Texture Perception: Studies of Intersensory Organization Using a Discrepancy Paradigm, and Visual Versus Tactual Psychophysics

Susan J. Lederman and Susan G. Abbott
Queen’s University, Kingston, Ontario, Canada

Three experiments were performed involving the perception of surface texture. Experiment 1 indicated that when vision and touch are presented with discrepant information concerning texture, the two senses appear to weight the information about equally. Moreover, Experiment 2 showed that using touch, vision, or touch and vision, subjects performed a texture identification task with comparable matching accuracy and precision. Experiment 3 demonstrated that using the same three modes, subjects performed a magnitude estimation task similarly, in terms of magnitude estimates of roughness, the rates of growth of perceived roughness, and response precision. The comparability of the two senses in texture-related tasks may underlie the relatively equal compromise between discrepant sources of texture information demonstrated in Experiment 1 (modality superiority interpretation). Such a compromise is somewhat different from that commonly reported in the sensory conflict literature. The relative weighting of multiple sources of sensory information about surface texture was also considered in terms of a directed-attention interpretation of intersensory organization.

In 1709, George Berkeley commented: “If we take a close and accurate view of things, it must be acknowledged that we never see and feel one and the same object. That which is seen is one thing, and that which is felt is another... the objects of sight and touch are two distinct things” (1709/1957, p. 34). Such distinctiveness in the quality of sensation appears to have also led psychologists to study the senses in isolation. For example, David Katz (1925, 1935) wrote about separate worlds of touch and color. And until recently, classical and “new” psychophysics, as well as many other areas of concern to sensory and perceptual psychologists (e.g., aftereffects, illusions, and perceptual constancies), have all been approached in much the same way.

However, a growing body of literature (see Marks, 1978), is now examining the unity of the senses both in terms of inter-
crepant information matched size entirely in accord with their visual experience of the standard. Very strong or complete visual dominance over touch\(^1\) has been demonstrated many times in a variety of perceptual tasks: size (e.g., Kinney & Luria, 1970; Miller 1972), curvature (e.g., Easton & Moran, 1978; Gibson, 1933), length (e.g., Teghtsoonian & Teghtsoonian, 1970), depth (e.g., Singer & Day, 1969), and spatial location (e.g., Hay, Pick & Ikeda, 1965).

The majority of the sensory conflict studies have created a discrepancy in spatial location, using a paradigm that originated with Hay et al. The observer views one hand through a laterally displacing prism and subsequently indicates (with the unseen hand) where she or he either saw or felt the visible hand to be. Responses in these two conflict conditions are compared to visual and proprioceptive control conditions in which the observer receives information from only one modality. Subsequent to Hay et al., studies on visual/proprioceptive discrepancies have quantified the degree of bias of vision over proprioception and the bias of proprioception over vision. Significantly less than 100\% visual dominance is typically found (e.g., Pick, Warren, & Hay, 1969; Warren & Cleaves, 1971; Warren & Pick, 1970); proprioceptive bias of vision also occurs but tends to be a good deal less. Pick et al. (1969) have also examined the mutual biasing effects between vision and audition and between audition and proprioception. Taken as a whole, studies of the resolution of an intersensory discrepancy in spatial location indicate that vision tends to bias both proprioception and audition very strongly. Proprioception biases vision to a lesser extent and audition to a very small amount. Audition biases vision not at all and proprioception to a small degree. It is evident from the partial dominance just described that at least in the case of spatial location, subjects do make compromise judgements that involve the use of information from at least two modalities.

The perception of texture is another task that permits the study of the coordinated function of the senses, since it involves cutaneous, kinesthetic, visual, and auditory information (Lederman, 1979). The only work on texture perception, which relates directly to the topic of intersensory conflict, has been done on vision and touch by Fishkin, Pishkin, & Stahl (1975) and on audition and touch by Lederman (1979). Fishkin et al. (1975) used a magnifying lens to artificially distort the visual cues to texture. Unfortunately, certain limitations in the design, analysis, and reporting of the experiment make the findings somewhat questionable. In the Lederman studies, subjects judged the magnitude of the perceived roughness of various grooved plates by touch alone, by audition alone (using the touch-produced sounds), and both touch and audition. The results indicated that people were capable of judging roughness separately by touch and by audition. Judgments were similar but not identical in the auditory and tactual conditions; overall, touch proved more discriminating than audition. When both sets of sensory cues were simultaneously available, thereby potentially creating a natural conflict between the senses, subjects tended to weight their estimates toward the control touch judgments.

In the present set of studies, we begin by examining the resolution of a texture discrepancy created between vision and touch (Experiment 1). In Experiments 2 and 3, we expand the initial psychophysical work on the perception of surface roughness (e.g., Lederman, 1974, 1979) to include visual versus tactual judgments. How do these two modalities compare in the performance of two different texture- (i.e., roughness) related tasks? The additional psychophysical data provided in Experiments 2 and 3 are further used to help interpret those obtained in the discrepancy task.

**Experiment 1\(^2\)**

Like the earlier Rock & Victor study (1964), the first experiment used a between-subjects design but created a discrepancy in texture rather than in size. Subjects exam-

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1 The term *touch* will be used loosely to refer to both cutaneous and proprioceptive-kinesthetic systems.

2 Experiment 1 is based on an honors psychology thesis carried out at Queen's University by the second author (Abbott, 1979) under the supervision of the first author.
ined a tactual standard (tactual control), a different visual standard (visual control), or both the tactual and visual standards simultaneously (discrepancy condition). They subsequently picked a match to the standard(s), using touch or vision alone or both touch and vision together. How is a discrepancy in visual versus tactual texture information resolved? Logically, the texture discrepancy may be resolved in favor of either the tactual or visual controls or by a perfect compromise between the two.

Method

Subjects. Ninety unpaid subjects, 36 males and 54 females, participated. They were required to serve in the experiment as part of the requirements of an introductory psychology course. Their ages ranged from 18 to 40 years.

Stimuli and apparatus. The matching stimuli consisted of nine identical pairs of abrasive papers (7.5 × 12.5 cm) mounted on a firm backing and painted with a semigloss, black enamel. The nine grit values were 40, 50, 60, 80, 100, 120, 150, 180, and 220. Grit refers to the number of openings in the sieves used to sort the particles. Thus, the larger grit values tend to describe surfaces that feel somewhat smoother than those with low grit values. Grit value is approximately proportional to the reciprocal of the diameter of the particle. The standard consisted of an additional pair of abrasive papers, one of grit 60 and one of grit 150. The 10 pairs were arranged in order of grit value around the perimeter of a large lazy Susan table. The stimuli to be felt were placed around the outside edge of the table; the stimuli to be looked at were arranged in an inner circle, adjacent to the tactual set. The visual stimuli were lit with a 60-watt incandescent bulb about 17 cm above and slightly to the right of the vertical. The table was screened in such a way that the subject could examine only one stimulus at a time, either tactual only (T), visually only (V) or tactually and visually (T + V). The apparatus is shown in Figure 1. A U-shaped metal framework with a black cloth curtain attached to it projected across the outer (tactual) member of each texture pair. In this way, the subject could not see his (her) hand during the T or T + V viewing conditions. On the T trials, a different curtain was lowered over the opening in the screen to obscure the sight of the visual stimuli. It should be noted that the curtain and metal framework projected over the stimulus pairs in such a way as to prevent either visual or tactile exposure to the joint point of the two abrasive papers, creating the impression that only a single paper was present. This was corroborated by postexperimental questioning; none of the subjects detected the discrepancy.\(^3\)

Experimental design. A two-factor, between-subjects design was used in which three types of standard presentations were crossed with three types of matching tasks. Subjects received the tactile standard only (grit 60), the visual standard only (grit 150), or both the tactile and visual standards together (discrepancy condition). Subjects were required to select a match using touch only, vision only, or both touch and vision together. Ten subjects were randomly assigned to each of the nine resulting conditions.

Procedure. After washing and drying his/her hands, the subject was seated in front of the apparatus and given a set of instructions to read. The subject was told that she or he was to examine the standard and then to pick a match for it from a group of similar textures. The instructions specified whether the examination of the standard was to be tactile, visual, or tactile and visual. After reading the instructions and hearing them reiterated verbally, the subject was shown the apparatus (with no texture in place). At this time, the subject was again encouraged to maximize the visual cues by moving his or her head. Since only one trial was given to each subject, the trial did not begin until she or he had a clear understanding of the task. On any trial, the subject was permitted as much time as needed. When the standard was given tactually, the subject began the trial by putting his or her preferred hand beneath the tactual curtain and then indicated readiness to proceed to the matching task by removing the hand. The visual curtain, which obscured the visual standard, was left in place during the examination. When the standard was given visually, the visual curtain was lifted to start the trial and dropped when the subject was ready to proceed. For the vision + touch standard presentations, the subject started the trial by putting his or her hand under the tactual curtain to examine the tactile standard. The experimenter watched closely and lifted the obscuring visual curtain at the same time the subject's hand made contact to ensure approximately simultaneous exposure. The visual curtain was dropped at the same time as the subject removed his or her hand. Only after the standard was examined was she or he instructed as to whether the matching would be done visually, tactually, or by vision and touch. The subject's exploration was started at one end of the matching array or the other on a random basis. Subjects were permitted to work through the matching array as often as necessary and at a rate that was comfortable to themselves. The experimenter turned the table in accord with the subject's commands, for example "go on," "go back," and so forth.

Results

An analysis of variance for the completely randomized design was performed on the data, which were the grit values corresponding to each subject's match.\(^4\) The two factors

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3 In this initial experiment on the resolution of a texture discrepancy, no attempt was made to measure the magnitude of the discrepancy. The effect of the size of the mismatch in textural information will be subject of future investigations.

4 A similar analysis of variance was performed on the logarithmically transformed scores, since logarithmic transformation reduced the heterogeneity of variance in the data. However, as the results were very similar, only the original analysis using the raw scores is reported here.
1. "visual" curtain
2. black background cloth
3. visual stimulus
4. tactual stimulus
5. hand of subject
6. "tactual" curtain
7. wooden screen
8. screen window

Figure 1. (a) Rear view of the apparatus: The lazy-Susan table is shown with the "tactual" and "visual" stimulus sets arranged around the circumference. (Only portions of the wooden screen and the viewing window are visible. Dashed lines are used to indicate the two occluded standard textures. The stippled area in the "visual" stimulus represents the central portion which the subject can see against a black cloth background when vision is permitted.) (b) Subject seated at front of apparatus (discrepancy condition in Experiment 1 and touch + vision conditions in Experiments 2 and 3. (The subject is unable to see his hand or the surface he is touching. The "visual" curtain is lowered over the wooden screen during the "touch only" trials.) (c) Close-up of (b).
were Modality of Standard Presentation and Matching Modality, each with three levels. The main effect of Modality of Standard Presentation was highly significant, $F(2, 81) = 11.07, p < .0005$. The mean grit size matched to the (60 grit) tactual standard was $72.33 \pm 42.8$; it was $114.33 \pm 33.9$ for the visual standard (grit 150), and $92.67 \pm 31.6$ for the conflicting standard (grit 60 to touch and grit 150 to vision). A priori orthogonal tests indicated that T mean estimates were significantly lower than the T + V estimates, $F(2, 81) = 5.19, p < .10$; the T + V estimates were significantly lower than the V estimates, $F(2, 81) = 5.53, p < .10$. (A .10 significance level was adopted because of the conservativeness of the Scheffé test in rejecting the null hypothesis.) Thus, subjects receiving the conflicting stimuli chose matches that were significantly different from matches of the tactile and visual control groups.

The relative bias of one modality over the other may be determined quantitatively by calculating the proportional influence of tactual and visual information on judgments of subjects who received the discrepancy condition. The differences between the mean of the discrepancy group and the means of the control groups are calculated as proportions of the range between the control group means:

$$\% \text{ visual influence} = \frac{\text{Mean (T + V standard)} - \text{Mean (T standard)}}{\text{Mean (V standard)} - \text{Mean (T standard)}}$$

$$\% \text{ tactual influence} = \frac{\text{Mean (V standard)} - \text{Mean (T + V standard)}}{\text{Mean (V standard)} - \text{Mean (T standard)}}$$

Averaged across response modality conditions, the proportional visual influence was 49.3%, and the tactual, 50.7%. The effect of Matching Modality was also highly significant, $F(2, 81) = 10.15, p < .0005$. The mean grit values for the factor of Matching Modality, that is, touch, vision, or touch and vision, were $82.0 \pm 41.4$, $116.33 \pm 47.8$, and $81.0 \pm 25.4$, respectively. A posteriori orthogonal comparisons on these data indicated no significant difference between the means for the touch and touch + vision matching groups, $F(2, 81) = .013, p > .05$; however, the difference between the means for the visual minus the combined touch and touch + vision matching groups was highly significant, $F(2, 81) = 15.52, p < .001$. The visual matching group tended to make smoother (higher grit value) matches to all the stimuli than did either the touch or the touch + vision matching groups. The reason for the bias is not apparent at this time, although additional research indicates that the phenomenon only appears to occur when the higher grit standard is presented to vision.\(^5\)

Although the interaction between Standard Modality and Matching Modality was not statistically significant, $F(4, 81) = .94$, $p > .50$, the trend is an interesting one. It generally shows that the influence of touch on judgments of discrepant texture information increased when a tactual response

\(^5\)The results of a fourth experiment (Experiment 4) indicate that the relatively equal compromise between touch and vision is not idiosyncratic to the direction of the discrepancy used in Experiment 1. In Experiment 4, a smaller discrepancy was used, that is, grits 60 and 120. (Grit 150 was replaced by grit 120 in an attempt to maintain the same magnitude of discrepancy when the standards were reversed for vision and touch. The anomalies in the visual versus tactual estimates of grit 150 have been discussed in Experiments 2 and 3.) The design of the study, however, was essentially identical to that of Experiment 1, with twice as many subjects ($N = 180$) participating. For 90 subjects, the touch standard this time was 120 and the visual standard 60 (T120/V60); for the other 90 subjects, the tactual standard was 60 and the visual standard 120 (T60/V120). For purposes of analysis, the matching response data were logarithmically transformed to reduce excessive heterogeneity of variance. The pattern of the data, however, remained very similar to that of the untransformed data: The latter will be discussed here. The results of the T120/V60 conditions were similar to those described in Experiment 1: There was close to a 50/50 compromise (visual bias = 51.5%; tactual bias = 48.5%) and a nonsignificant tendency to show a shift in bias toward the control match of the modality used for the response. However, the visual bias to choose higher grit matches
did not occur. In the T60/V120 condition, the main effect of Standard Modality was once again highly significant; averaged across response modalities (to compare directly to previous results), the magnitudes of the visual and tactual biases were 51% and 49%, respectively. The tendency to make smoother (higher grit) matches when vision was used for the response was also evident. This time, however, there was a highly significant ($p < .0005$) interaction between Standard Modality and Response Modality: In the discrepancy condition, subjects chose matches that were not significantly different from the touch control match, when the response involved touch, or from the visual control match, when the response involved vision. Such findings are in accord with those reported in Experiment 1. However, when the response involved touch + vision, the match was not significantly different from the touch control. This last finding differs from that of Experiment 1 in which touch and vision were used about equally. One can only say that with a between-groups design, the influence of response modality on the resolution of a visual/tactual texture discrepancy is interesting but variable. See discussion.

Subjects tended to effect close to a perfect compromise between the two sources of information. This effect can be seen in Figure 2, which shows mean matches as a function of Standard and Matching Modality.

In summary, subjects tended to weight the discrepant visual and tactual information concerning surface texture about equally. Although statistically nonsignificant, there also was a tendency to shift or bias the sensory compromise in favor of the modality used to make the match (see Footnote 5).

Experiment 2

Experiment 2 assessed relative performance of T, V, and $T + V$ in terms of the relative matching accuracy and response precision in a roughness identification task.

Method

Subjects. Twelve subjects, 3 males and 9 females, were paid for their participation. None of these individuals had been in the previous experiment. Their ages ranged from 19 to 22 years.

Stimuli and apparatus. The apparatus is described in Experiment 1. Two identical standard sets of nine abrasive papers each consisted of grit values 40, 50, 60, 80, 100, 120, 150, 180, and 220. Two identical comparison matching sets each consisted of 11 abrasive sheets—the 9 just mentioned plus grit values 36 and 320. The matching stimuli were once again arranged around the perimeter of the revolving table; the tactual set around the outside and visual set immediately inside of that.

Experimental design. A four-factor, completely crossed design was used, the factors being Subjects (12), Days (6), Modality (3), and Grit Value (9). The last three factors were within-subject. Order of presentation of the nine surfaces within a modality ($T$, $V$, $T + V$) was randomized: The six possible orders in which the modalities were used were randomly assigned across subjects within each day. One day of practice was given each subject to thoroughly familiarize him or her with the task.

Procedure. Subjects were given a set of instructions to read. They were told that they would be presented with a number of surfaces, one at a time, and that they should identify each surface by picking a texture match from among a set of similar surfaces arranged in order of texture around a revolving table. They were also told that sometimes the examination and matching would be performed by vision alone, sometimes by touch alone, and at other times by both vision and touch. Each subject thus participated in three sets of 9 trials—27 trials in all. Other procedural details are discussed in Experiment 1.
Results

Since the matching data (i.e., grit values of the comparison surfaces picked as matches for the standards) were not normally distributed and did not show homogeneity of variance, nonparametric tests were used in the following analyses. These analyses were performed within subjects, since it was quite possible that touch or vision might be relatively superior for some subjects, whereas the two modalities might be about equal for others. Such individual differences had been previously demonstrated by McDonnell and Duffet (1972) and, therefore, seemed important to consider here.

The means of the grits chosen as matches for the Modality × Grit conditions were plotted for each subject (not shown here). As expected, the grit values of the matches tended to increase with increasing grit values of the standard stimuli. However, there were two striking anomalies in the data of all subjects: Grit 150 was matched by touch to considerably smoother (higher grit) surfaces than anticipated. (There are unfortunately no other published data that provide information about how the surface typically feels.) Grit 180 was also matched to somewhat smoother surfaces than expected, when vision only was used. These anomalies would appear to be in the ordered arrangement of the matching stimuli. Most of the subjects freely commented that grit 150 was out of order in the texture series and that it should have been placed further along the smooth end of the continuum. Many of the subjects also volunteered the information that grit 180 appeared darker than expected by its position in the visual matching array. As we shall discuss later, subjects may well have been using luminance as a cue to texture in visual matching conditions. If this suggestion is true, then there are two stimulus conditions that have unintentionally created a discrepancy between the visual and tactual information concerning texture. More will be said about this shortly. The three functions describing the T, V, and T + V conditions in all but one of the subjects tended to lie very close together (except for grit values 150 and 180). Moreover, there were no clear differences in the way the matches were made by touch, vision, or by touch + vision. Figure 3, therefore, shows the mean matches (averaged across subjects) for the various grit values, using T, V, and T + V.

The first set of analyses compared the relative matching accuracy of the T, V, and T + V data separately for each subject. The data for the grit 150 and 180 surfaces were not used, as the objective grit values would not accurately reflect the texture of the actual standards used. Accuracy was calculated as the matched grit value minus standard (objective) grit value. Wilcoxin matched-pairs, signed-ranks tests were performed on the error scores for touch versus vision, vision versus touch + vision, and touch versus touch + vision.

The results are very clearcut: Only 1 of 12 subjects showed a statistical difference in visual versus tactual matching accuracy; only 2 of 12 subjects showed a statistical difference between the accuracy of touch versus touch + vision (touch relatively less accurate); and none of the subjects showed a difference in accuracy between vision and touch + vision. Overall, the three matching conditions appeared to be about equal in matching accuracy.

A different way of comparing T, V, and

![Figure 3. Experiment 2: Mean grit values matched as a function of standard grit value for tactual, visual, and tactual + visual matching.](image)
T + V is to compare the relative precision or consistency of the matches made, using days as the repeated measure. Three Wilcoxin matched-pairs, signed-ranks tests were performed as above, using standard deviations in place of error scores. There were no statistically significant differences in the data, that is, the precision of subjects' matches is about the same, whether vision, touch, or touch + vision is used.

The large but consistent discrepancy between the tactual and visual estimates of grits 150 and 180 provided an excellent if unanticipated opportunity to examine the resolution of the natural conflict, when touch + vision was used. It was clear from examining the individual subject data that some form of compromise between vision and touch was taking place. Consequently, a third form of analysis was undertaken to determine the nature of the sensory compromise or bias exhibited in this texture-matching task. A Wilcoxin matched-pairs, signed-ranks test for correlated groups was performed on the absolute magnitudes of the separation between T and T + V scores and between V and T + V scores, that is, |T - (T + V)| - |V - (T + V)|. The scores were the means of the matching responses averaged across days for each subject presented with grit 150 and 180 standards (n = 24). It is clear (T(-) = 143; n = 24, p > .05) that there is no statistically significant difference in the position of the T + V response relative to those for the T and V controls. In other words, across subjects the tactual and visual information concerning texture is weighted about equally.

Summarizing the results of Experiment 2, touch, vision, and touch + vision perform about equally in terms of relative matching accuracy and precision of response. Moreover, the information from these two modalities is weighted about equally in the unintentional conflicts created with standards 150 and 180.

Experiment 3

Experiment 3 was also designed to compare tactual (T), visual (V), and tactual + visual (T + V) judgments of roughness, only this time in terms of the magnitude estimates, the rates of growth of the psycho-physical functions, and the variability associated with the three sensory modes of judgement.

Method

Subjects. Six experimentally naive subjects, three males and three females, were paid for participating. Their ages ranged from 19 yr. to 23 yr.

Stimuli and apparatus. The stimulus items consisted of two identical sets of 11 abrasive papers (prepared as before): grit values 36, 40, 50, 60, 80, 100, 120, 150, 180, 220, and 320. The arrangement of the stimuli and the apparatus is described in Experiment 1.

Experimental design. A five-factor, completely crossed design was used: Subjects X Days X Replication X Modality X Grit Value. Each subject judged the roughness of all 11 abrasive papers in blocks, once by touch alone, once by vision, and once by both touch and vision. This was performed twice on each of six days. The order per day of presentation of the surfaces within a modality (T, V, and T + V) was randomized; the six possible orders in which the modalities were used were randomly assigned across subjects within a day. Subjects were given 1 full day of practice.

Procedure. The subject was given a set of instructions to read, which outlined a magnitude estimation procedure for judging the roughness of a set of surfaces by touch alone, by vision alone, or by both touch and vision together. The subject was told that the first stimulus (grit = 100) in each block should be called 10. This surface served as a standard, and it appeared at the beginning of each block of exposure conditions (T, V, and T + V); it also appeared as one of the subsequent 11 stimulus surfaces. Any positive, nonzero numbers could be used, that is, decimals, fractions, or whole numbers. The subject assigned numbers to represent the roughness of each surface in proportion to that assigned to the standard. On the V and T + V trials, the subject was encouraged to move his or her head to maximize the visual cues to roughness. No time limit was imposed.

Results

An analysis of variance was performed on the logarithmically transformed magnitude estimates. The main effect for grit was highly significant, F(10, 50) = 27.1 p < .0001. Neither the effect of Modality nor any of the other main effects was significant. The two-way interaction, Modality X Grit, was significant, F(20, 100) = 5.23, p < .0001, as was the triple interaction, Days X Modality X Grit, F(100, 500) = 1.50, p < .005. However, each of these effects accounts for considerably less than 1% of the total sums of squares and is likely significant because of the large number of degrees of freedom. The geometric means of the magnitude estimates of roughness are
presented in Figure 4 as a function of grit value and modality of presentation. The three functions representing touch, vision, and touch + vision are very similar; the only surface that seems to differentiate the three modes of stimulus presentation is grit 150. However, this effect is likely due to some physical anomaly in the paper (reported in Experiment 2), which made it feel somewhat smoother than grit 150 surfaces typically feel. Consequently, the data for grit 150 were excluded in the least squares fit used to calculate the slopes of the straight lines that best fit each of the three psychophysical functions for roughness. (It is most puzzling why the matching anomaly for grit 180—Experiment 2—is not also reflected in the data.) The slopes and $r^2$ values are shown in Table 1 for individual subjects and for the group overall.

$T$ tests for correlated samples indicated no significant differences in the slopes of the roughness functions for touch, vision, and touch + vision; $t(5) = 1.53, p > .05$, for touch versus vision; $t(5) = .96, p > .05$, for touch versus touch + vision; and $t(5) = 0, p > .05$, for vision versus touch + vision. Consequently, the best fitting line across modalities of stimulus presentation is shown in Figure 4. The slope and $r^2$ values are $-.92$ and $.98$, respectively.

In addition to comparing the magnitude estimates of roughness by vision, touch, and touch + vision, we were also interested in the relative precision with which subjects made their estimates of roughness. Accordingly, a second analysis, called ANOVA, was performed on the transformed magnitude estimates. It is an analysis of variance that uses an estimate of variability calculated from the multiple judgments (obtained across days) as raw data (for details, see Appendix of Lederman & Taylor, 1972). The results of the analysis indicated that there were no statistically significant differences among the three modes of stimulus presentation in terms of relative precision. The effect of grit was highly significant, $F(10, 50) = 4.91, p < .0005$: The precision tended to decrease slowly as grit value increased to 100; it then decreased rapidly, peaking at 150, and subsequently leveling off at a slightly higher level of precision as grit increased to 320. The interaction of Grit Value X Modality was not significant.

In summary, then, there are no striking ways in which touch, vision, or touch + vision differ with respect to the magnitude

![Figure 4](image)

**Figure 4.** Experiment 3: Geometric means for apparent roughness estimates as a function of grit value (log scales) for touch, vision, and touch + vision presentations. (The straight line indicates the best fit to the overall data).
estimates of the perceived roughness of abrasive papers, the rate of growth of the roughness percepts, or the relative precision of the judgments.

### General Discussion

**Sensory Bias and Intersensory Organization**

The results of Experiment 1 provided data on the resolution of a discrepancy between tactual and visual information concerning surface texture. Briefly, subjects presented with discrepant textures selected matches that were compromises between the tactual and visual information: The matches tended to lie approximately midway between those selected in the visual and tactual control conditions. Since a between-subjects design was used in this first study, we cannot be certain whether the 50% resolution was due to an equal weighting of the tactual and visual information or to an artifact of combining the values of strongly visually and strongly tactually dominant subjects. However, if there were in fact a bimodal distribution, one would expect higher variability in the discrepancy condition than for the touch or vision controls. This was clearly not the case: The SD for the discrepancy condition was 31.6, whereas it was 33.9 for vision and 42.8 for touch. The relatively equal weighting of the sensory information is not typical of previous findings in the field: Strong or total visual dominance tends to be the rule. What then determines the nature of the intersensory organization and resolution of an intersensory discrepancy?

Welch, Widawski, Harrington, and Warren (1979) discuss two kinds of hypothesis, primarily with respect to the task of spatial localization. The first is that "vision is given greater weight than the limb-position sense because vision is much more precise (i.e., less variable in its accuracy from moment to moment)" (p. 126). They call this the modality precision hypothesis. There has been mixed support for the explanation. The data of Welch et al. (1979), for example, support it: The higher the ratio of proprioceptive to visual response variability, the greater the visual bias of proprioception. However, Bertelson & Radeau (1976) did not find a change in the amount of visual bias of audition in a spatial localization task when they experimentally altered the precision associated with auditory information. Perhaps, the modality precision interpretation of sensory bias is too narrow in scope. After all, we do not know at present if precision is the most important (or only) measure of what we will call modality superiority; it could be accuracy, sensitivity, discrimination, precision, or some other aspect(s) of performance, singly or in some combination. For example, the evidence is very strong that vision is considerably more accurate and precise than touch on form-matching tasks (e.g., Bryant & Raz, 1975; Cashdan, 1968; Milner & Bryant, 1970; etc.). This is not surprising when one considers that the sequential processing strategies used to code information about shape (or size) tactualy involve very heavy memory demands. Such demands may result in relatively poor performance by touch on
macrospatial tasks, compared to vision with its simultaneous processing strategies. This difference may, in turn, result in the strong visual dominance commonly found in tasks involving shape or size discrepancies between touch and vision.

Now consider the performance of texture-related tasks. Lederman (1979) found that subjects generally differentiated the apparent roughness of surfaces better by touch than by audition; and, moreover, when tactual and auditory cues were simultaneously available, judgments more closely approximated the tactual rather than auditory controls. On the other hand, tactual and visual performance of textural tasks are very similar (Experiments 2 and 3). This similarity is probably due to the fact that information may be obtained quickly and easily by both modalities—the memory load for tactual information about texture-related tasks is not as great as it is for tasks involving the perception of form. According to the modality-superiority interpretation, the relatively equal compromise between touch and vision in the resolution of texture discrepancies (demonstrated in Experiments 1 and 2) may be due to the relatively equal performance of the two modalities.

However, Welch et al. (1979) have also outlined a second kind of interpretation current in the field: “Visual inputs are typically more salient than proprioceptive–kinesthetic inputs, or at least more closely attended” (p. 126). This they refer to as the directed-attention hypothesis, for which there is also empirical support (e.g. Canon, 1970; Kelso, Cook, Olson, & Epstein, 1975; Warren, 1979). The ecological validity hypothesis discussed by Lederman (1979) may also be considered a variant of the directed-attention interpretation. Lederman argued that one reason that touch may bias audition in a texture-related task, at least in situations where audition is less discriminating than touch, is that tactual cues to texture are more ecologically valid than auditory cues. We may speak of a task as being more ecologically valid for modality A than modality B, when the sensory cues used by A are more reliably present than those used by B. Thus, tactual cues for texture may be considered more ecologically valid than auditory cues because the latter are frequently masked by extraneous sounds in the environment. Sensory cues that are reliably present, in turn, likely elicit greater attention than those that occur only irregularly. On the other hand, since information concerning texture is frequently available to and used by both vision and touch, the task may be considered ecologically valid for both modalities. One might, therefore, expect a more equal weighting of information by vision and touch in texture-related tasks. This is of course what was found in the experiments reported in this article.

Now, let us also take another look at the task of form perception, only this time we will interpret the bias of vision over touch from an ecological validity (or more generally, directed-attention) point of view. We actually rarely need to, and often cannot perform form perception tasks by touch—visual information can certainly be obtained faster and more accurately. But more important to this argument, we are limited to the information we can obtain about objects within arm’s length. We might argue, therefore, that the perception of form by touch is not an ecologically valid task—certainly not compared to its visual equivalent. Thus, people may attend more to the visual cues, resulting in the strong visual dominance shown in visual/tactual form conflict situations.

Still other experiments have demonstrated along the lines of the directed-attention hypothesis that when attention is shifted experimentally by instructions alone, the manipulation is rarely effective in altering the amount of visual bias of proprioception and vice versa. However, when attention is redirected by task-induced manipulations, the degree of bias can be altered (Warren, 1979; Warren & Schmitt, 1978). The effect of response modality on the direction of sensory compromise obtained in Experiments 1 and 4 (Footnote 5) of this article offers tentative support along these lines in terms of a tendency for the response modality to shift the direction of sensory bias toward the control response for that modality. We are currently reassessing the response modality biasing
effect using a within-subject design to reduce
the variability associated with the effect.

It is clear, however, that the general re-
sults of the resolution of a visual/tactual
discrepancy in texture reported here may be
considered from directed-attention and/or
modality-superiority perspectives. The dis-
tinction above is not intended to imply that
the two hypotheses concerning sensory bias
and conflict are mutually exclusive. Both
kinds of interpretation may play a role in
defining the nature of intersensory organi-
ization and the resolution of intersensory dis-
crepancies.

Finally, we should observe that touch, vi-
sion, and audition do not behave the same
way in texture-related conflicts as they do
in spatial localization conflicts. Recall that
Pick et al. (1969) and Warren and Pick
(1970) found that vision strongly dominates
touch and that touch dominates audition. In
the texture tasks (Lederman, 1979; this ar-
ticle), however, vision and touch are weighted
about equally, whereas touch once again
dominates audition. Clearly, the nature of
the task is important in determining the na-
ture of the intersensory organization pro-
cesses. It appears that it is not possible to
speak of a general ordering of the senses in
terms of absolute sensory bias.

Psychophysics of Texture

The data of Experiments 2 and 3 provided
information concerning the tactual and vi-

cual psychophysics of texture. The results
indicated no important differences between
the magnitude of the visual and tactual es-

imates of the roughness of abrasive papers.
The simultaneous use of both vision and
touch yielded roughness estimates that were
indistinguishable from those of either mo-
dality used alone. The data in Experiment
3 (Figure 4) were thus combined across the
three conditions of presentation, and a single
power function was determined. The expo-

ent of the psychophysical function for roughness was -.92. This value is substan-
tially below -1.5 reported for touch by Ste-
vens and Harris (1962) and by Ekman, Hos-
man, and Lindstrom (1965), somewhat lower

than the value of -1.18 reported by Stone
(1967), but quite consistent with unreported
data from this lab. It should be emphasized
that power functions fit the individual data
in this experiment quite well, although ex-
ponents vary considerably across subjects
(as they do in all the tactual experiments
just mentioned).

The similarity in visual versus tactual per-
formance of textural tasks was also dem-

onstrated in a study by Bjorkman (1967),
although the task was different again from
those used in the present article. He had sub-
jects make equal or different judgments of
pairs of abrasive papers presented sequen-
tially, either intramodally (T-T; V-V)
or intermodally (T-V; V-T). Intramodal
matching was (like the present results) sim-
ilar for vision and touch, although the linear
fits of the data were slightly better for vision;
intermodal matching data were best fit by
power functions. Unfortunately, it is diffi-
cult to interpret these results any further
with regard to the present concerns because
Bjorkman did not specify the dimension
along which the stimulus pairs were to be
compared. Subjects may well have chosen
to use entirely different kinds and/or num-
bers of dimensions visually and tactualy.

One may speculate about the physical pa-
rameters that underlie judgments of rough-
ness by touch and/or vision. Grit value
clearly affects both tactual and visual esti-
mates of roughness. But which aspect(s)
is(are) the most important: particle size, par-
ticle density (i.e., spatial frequency), spacing
between the particles, or, perhaps, jagged-
ness (the particle irregularity), to name only
a few. Abrasive papers are extremely vari-
able in terms of these measures. However,
Lederman & Taylor (1972) have shown with
more precisely controlled grooved metal grat-
ings that spacing is likely to be one of the
most important parameters of perceiving
roughness by touch: Apparent roughness in-
creases with increases in spacing. The lower
grit values also have wider spaces and the
rougher textures. Jaggedness was not exper-
imentally manipulated in these experiments,
but it is also likely to play a critical role. For
example, subjects in Experiment 2 fre-
quently commented that when they exami-
ined the whole range of abrasive papers ranked in order of grit value, there appeared to be a very rough set, which was described as having a common component of "jaggedness" to it, and a "smooth" set, which lacked "jaggedness." The difference in degree of jaggedness was confirmed by examination under the microscope. Grit value also strongly affected visual estimates of apparent roughness. Which visual cues may be important? Once again, any of the physical parameters mentioned above could contribute to the visual estimates of roughness. In addition, there are important aspects that affect vision alone, for example, reflectance, luminance, and so forth. On an ad hoc basis, we measured the luminance values associated with the different abrasive papers used in Experiments 2 and 3. The correlation between log grit value and log luminance was \(-.86\). However, the data seem to be further differentiated into two distinct sets—grits 36 to 80 and grits 100 to 320; within each of these sets, there are consistent changes in the luminance values. Correlations performed on the separate sets yielded values of \(-.95\) and \(-.86\), for the lower and higher grit sets, respectively. These relations are shown graphically in Figure 5. Correlating the log magnitude estimates for vision with log luminance values gave an overall correlation of \(-.82\) and correlations for the low and high grit surfaces of \(-.95\) and \(-.89\), respectively. Corresponding correlations for the logs of the matching responses in Experiment 2 were \(-.65\), \(-.90\), and \(-.97\), respectively. It would seem, therefore, that luminance is also highly correlated with changes in the apparent roughness obtained by visual examination; however, there must have been at least one other factor involved that separated the abrasive papers into two groups.

In summary, the three experiments discussed in this article provide data on the resolution of a discrepancy between visual and tactual information concerning texture. The results indicate that people tend to weight the two sources of information about equally. This equal compromise may be due, in part, to the findings (Experiments 2 and 3) that touch and vision perform texture-related tasks about equally (modality superiority interpretation). It may also be due to the ecological validity that textural tasks possess for both modalities (directed-attention interpretation).

The results reported in the texture-conflict study differ considerably from the more usual demonstrations of strong if not complete visual dominance. However, the modality superiority and ecological validity interpretations presented in this article argue for consideration of relative dominance in terms of the appropriateness of the task for the modalities in question. Accordingly, macrospatial tasks, such as form, size, location, and so forth, are more suited to vision than they are to touch; it is not surprising then that vision dominates touch in such situations. On the other hand, texture-related

![Figure 5. Luminance as a function of grit value (log scales).](image-url)
tasks are more equally appropriate to both modalities, and a relatively equal sharing between the senses may be the result.

Such considerations make ever current sweeping statements such as "vision is the dominant modality" or "vision dominates touch and audition" unacceptable. The demands of the task must be considered as well as their compatibility with the normal processing characteristics of the modalities in question.

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