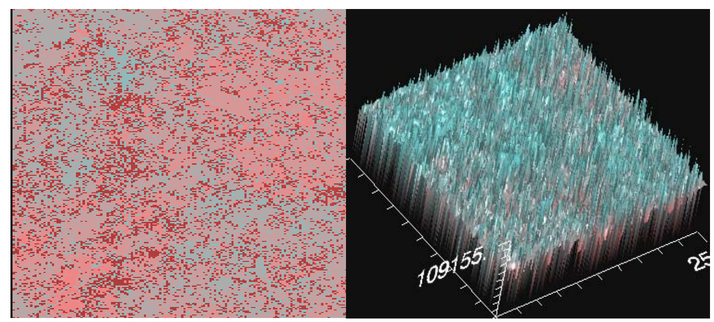
2D 3D



250 (14.138μ)



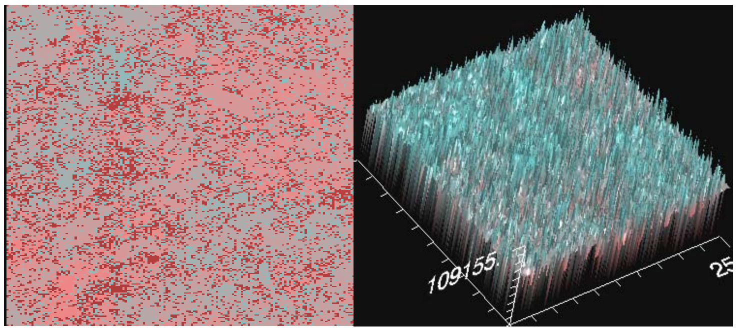
800 (11.353μ)



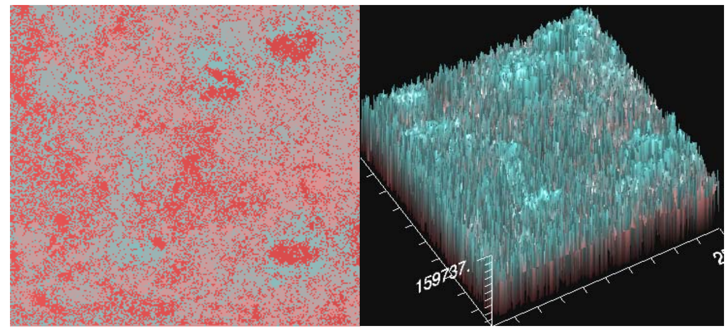
1000 (10.948μ)

Waterstone (Smooth Values)

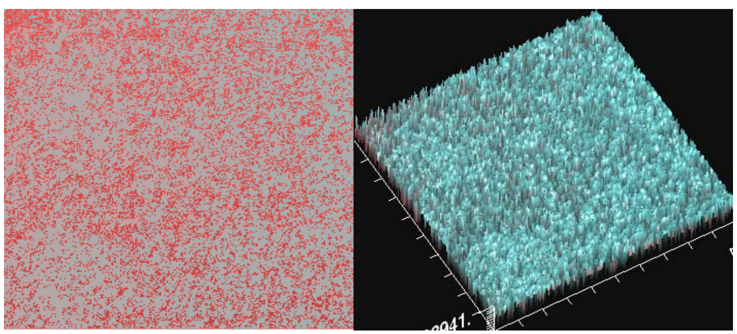
2D 3D 2D 3D



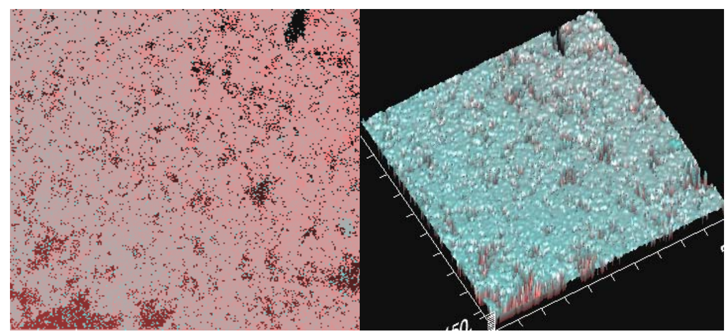
1000 (10.948μ)



1200 (9.441μ)



4000 (4.089μ)



6000 (1.605μ)