Texture in Tactual Maps and Graphics for the Visually Handicapped

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Abstract: Discusses the state of the art in using texture in tactual maps and graphics for visually handicapped persons. Previous studies that have attempted to determine a set of highly discriminable textures are examined in detail. The discrimination of textures occurring within the context of other map symbols is also considered, along with the interference effects of texture on the identification of other classes of map symbols. Finally, suggestions for further research are offered.

Tactual maps potentially offer visually handicapped pedestrians the possibility of independent travel. In addition to their function as mobility and orientation aids (e.g., providing the spatial layout of a specific area), tactual maps may be used to provide political and geographical information about towns, regions, countries, continents, and the whole world. However, such maps are not often used. Many persons with visual impairments have never encountered a tactual map; moreover, those individuals who have used them have often been discouraged by the poor quality and design of the maps available. Such difficulties have created the unusual situation in which research on tactual maps has somewhat preceded consumer demand (Sherman, 1978). Such a condition brings with it the additional problem that the evaluation and advancement of map design is severely hampered by the lack of map reading skills (Nolan & Morris, 1971). Moreover, knowledge of basic geographical concepts, both concrete and abstract, is still rather limited in those people for whom the maps are intended (Franks & Nolan, 1970, 1971).

Partly dictated by such concerns, research on tactual maps has been conducted in three main areas. The first deals with map design, and focusses primarily on the choice of a legible tactile symbology. The second deals with methods of map production and reproduction (e.g., Ogrosky, 1973; Gill, 1974). The third area concerns the evaluation and teaching of map reading skills (e.g., Berla, 1972; Berlā, 1973; Berlā, Butterfield, & Murr, 1976; Berlā & Butterfield, 1977). Although it is useful for descriptive purposes to make such conceptual distinctions, the areas are in fact very much interrelated. For example, tactual legibility is determined, in part, by the technique used to produce the map, and by the material on which the map is produced.

This article examines the role of texture in tactual map design; however, the discussion is relevant to all forms of tactual graphics. Texture is, at least potentially, an effective symbol to choose for any tactual graphics. In our daily lives we regularly examine textures by touch—we check the surface finish on furniture, the quality of fabrics, the roughness of sandpaper, the smoothness of baby’s skin. These are tasks all of us perform comfortably and easily by touch. The senior author (SL) has conducted extensive research on tactual texture perception in the normally sighted (e.g., Taylor, Lederman, & Gibson, 1973; Lederman, 1974; Taylor & Lederman, 1975; Lederman, 1976), and we are now extending this work to tactual maps and graphics for the visually impaired. The task of designing effective tactual maps for such a heterogeneous population as the visually handicapped is far from easy. It could benefit substantially from a successful marriage between basic and applied research, each providing questions and possible approaches for the other. It is now becoming less and less possible, in fact, to clearly separate the two kinds of work, although applied research typically aims at providing immediate solutions. Thus, information and techniques obtained from basic perceptual research (and tactual texture perception, in particular) may prove useful in evaluating and extending the current research on texture in maps and other forms of tactual graphics.
Texture Discrimination

In this section, we discuss more thoroughly than is usual, the methodology and conclusions of studies that evaluated the discriminability of textured surfaces. Such work focusses primarily on the development of a set of legible symbols for use in tactual graphics. Three different sets of tactual symbols are typically used—areal (texture), line, and point. Areal symbols are used to represent a particular space; lines represent a boundary or continuous connection between two locations; and point symbols represent a single landmark or place.

Bauer (1952) was perhaps the first to investigate the discriminability of a number of textures that might aid in errorless identification of control knobs, buttons, etc. on industrial and military equipment. He chose ten different textures, each a 5 x 56 x 63 cm \(2'' \times 2'' \times 4/''\) block of wood with one side textured. The textures varied along a number of different dimensions; some surfaces were polished wood with incised parallel grooves, either wavy or straight (the size of grooves and uncut portions between the grooves both varied from plate to plate), or in the form of a grid; other surfaces were simply polished, “roughed up” by pitting with small gouges, diagonally patterned with raised hemispheres, covered with different sandpapers, or filled with precisely-cut holes. Sighted (blindfolded), male college students were first presented with the “standard” stimulus for one second. They were then presented with the other nine stimuli plus the standard, each for one second. The subjects were required to identify the stimulus they had initially felt. Only two of the conditions will be described in this section in a “no-movement” condition, 25 subjects held their hands steady as the texture was applied to the fingers with a 10-oz. force; in a “movement” condition, each of 10 subjects moved his fingers across the textured surfaces for one second, again with 10-oz. of force. Movement enhanced the subjects’ ability to correctly identify the textures; in this condition, the raised hemispheres, sandpapers, large linear grooves, and hole surfaces proved the easiest to recognize. However, since the surfaces varied simultaneously along many dimensions, it is impossible to determine what makes such textures more accurately recognized. This last criticism may be made of all the studies that have assessed texture symbol legibility, and we will discuss it in greater detail later.

Heath (1958) pioneered the use of scientific procedures for determining a set of highly legible tactual patterns (5 x 5 cm, \(2'' \times 2''\)) that could be used in maps and graphics for blind persons. Choice of textures was determined (mainly by visual criteria) from a large number of patterns commercially available for graphic art purposes. The patterns chosen varied along a number of different dimensions, not all of which were independent of each other, e.g., kind of element, spacing between elements, size of elements, regularity vs randomness. The tactual patterns were produced by Virko-type, a process in which wet ink images were dusted with a resinous powder and heated to produce a solid embossed image, about .1 mm \(1/1000''\) high. The 40 symbols chosen were randomly divided into four groups with 10 stimuli in each. Both blind and sighted (blindfolded) subjects, 10-40 years of age, partici-pated. Subjects were assigned to one group only. Each of the 10 stimuli in a group was paired with itself and with each of the other nine textures. Members of a pair were presented simultaneously, one to each hand. Subjects were “... asked to discriminate between them where possible.” There were no significant differences in the errors made by the two groups, although the blind subjects made fewer errors overall and were significantly less variable in their responses. The orders in which the stimulus patterns were ranked for blind and sighted subjects (according to discriminability) were highly correlated.

Unfortunately, with the design Heath used it was not possible to determine a set of maximally discriminable stimuli from the total group of 40. Moreover, no absolute criteria were specified for accepting a symbol as “legible.” To evaluate the practical limits for areal symbol size on a map, therefore, Heath simply used the 11 most discriminable patterns determined in the study above. Pattern recognition did not decline appreciably with decreases in size, but again, Heath did not comment on the relatively poor performance demonstrated overall on the texture discrimination tasks. How many of these symbols would be satisfactory on some absolute basis? And what are the dimensions which underlie the obtained texture confusions and discriminations?

Culbert and Stellwagon (1963) used the same 40 Virko-type tactual patterns previously used by Heath; only the outer dimensions were altered (7.6 x 12.6 cm, \(3'' \times 5''\)). One hundred and fifty sighted (blindfolded) college undergraduates made simultaneous comparisons of pairs of textures and responded as to whether the members of the pair were the same or different. Subjects were permitted to touch for six seconds on each trial. The design of the experiment permitted the authors to determine the most discriminable tactual patterns of the 40 surfaces, both when pairs were presented from across the entire set of 40, and when pairs involved comparisons of surfaces within subsets of the 40 textures. The authors chose 11 and 12 surfaces, respectively, as “... discriminable enough from all others to be useful in the preparation of material such as maps for the blind.” The 11 patterns chosen as most discriminable when judged within the context of the entire array of 40 surfaces were all regular patterns, such as grids made of solid lines or dots (both in several sizes), broken vertical lines (again in several sizes), and several diagonal line (solid and broken; different orientations) patterns. Stellwagon and Culbert (1963) further compared 50 legally blind persons with 50 college students (groups matched only in age) in their discrimination of 10 of the embossed patterns used in the previous study. No differences were found between groups, and the two orders of pattern discriminability were highly correlated (rho = .94).

Carson Nolan and June Morris of the American Printing House for the Blind have reported an extensive series of studies on tactual maps which includes work on areal, point, and line symbol legibility. The general method they have used involves same/different judgments of all possible pairs of symbols used in the experiment, each symbol paired once with itself and once with all other symbols. We would like to show all of the areal symbols
used in the various studies to enable the reader to look independently for dimensions which may be relevant to the same/different judgments of texture. An early experiment by Morris and Nolan (1961) attempted to extend the number of areal symbols Heath (1958) had found to be discriminable. Twelve textures (see Fig. 1) were printed in Viskotype as 5 x 5 cm. [2” x 2”] squares. Legally blind students from schools for the blind (n = 96; grades 4-12) made same/different judgments of all pairs of textures, using the procedure just described. Subjects could use either or both hands together as they wished, for a maximum of one minute per trial. The criterion for legibility was that “no pattern would be accepted as ‘discriminable’ if it was confused with any other pattern or itself on 10 percent or more comparisons.” A total of eight stimuli (asterisked) were found to be acceptable. The results were unaffected by age, sex or grade level, and only slightly by IQ.

However, Morris and Nolan’s experience with the Viskotype process showed that the degree of symbol relief (approximately .1 mm. [1/1000"] maximum) was “inadequate for good legibility” and that the precision of production and the preservation of material in humid weather were poor. For these reasons, they replaced the Viskotype medium with plastic symbols produced by a vacuum-forming process. [Unless otherwise mentioned, symbols discussed have been reproduced in plastic using the vacuum-forming process.] Nolan and Morris (1963) claimed to have replicated their earlier study using the eight discriminable stimuli previously identified plus five additional symbols. The 13 symbols are shown in Figure 2; however, if Figures 1 and 2 are compared, it looks as though not all of the previous discriminable symbols were used. Why this was done is not readily apparent. In any event, 7 of the 13 stimuli were considered discriminable according to a tighter set of criteria (Nolan & Morris, 1963, pg. 2):

(1) average confusion with other acceptable symbols should be five percent or less and
(2) confusion with itself or any other single symbol acceptable by criterion (1) should be ten percent or less.
(3) for any set of symbols acceptable by criteria (1) and (2), there should be no significant differences in discriminability of acceptable symbols among children in grades ranging from 4 through 12.

As with all of these studies, we wish to know whether the small number of highly discriminable textures is caused by some inherent limitation in ability to process information about texture, whether it might be due to some limitation in the procedures used to evaluate texture discrimination, or by both factors.

Jansson (1972) has summarized the kinds of confusion visually apparent in Nolan and Morris’s 1963 data (see Fig. 2); symbols made up of straight parallel lines oriented in different directions, e.g., E and K; symbols consisting of continuous lines versus broken lines with very small breaks between dashes, e.g., E and M, and K and G; symbols varying in the form of the elements which comprise the pattern, e.g., D and H; symbols possessing similar contours, e.g., C and J; and continuously straight versus continuously wavy lines, e.g., E and L.

As part of their evaluation of tactile symbol legibility, Morris and Nolan (1963) also attempted to establish minimum outer dimensions for each of the seven discriminable textures (Figure 3), each serving as standard. Although the authors claim to have used the seven patterns from the Nolan and Morris (1963) study on areal symbols, it can be seen that patterns E and F, which were not previously acceptable, have replaced two others that were. Again, it is unclear why this was done. Sixty braille reading students from a school for the blind, grades 4-12, examined a standard areal symbol, 5 x 5 cm. [2” x 2”], and then picked out the same pattern from among seven response symbols, all of a given size. The response sets varied in size from 5 x 5 cm. [2” x 2”] down to .6 x .6 cm. [1/4” x 1/4”], in .6 cm. [1/4"] steps. A symbol was considered legible at any size if it could be identified 90 percent of the time. Only patterns

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Figure 1: The 12 Viskotype areal symbols used in the Morris & Nolan, 1961 study (from: Nolan & Morris, 1971, p. 6). The outside dimensions are one-half those used in the study; the dimension of the patterns themselves are not altered. Asterisks indicate the highly discriminable stimuli. Reproduced with permission of the American Printing House for the Blind.
Figure 2: The 13 plastic areal symbols used in the Nolan & Morris, 1963 study (from: Nolan & Morris, 1971, p. 7). The outside dimensions are one-half those used in the study; the dimensions of the patterns themselves are not altered. Asterisks indicate the highly discriminable stimuli. Reproduced with permission of the American Printing House for the Blind.

Figure 3: A sample response card used in the Morris & Nolan, 1963 study. (From: Morris & Nolan, 1963, p. 49.) Reproduced with permission of the Association for Education of the Visually Handicapped.

B and F were discriminable at all sizes. The authors observed that the loss in discriminability with decreasing size of the outer dimensions of large-scale patterns may be due to the destruction of the overall pattern: patterns B and F both involve relatively small-scale designs which remain essentially the same when the outer dimensions are reduced.

In a final attempt to increase the number of highly discriminable areal symbols, Nolan and Morris (1971) presented a set of 11 areal symbols to 60 legally-blind, braille readers enrolled in residential schools, grades 4-12. The 5 x 5 cm. (2" x 2") symbols included some, but not all, of the acceptable textures from previous work, plus four entirely new patterns (Figure 4). Choice of symbols was based, in part, on earlier work in which the authors felt suggested the following relevant dimensions for texture discrimination: continuous vs interrupted, regular vs irregular, pattern density, and size of the elements forming the pattern. Eight of the 11 areal symbols (asterisked in Figure 4) satisfied the tighter criteria for legibility described earlier. The authors concluded that the dimensions for texture found in previous work were again relevant. Directionality of patterns was not a good cue, since a pattern paired with a 90° rotation of itself was confused about 20 percent of the time. They also believe that their data suggest an upper limit (eight) to the number of highly discriminable tactual areal symbols in a set.

Other work on areal symbology includes that reported
Schiff (1966), Jansson (1972), Wiedel and Groves (1972), and James and Gill (1975)
Schiff (1966) has described research with 12 high school and college level blind students, in which four vacuumformed areal symbols (19mm. [3/4"] to a side), produced from different grades of sandpaper, were found to be distinguishable. He also examined the discriminability of textures produced by different embossing tools. Such work has pointed to the additional contribution of the sharpness of the elements in the pattern to texture discrimination. However, element shape and orientation of line elements were considerably less important.

Jansson (1972) briefly described the occurrence of some confusions in the use of five different textures produced in plastic from cardboard, cloth, fine- and coarse-grained sandpapers, and canvas. The five areal symbols were chosen by a Scandinavian committee for the production of educational maps to be used in teaching geography to the blind.

Wiedel and Groves (1972) have also reported the evaluation of several areal symbols for tactual maps. Of the three tested (Figure 5), only one was acceptable. Unfortunately, the testing method and criteria for legibility were not reported; there are too few symbols to comment on the possible relevant dimensions for texture discrimination.

Finally, James and Gill (1975) examined the discrimination of eight tactual areal symbols (Figure 6), many of them chosen from the textures used in the work by Nolan and Morris. Sixty-two resident blind schoolboys, all braille readers, made same/different judgments of the textures of all possible pairs of 5 cm. x 5 cm. [2" x 2"] areal symbols. Both errors and reaction times were recorded. Five of the eight symbols (asterisked in Figure 6) were considered legible, according to the first two criteria used by Nolan and Morris. As James and Gill point out, the relatively high confusion between symbols B and D, i.e., symbols with similar contours oriented in different direc-

Figure 5: The 3 areal symbols tested by Wiedel & Groves, 1972. Asterisk indicates the one tactually “discrete” symbol. (From: Wiedel & Groves, 1972, p. 9.) Reproduced with permission of the authors.

Figure 4: The 11 plastic areal symbols used in the Nolan & Morris, 1971 study. (From: Nolan & Morris, 1971, p. 17.) The outside dimensions are one-half the size used in the study; the dimensions of the patterns themselves are not altered. Asterisks indicate the highly discriminable stimuli. Reproduced with permission of the American Printing House for the Blind.
The experiences reported in the previous section were all concerned with determining a set of legible tactile texture symbols for coding purposes. Success has been very limited, and there has been no universal standardization of such symbols. Standardization of areal symbols is desirable but given the limited set of highly discriminable texture patterns, it may not be advisable to standardize the meanings associated with them. Not standardizing the meanings is the procedure adopted in the raised map-making kit put out by the Blind Mobility Research Unit in Nottingham, England (James, 1975). In considering the use of texture (or any other symbol class) in maps and other tactual displays, one must not ignore the possibility that legibility will be further affected by the presence of other symbols. Notice that all texture discrimination experiments mentioned were performed with pairs of surfaces in isolation.

One aspect which must be considered in the proper design of tactual displays is the problem of figure/ground. A display may use three different kinds of symbols. Identifying or tracking a given symbol requires the reader to ignore all others, within and across these three classes. Whatever the target symbol is for the moment becomes “figure”; non-targets, by definition must be “ground.” Does the nature of the ground interfere with the identification of a target and its spatial representation on a map? In the language of communication theory we say that the person must detect a “signal” (i.e., the target symbol or “figure”) in the presence of “noise” (i.e., anything that is not the stimulus to be detected, or “ground”). The textured areal symbol is likely to provide noise. The presence of adjacent areal symbols (noise) could aid or hinder the accurate detection of a given areal symbol (signal). We know of no research that examines this issue. Adjacent areal symbols may also interfere with the reader’s ability to pick out line and point target symbols. Berlá and Murr (1975) investigated this by having young braille readers locate instances of a given point symbol and track a dotted line on a tactual pseudomap with either a “noise-free” or “noisy” background (i.e., irrelevant areal symbols present). Subjects were trained to use a vertical scan technique (Berlá, 1973) on the location task. Accuracy and speed of finding point symbols and tracking a line were both measured. The addition of irrelevant textured symbols in the point symbol location task significantly increased the number of errors (missed point symbols), the variability of error performance, and the scan time. In the tracking task, the presence of background texture similarly increased the variability of performance and also the scan time; it had no effect on the proportion of subjects who failed to cover sections of the line track. It is apparent that irrelevant textures may interfere with the coding of point and line symbols on a tactile map.

Reducing Interference
How can one eliminate or at least reduce the interfering effects of texture? Nolan and Morris (1971) attempted to
separate point, line, and areal symbols perceptually on a tactually pseudomap by increasing the lateral separation between symbols, and by presenting the three classes of symbols at increasingly separate heights, i.e., all symbols at the same height, line and point symbols at the same height but higher than that for areal symbols, and point higher than line and line higher than areal symbols. Does the increased physical separation improve the location of six areal and five point symbols (both of one kind) and the tracking of a dotted line path by blind elementary and high school students? The map was constructed with different areal, point, and line symbols—five of each—chosen from the set of legible symbols determined in previous work. There were very few errors in identifying the textured symbols; response times were unaffected by differences in either symbol height or lateral separation. Increasing the relative height (but not the lateral separation) tended to decrease the time required for following the line path. Both separation factors affected the accuracy and response times for locating point symbols, with the greatest degree of symbol separation providing the best performance.

In the Nolan and Morris study, height was used effectively as a source of redundant information concerning symbol class, i.e., different heights were associated with areal, line, and point symbols. The value of using redundant information on a tactile display supports earlier work by Schiff and Isikow (1966). They showed that if texture is used in a redundant manner, its presence can improve the accuracy of performance using a bar graph. Legally blind (total blindness or light perception only) high school students ordered a set of bars presented in a tactile histogram according to length. Information about the length of the bars was presented in five different ways: raised outline only, bars represented by different grades of sandpaper, bars represented by different heights, outlines plus corresponding changes in texture, and corresponding changes in texture and height. The mode of presentation thus varied in terms of the amount of correlated or redundant information about tactually length, as well as in the quality of redundant information presented. In addition to varying the mode of presentation, Schiff and Isikow also varied the degree of difficulty of the histogram displays by varying the size of the differences in bar length, and by changing the order in which the bars were presented, i.e., regular (stepwise) vs irregular sequences. Briefly, the results indicated that the maximum amount of redundancy (texture + height) produced the lowest number of errors, but only for the most difficult problem with respect to size difference; when the medium and large differences in length were presented, textures, outlines + textures, and texture + height proved about equally effective in reducing errors relative to the raised outline presentation. There were no significant differences in the reaction times for the five modes of presentation. Thus, if used appropriately, texture might serve to enhance tactile map reading.

Few studies have actually evaluated the accuracy with which symbols including the areal variety, are identified in a map context. Berlá and Murr (in Nolan, 1976) required young braille readers to locate on a tactually pseudomap as many of 16 point symbols (raised hemispheres) and 6 areal symbols (grid-like texture) as possible within a five-minute period. There were four different kinds of point, five line, and five areal symbols in all. On the basis of research by Nolan and Morris (1971), the classes of symbols were presented on the map at different heights, with areal symbols lowest, line symbols a little higher, and point symbols highest of all. Berlá and Murr were concerned with the effects of providing a frame of reference (obtained from a preliminary map scan) on the subsequent search for point and areal symbols on the pseudomap. Regardless of strategy, the students performed very poorly when locating point symbols embedded among symbols of all other classes. Average accuracy for each grade group tested was approximately 60 percent, 57 percent, and 62 percent for grades 4-6, 7-9, and 10-12, respectively. Performance on the areal recognition task was somewhat better, with the average grade grouping score being about 72 percent for the lowest grade, about 67 percent for the middle, and about 70 percent for the upper grade. No numerical values for duplication errors (i.e., locating the same stimulus a second time) were provided, although it was stated that fewer occurred in areal than in point location when instructions were provided with the preliminary scan. Generally speaking, however, symbol recognition on the tactile pseudomap was a good deal lower than should be acceptable. Unfortunately, the reasons for the poor performance are impossible to isolate within the design of the experiment. They may have been due to any number of factors, e.g., poor map reading strategies, complexity of map design (e.g., noise added by background and other target symbols), and/or heavy memory demands (especially with respect to the many point symbol targets).

We could find no other studies which presented performance data on the identification, memory, etc., of target areal symbols, or of point and line symbols in the presence of areal symbols, on a tactile display.

Where Do We Go From Here?

Having presented fairly detailed descriptions of the available research on the role of texture in tactile maps, we would like to suggest the issues we think are critical at this stage in the field, and possible ways to proceed. Research to date suggests that texture as a symbol on tactile maps is fairly limited. At best, Nolan and Morris have found no more than eight highly discriminable symbols according to their criteria for legibility. They believe that this limit is inherent in the processing of texture. We feel that Nolan and Morris may be somewhat premature in drawing this conclusion.

From the section on texture discrimination, it is evident that the choice of texture patterns by investigators to date has been somewhat arbitrary (with visual criteria for apparent discriminability often determining the items selected). With this approach, items have often differed along more than one dimension at a time. To which dimension(s) can we attribute the high discriminability? Conversely, why do two physically different patterns feel so similar? Could one reason be that although the dimension(s) sampled may be relevant, the values arbi-
Do we have any idea about what the relevant dimensions for tactile texture discrimination are? Nolan and Morris's work has suggested several: continuous vs interrupted, regular vs irregular, pattern density and size of the elements which form the pattern. Schiff has suggested that the sharpness of the pattern is also important. There may well be others, and sophisticated multivariate designs and analyses exist for examining such questions. Multidimensional scaling is one such approach, discriminant analysis another. Such methodologies allow the investigator to see how a variety of items cluster perceptually, and to begin to understand the dimension(s) that underlie the clustering. Following this broad attack to the problem, the investigator could determine a set of textures which were judged to be very dissimilar on the most important dimensions. Using these items in a paired-comparison (same/different judgment) or matching task would allow one then to evaluate legibility according to criteria such as those used by Nolan and Morris. Furthermore, knowing somewhat better what dimensions were relevant to tactile texture perception, one could attempt to expand the set of legible stimuli by systematically extending the range of values used for the various dimensions.

The work of one of us (SL) also bears on the issue of dimensions of texture. We suspect that same/different judgments of the pairs of tactile textures described in this article may be based, at least in part, on the evaluation of roughness. Lederman and Taylor (1972) and Lederman (1974) have carried out a series of psychophysical studies examining the parameters affecting the magnitude of roughness estimates of linear, grooved metal plates. The subjects assigned numbers (decimals, fractions, or whole numbers) in proportion to the magnitude of their sensations of roughness. This procedure is known as “magnitude estimation,” and can be used to gather a considerable amount of data in a short period of time. With this technique, it was found that the size of the spacing between the elements, i.e., groove width, was the single most important factor affecting roughness, the latter increasing as the spacing also increased. The width of the uncut portions or ridges between the grooves proved to have a small and somewhat ambiguous effect on roughness; perceived roughness either remained unchanged, or tended to decrease with increases in the width of the ridges. (Berlã and Murr (1975), p. 190, have incorrectly quoted this work. It should read: “For example, Lederman and Taylor (1972) showed that the narrower the elements and the wider the spacing between elements in a texture, the greater the subjective estimate of roughness.” (Emphasis added.)) The spatial frequency (cycles/cm.) or density of elements, as referred to by Nolan and Morris (1971), did not play a significant role in the perception of roughness.

In many of the textures we have examined in this paper, the density of elements was altered by changing both the width of the elements and the spacing between the elements. The same is true of the Stevens and Harris (1962) study in which magnitude estimates of perceived roughness were found to increase as a power function of the grit value of the sandpapers used. “Grit” refers to the number of openings in the sieves used to produce the particles. Lederman's data suggest that it might only be the spacing between elements which is crucial in the same/different judgments of texture. Finally, her work indicates that the ratio of the width of the elements to the spacing between the elements is unimportant in judgments of roughness. Together with additional data from these experiments which related method of tactile exploration (i.e., finger force) to perceived roughness, the results served as a data base for the development of a model of perceived roughness of grooved surfaces in terms of the static deformation of the skin (Taylor & Lederman, 1975). The model suggests several possible “stimuli” for roughness, all of which relate to the amount of skin deformed in the spacing between the elements—the depth to which the skin descends in a groove, the cross-sectional area of the finger within the grooves, and the cross-sectional area of the finger which deviates from its resting position. Lederman (1978a) has further speculated on the peripheral nerve endings which may be coding roughness, but the suggestions remain strictly tentative at this time. A mechanical analysis of skin deformation could theoretically determine the variation in these skin deformation parameters for a variety of areal patterns. Models such as the one proposed permit the investigator to make predictions about potentially discriminable stimuli and evaluate their effectiveness as symbols in tactual displays. Jansson (1972) has referred to the value of such theoretical analyses for the development of a tactual symbology.

It also seems appropriate at this point to suggest that the line symbols typically used in studies of legibility also possess a degree of “roughness” to them. It is then possible that confusions among line patterns are due, in part, to their similarity along a roughness dimension. It would be a simple matter to test this hypothesis by having people judge the “roughness” of the various line symbols; symbols which are distinct from one another should lie at the far ends of the roughness continuum. Should this hypothesis be confirmed, we can again use the dimensions of perceived roughness already isolated to develop additional line symbols for testing. Once again, we emphasize the value of systematic psychophysical studies.

Another important issue in the evaluation of symbol legibility concerns the methods of testing. Although most investigators have recognized the need to evaluate areal symbols within the context of a map, none has systematically done so. We need studies which evaluate texture recognition within the context of other textures present on the map; we may find we can use adjacent textures to heighten the differences between areal symbols. We also need to know more about the interference effects of areal symbols on line and point symbol legibility. Berlã and Murr (1975) have previously documented this context-dependent interference. Can we eliminate or reduce its
Effect on the map reading process? Nolan and Morris (1971) used differences in the heights which line, point, and areal symbols are presented to reduce error. It may well be that information coded by areal symbols can be presented even more effectively, when necessary, in underlays as Kidwell and Greer (1972) and Gill (1973) have done. Such a technique would provide the "noise-free" map environment Berlãa and Murr found to be desirable, by keeping areal symbol information physically separate from line and point symbols. Finally, can we use texture on maps in a redundant fashion, as Schiff (1966) effectively demonstrated with his tactual histograms? Consider for example areal size—it can be used on a map to represent a country, a region containing a particular mineral or type of vegetation, even population density. But relative size is difficult to evaluate by touch. Could this process be improved by including variations in the textures of these area-varying stimuli which correlate with a specified range of area—the larger the area, the rougher the texture? We are speculating that there may be a natural tendency to link perceptions of increasing roughness with those of increasing area (analogous to the method Schiff, Kaufer, and Mosak (1966) used in the development of their "tactual arrow" symbol). If this proves to be true, the additional information about area, inherent in the texture of the stimulus, might improve the accuracy and speed with which complex information regarding relative size is interpreted.

Another method which ought to be used more often is a matching task in which a standard is presented and then must be chosen from among a set of comparison stimuli. Such a task is difficult to perform by touch alone because of the heavy memory load imposed by the serial order of stimulus presentation. However, it does correspond more closely to the map reading task of examining a symbol key followed by a variety of symbols on the map itself.

**Force and Speed of Hand Motion**

Legibility of texture symbols may be affected by other aspects of the tactile exploration process as well, namely force and possible speed of hand motion. As early as 1952, Bauer mentioned that accuracy of texture discrimination was altered by variations in force, although he gave no data to support his claim. However, Lederman and Taylor (1972) and Lederman (1974) have since shown that estimates of the magnitude of tactile roughness increase substantially with increases in finger force. Given that roughness is a prominent component of tactile texture, it is reasonable to predict that variation in finger force might well interfere with the proper discrimination of surface textures on a map. It is probably necessary, therefore, to teach the maintenance of a relatively constant force in any map reading training program. Lederman (1974) has also shown that roughness tends to decrease with increases in hand speed; however, this effect was negligible over a 25-fold change in hand speed, and can probably be safely ignored.

**Sound As Aid to Texture Discrimination**

One idea which has not been carefully considered in the study of tactile symbols is the role that audition may serve. When you run your hand across a surface, you produce sounds which are characteristic of the material you are touching, as well as of the speed and force of the hand motion. Can people benefit from using such information concerning texture? Many years ago, Katz (1925) demonstrated the success with which people could identify materials using only touch-produced sounds. Furthermore, Bauer (1952) mentioned, though only in passing, that some of his subjects tried to use the different sounds produced when comparing pairs of stimulus textures. None of the other studies reported in this article appears to have either eliminated such cues or examined their role in texture discrimination. More recently, Lederman (in press) has systematically studied the contribution of touch-produced sounds to the magnitude of perceived roughness of grooved metal plates (described earlier). People are capable of judging roughness by sounds alone, but they generally do so somewhat more poorly than by touch only; moreover, when both auditory and tactile information are available simultaneously, subjects tend to use the tactile information.

None of the studies reported earlier has considered the possible contribution that auditory cues to texture might make in a discrimination or symbol-finding task, as opposed to the task Lederman used. Auditory cues to texture may be most useful on single-copy maps, which often use different materials, such as sandpapers, linoleum, etc., to vary texture. Such areal symbols are provided in the kit for raised maps produced by the Blind Mobility Research Unit in Nottingham, England (James, 1975). However, auditory texture may prove somewhat less useful on the vacuum-formed plastic sheets frequently used for reproduction. Here (as with Lederman's metal plates), the plastic material on which the surface texture is produced remains unchanged, and so too do the fundamental sounds characteristic of that material.

In this article, we have dealt fairly extensively with the literature on texture perception, and have related it to the production and use of tactual maps for the blind. Areal symbols have been used very little on mobility maps to date. More often, texture has been used to code political and geographical information. One of the major problems which the experiments on texture discrimination have highlighted is the limited number of legible symbols which can be used on a map, or other graphic displays. We have tried to suggest new approaches which might extend the range of available textures, and have considered the effects of presenting symbols, and symbol (areal, line or point), within a map context.

**Limitations of the Tactual Sense**

Finally, we offer a caveat to the reader. Even assuming the best possible research on design and use of tactual maps and other graphics, we must seriously consider the degree of success possible with such spatial displays. One of us has argued (e.g., Taylor, Lederman, & Gibson, 1973; Lederman, 1978b) that spatial information is not coded well by the tactual system. Because the information is usually presented sequentially, it imposes a heavy memory load and makes it difficult to obtain a holistic appreciation of the object. It is not surprising therefore, that people
In their present form, tactual maps involve similar kinds of spatial tasks, as well as a general appreciation of space at the conceptual level. As Armstrong (1978) and Bentzen (1978) have both mentioned, we must determine whether such tasks are reasonable to ask of the visually impaired, and particularly of the congenitally blind. We may have to rethink the ways in which we present spatial information to the visually handicapped if we wish to use the tactile channel.

References


Katz, D. Der Aufbau der Tastwelt (The World of Touch). Leipzig, Germany: Barth, 1925.


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