Similarity of tactual and visual picture recognition with limited field of view

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Abstract. Subjects attempted to recognize simple line drawings of common objects using either touch or vision. In the touch condition, subjects explored raised line drawings using the distal pad of the index finger or the distal pads both of the index and of the middle fingers. In the visual condition, a computer-driven display was used to simulate tactual exploration. By moving an electronic pen over a digitizing tablet, the subject could explore a line drawing stored in memory; on the display screen a portion of the drawing appeared to move behind a stationary aperture, in concert with the movement of the pen. This aperture was varied in width, thus simulating the use of one or two fingers. In terms of average recognition accuracy and average response latency, recognition performance was virtually the same in the one-finger touch condition and the simulated one-finger vision condition. Visual recognition performance improved considerably when the visual field size was doubled (simulating two fingers), but tactual performance showed little improvement, suggesting that the effective tactual field of view for this task is approximately equal to one finger pad. This latter result agrees with other reports in the literature indicating that integration of two-dimensional pattern information extending over multiple fingers on the same hand is quite poor. The near equivalence of tactual picture perception and narrow-field vision suggests that the difficulties of tactual picture recognition must be largely due to the narrowness of the effective field of view.

1 Introduction

Simple line drawings that are immediately interpretable by sight are recognized only with difficulty when presented as raised images to the sense of touch. Evidence for this comes from a number of studies which indicate that raised drawings of common everyday objects are correctly recognized at rates varying between 10 and 40 percent correct, with latencies ranging from seconds to minutes (Torii et al 1975; Kennedy and Fox 1977; Magee and Kennedy 1980; Heller 1989; Lederman et al 1990).

There are a number of reasons that might account for tactual picture perception being much more difficult than visual picture perception. One of these involves channel capacity, the rate at which pattern information can be transmitted through the sensory channel; channel capacity is determined jointly by temporal bandwidth and spatial bandwidth (Loomis and Lederman 1986). Spatial bandwidth, in turn, is determined jointly by the field of view and the number of spatially resolvable points per unit area. When the spatial bandwidth of the channel is insufficient for processing a given pattern in a single spatial sample, as is frequently true of touch, sequential exploration of the image becomes necessary. With sequential presentation of spatial patterns, temporal bandwidth (or temporal resolution) comes into play by limiting the number of successive pattern samples that can be transmitted without degradation through the sensory channel within a fixed time interval. If the effect of reducing the field of view is solely to reduce the rate at which information can be acquired, then it should be possible to maintain a constant level of recognition accuracy by increasing the length of the exploration period in a compensatory fashion.

A second possible reason for the difficulty of tactual picture perception involves the kinesthetic component of tactual processing (Loomis and Lederman 1986).

If there is more uncertainty or distortion associated with the kinesthetic monitoring of hands and fingers than with that of the eyes (relative to the size of the patterns being scanned), as appears plausible (Klatzky and Lederman 1987; Balakrishnan et al 1989), then one would expect touch to be at some disadvantage relative to vision in the integration of successive patterns of receptor activation.

Beyond the differences in sensory processing, there are possible limitations associated with higher-level processing. One involves the ability of the subject to simultaneously attend to noncontiguous regions of the body surface (eg two fingers of the right hand). Although the sensory channel capacity of two fingers of one hand ought to be twice that of either finger, subjects seem unable to take full advantage of this doubling of channel capacity when interpreting 2-D pattern information (Lappin and Foulke 1973; Craig 1985). Two other potentially limiting factors involve working memory and perceptual integration over time. Because tactual perception normally relies more upon sequential exploration than does vision in order to take in the same amount of information, the subject depends more upon both working memory and the process of integration that builds a coherent perception on the basis of sampled information (Hochberg 1986). If either of these factors limits performance, as seems likely, then touch must be at a disadvantage.

A final possible reason for tactual picture perception faring badly in the comparison with visual picture perception would be that line drawings often use 3-D pictorial conventions (eg occlusion, perspective) that have less meaning for touch than for vision. Apparently in support of this claim are the results of several studies. Torii et al (1975) (reviewed in Wake et al 1980) presented raised pictures to blindfolded sighted, adventitiously blind, and congenitally blind observers. The stimuli were four pictures in which one simple figure was occluded by another, and eleven pictures in which perspective was used to depict simple 3-D objects. The congenitally blind were much poorer than the other groups in interpreting the pictures. Three other studies (Kennedy and Fox 1977; Heller 1989; Lederman et al 1990) have also confirmed that the congenitally blind perform more poorly in recognizing raised pictures than those with previous visual experience. As these experiments show that previous visual experience facilitates the tactual perception of pictures, especially those employing 3-D pictorial conventions, it would be incorrect to conclude that 3-D pictorial conventions are ineffective for tactual sensing, for it is possible that blindfolded sighted observers are able to interpret pictorial conventions sensed tactually by employing visual imagery to mediate recognition (Lederman et al 1990). The proper way to evaluate this possibility is to compare visual and tactual picture perception when the two senses are matched closely in terms of the information available.

Besides addressing this possibility, the present study also sought to determine the extent to which the difficulty in recognizing pictures tactually might be attributable to the limited field of view associated with tactual exploration of 2-D images. We examined this question by having subjects attempt to recognize pictures tactually and visually when the spatial information available to the subject was matched as closely as possible in the two conditions. In the tactual condition, subjects explored pictures using one or two fingers. In the visual condition, subjects scanned the same pictures by means of a computer-driven visual display; the subject "explored" the picture by moving an electronic pen over a digitizing tablet in much the same way as the hand moved over the raised picture in the tactual condition. As the pen moved, a portion of the internal image was displayed within a rectangular aperture fixed in position at the center of the display screen. Thus, the subject saw what appeared to be a picture moving behind a stationary aperture, with the visible portion at any moment being determined by the location of the electronic pen. In addition to the field of view being limited, the picture details were blurred to simulate the loss of spatial detail

resulting from spatial filtering by the cutaneous sense (Loomis 1990). This display allowed us to match the visual information to that available through the cutaneous sense, and the subject had virtually identical kinesthetic information from the exploring hand in the two conditions. Thus, strictly speaking, the visual condition provided the subject with a combination of visual and kinesthetic stimulation.

It might be thought that a better visual simulation of tactual exploration would involve the moving aperture mode described in the article by Loomis (1986) rather than the stationary aperture mode used here. In the moving aperture mode, the viewing aperture moves over the stationary image under active control of the subject. We opted not to use this mode in the comparison between touch and vision, for the subject would have received information about the layout of the image both from visual information on the screen and from kinesthesis provided by the hand controlling the electronic pen, thus providing vision with two sources of position information while tactual exploration had only one. However, in response to a suggestion by one of the reviewers, we decided to compare the two visual scanning modes in an experiment subsequent to the first submission of the paper. This subsidiary experiment is presented along with the main experiment in sections 2 and 3.

2 Method
2.1 Subjects
The fourteen female subjects and ten male subjects were students at the University of California, Santa Barbara. Some had participated previously as subjects in visual or tactile experiments, but none of these experiments had dealt with picture perception. By self report, all subjects had normal tactual sensitivity and normal or corrected-to-normal visual acuity. All subjects were naive about the purpose of the experiment.

2.2 Stimulus materials
The twenty-four line drawings used in the experiment are slight variants of a subset of the standardized pictures developed by Snodgrass and Vanderwart (1980); they are shown in figure 1. Seventeen of these were used in the previously mentioned study (Lederman et al 1990). The line drawings depicted objects that could be held with
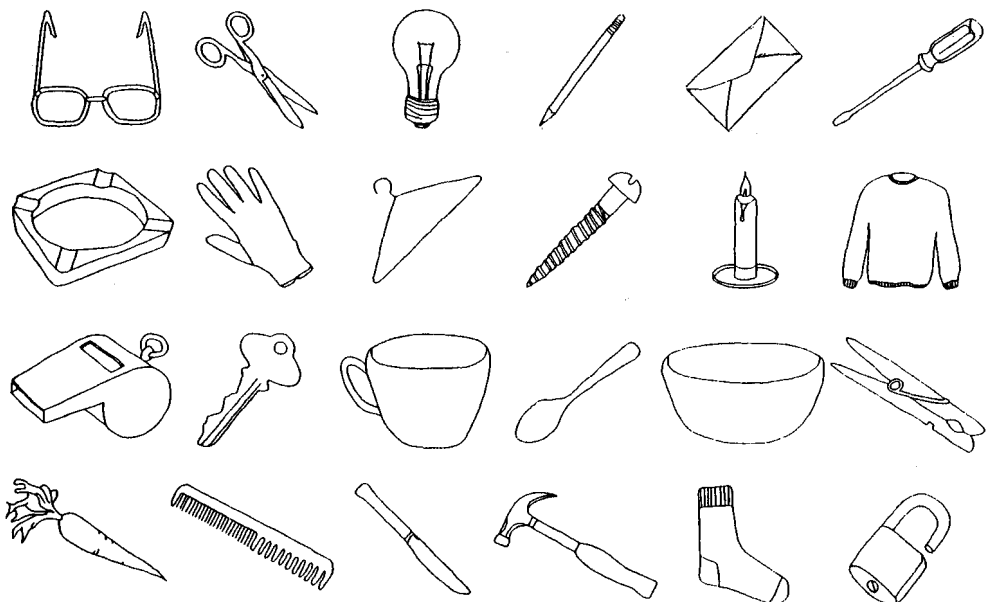

Figure 1. The pictures used in the experiment.

one or two hands and that are labeled with high intersubject agreement. For this experiment, all drawings were scaled up or down in size so that their largest dimension (width, height, or diagonal) just fit within a rectangle 159 mm wide and 113 mm high.

2.3 Tactual stimuli

Raised facsimiles of the pictures in figure 1 were created by xeroxing the drawings onto special heat-sensitive paper and then putting these copies through a Matsumoto Stereo Copy Developer. This method of embossing has been shown to produce tactile maps of superior tangibility (Dacen and Coulson 1988). The resulting raised pictures had lines of uniform stroke width (0.3 mm), uniform height above the paper surface (0.2 mm), and were of the same dimensions as the original line drawings. All picture details were preserved in the reproduction process. During the experiment, the picture for a given trial was placed within a wooden frame of slightly larger dimensions; this frame allowed the subjects to sense the limiting boundary of the tactual workspace.

Subjects in the one-finger condition actively explored the raised pictures with the distal pad of the outstretched right index finger, while subjects in the two-finger condition used the juxtaposed distal pads of the outstretched index and middle finger of the right hand. Subjects were instructed to keep the longitudinal axis (axes) of the finger(s) parallel with the sides of the frame and to ensure that the distal pads were in more or less even contact with the raised parts of the drawing; tilting of the finger to produce contact with the fingertip was not permitted. The purpose in so restricting exploration was to promote closer equivalence with the visual condition. Given these constraints, lateral motions of the hand were effected mostly by rotations about the shoulder while radial motions toward and away from the body were effected by flexions and extensions about the elbow.

In the planning stages we made measurements of the contact area of the distal pad of the right index finger using fingerprinting; this was done in order to match stimulation in the visual condition to that in the tactual condition. Referring to figure 2a, the average contact width (W_t) of the three authors and a fourth person was 9.9 mm for light contact while the average contact length (L_t) was 16.1 mm; these values represent well the average contact region which is actually slightly oval-shaped. These four subjects were judged to be representative of adult subjects since the average full
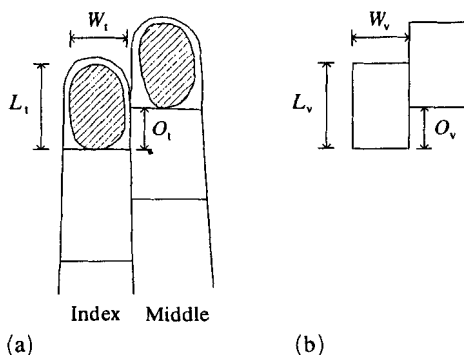

(a)   (b)

Figure 2. (a) Depiction of the index and middle fingers of the right hand viewed from above and behind. The approximately rectangular contact areas were specified in terms of their maximal lengths (L_t) and widths (W_t); the relative offset of the two distal segments is given by O_t. (b) Depiction of two adjoining visual apertures used to simulate the tactual contact areas. Their sizes and relative position were specified by L_v, W_v, and O_v. The scale of the visual apertures was selected so that they were in the same ratio to the size of the visual pictures being scanned as the tactual contact areas were to the raised pictures.

widths and lengths of their distal pads measured by xerography were virtually identical to those of a much larger sample of eight males and ten females obtained in previous work. For the purpose of matching the visual stimulation, the total contact area in the two-finger condition was assumed to be double that of the index finger, and the two contact regions were assumed to abut one another, whereas in fact there was a lateral gap of several millimeters separating the two (figure 2a).

Another measurement was also made for the purpose of matching visual stimulation. For most people, when the index and middle fingers are outstretched and touching one another, the creases separating the distal and medial segments of the two fingers are misaligned (figure 2a). Thus, for each subject we measured the offset (O_t) of the distal segment of the middle finger relative to that of the index finger.

2.4 Visual stimuli

An Applie II Plus microcomputer and an Apple Graphics Tablet (digitizing pad) were used to create a visual simulation of tactual exploration. Prior to the experiment the twenty-four line drawings had been entered into the computer using the digitizing pad. The software allowed presentation of either full or scanned images; these were displayed on a Conrac SNA15/C black-and-white monitor. The video refresh rate was 60 Hz for both display modes; for scan display, the sampling rate of the pen position and the video update rate were both 20 Hz. Full images had a maximum possible horizontal extent of 178 mm (225 pixels) and a maximum possible vertical extent of 128 mm (164 pixels); at the viewing distance of 80 cm, the corresponding angular dimensions were 12.7 deg and 9.2 deg.

In the scanning mode used in this experiment, the subject held an electronic pen in the right hand and moved it over the surface of the digitizing pad in order to reveal different portions of the stored image within the stationary aperture at the center of the screen; a modified version of the program described by Loomis (1986) was developed to effect this mode of scan display. The software was adjusted so that the movement of the pen over an area of 157 mm (lateral) by 104 mm (sagittal) revealed all portions of any image stored in memory. A cardboard frame of slightly larger dimensions limited the movements of the pen in much the same way that the wooden frame limited movements of the fingers in the tactual condition. The dimensions of the pen workspace were quite close to those of the tactual workspace; thus, the subject received virtually identical kinesthetic information when scanning the visual images and when scanning the raised images.

The visual aperture represented either 'one finger' or 'two fingers'. In the one-finger or narrow field condition, the rectangular aperture was 14 pixels wide (11 mm) and 23 pixels high (18 mm), thus constituting 6.2% of the maximum possible width of the picture stored in memory and 14.0% of its maximum possible height (see figure 3). Because the corresponding values in the touch condition were 6.2% and
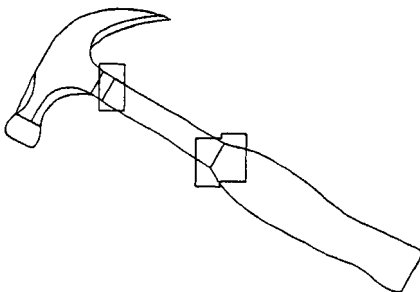

Figure 3. Depiction of the sizes of the 'one-finger' and 'two-finger' apertures relative to the picture of a hammer (in figure 1) in the vision condition.

14.2%, the simulated one-finger aperture covered virtually the same proportion of any given drawing as did the average finger pad in the touch condition. In the two-finger or wide field condition, two apertures of 14×23 pixels were juxtaposed horizontally without any gap. The one-finger and two-finger apertures were fixed in size for all subjects because the software only permitted aperture widths that were integral multiples of 7 pixels (Loomis 1986). In contrast, their relative vertical positions were adjusted for each subject to reflect the relative position of the distal and medial segments of the index and middle fingers; thus, the simulated middle finger aperture was displaced vertically by a number of pixels proportional to the size of the simulated index fingers.

To complete the visual simulation of what the observer experienced in the tactual condition, the imagery on the video monitor was optically blurred so as to mimic any loss of picture detail resulting from the limited spatial resolution of the finger pad (Loomis 1990). To effect an approximate match between visual and tactual spatial resolution, we began by measuring the subject's two-point spatial limen using a series of two-point targets created with the embossing process discussed above; the subject indicated the smallest separation at which the two points were experienced as 'two points'. We then illuminated two pixels on the video monitor that had the same separation when expressed as a proportion of the 'finger width' of the visible aperture. From the subject's viewing distance these would normally be easily resolved. However, a large glass translucent diffusing screen was positioned between the monitor and the subject and was moved toward the observer (thus increasing the blur) until the subject reported the two points to be barely separated. Although this aspect of our procedure ensured that the perceptual fidelity of the visual pictures was approximately equal to that of the raised pictures, it probably was of no great consequence, for very few of the picture details were filtered out under these levels of blurring.

To summarize, the visual pictures were sensed under conditions that provided virtually the same information to the observers as when the raised images were tactually explored. By limiting the visual field of view and the spatial clarity of the video image, the visual information was matched as closely as possible to the cutaneous information in the touch condition. Information about the general layout of the picture was provided in both conditions by the kinesthetic information resulting from hand movement, information that was virtually identical in the two conditions.

2.5 Procedure

Sensory modality was investigated within subjects while the effect of the field size was compared between subjects. Twelve of the twenty-four subjects were assigned randomly to the narrow field condition and the other twelve to the wide field condition. The twenty-four pictures were arranged in four sets (the different rows of figure 1), selected so that all sets were approximately equal in recognizability as assessed in a previous study (Lederman et al 1990). In the experiment proper, each subject was presented with the four sets in counterbalanced order, and the modality was altered after every set (six trials). For example, one subject would be presented with sets of trials in the following order: set 1 with vision, set 3 with touch, set 2 with vision, and set 4 with touch. The starting modality was also counterbalanced across subjects.

Subjects were instructed that the drawings depicted common objects ranging in size from a wedding ring to a pair of trousers but that the drawings had been rescaled to fit the size of the tactual workspace or that of the pen. Prior to the experiment proper, the subjects participated in a practice session in which they received three touch trials and three vision trials using stimuli similar to those in the experiment proper. They were allowed 2 min to respond and were given feedback about the correctness of their response. In the experiment proper, they were also given up to

2 min to respond but received no feedback. Latencies were recorded by means of a stopwatch.

2.6 Subsidiary experiment

As mentioned in section 1, we conducted a subsidiary experiment involving only vision to compare the effectiveness of two ways of displaying pattern information obtained through scanning. The design crossed the two display modes with two aperture sizes. In the stationary-aperture mode, also used above, the scanned information was presented within a stationary aperture at the center of the screen. In the moving-aperture mode (Loomis 1986), the aperture moved about the video screen in concert with the digitizing pen, the result being akin to moving an occluder with a rectangular opening in front of a stationary picture. The glass diffuser used to blur the imagery in the main experiment was fixed in this case at the average distance employed in the main experiment. The two aperture sizes used previously were used here for the two modes, except that there was no vertical offset between the two halves of the wide aperture. In the moving-aperture mode, subjects were not permitted to move the digitizing pen rapidly back and forth, for such a method would have produced an effective visual field much larger than intended, since very rapid scanning differs little from simultaneous full display (Ikeda and Uchikawa 1978) by virtue of screen and visual persistence; instead, subjects were instructed to scan along the contours of the picture in much the same way as they naturally chose to do in the stationary-aperture condition. Because of these much slower scanning velocities and because of the contrast reduction produced by the diffuser in front of the display, screen persistence and visual persistence were deemed negligible. Each of the eight new subjects was presented with six pictures in each of the four conditions; picture sets were counterbalanced across conditions and the order of conditions was counterbalanced across subjects.

3 Results

3.1 Main experiment

Figure 4 gives recognition accuracy (percent correct) and response latency as a function of field size and modality in the main experiment; the error bars represent one standard error of the mean. One obvious result is that visual recognition performance closely matched tactual recognition performance for the narrow field size. Another clear result is that increasing the field size had no effect for touch but a large effect for vision. This latter result was confirmed with mixed-model ANOVAs performed on both measures; for recognition accuracy, there was a significant field
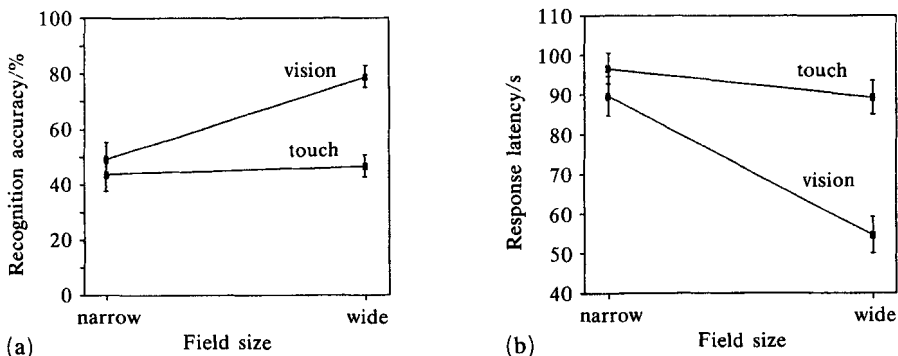

Figure 4. (a) Recognition accuracy and (b) response latency as a function of field size for visual and tactual exploration. Narrow field represents one finger and wide field represents two fingers. The error bars represent one standard error of the mean.

size by modality interaction $(F_{1,22} = 9.02, p < 0.01)$ as well as main effects of modality $(F_{1,22} = 15.24, p < 0.001)$, and field size $(F_{1,22} = 7.30, p < 0.02)$. Similarly, for response latency, the interaction was significant $(F_{1,22} = 11.91, p < 0.01)$ as were the main effects of modality $(F_{1,22} = 26.65, p < 0.001)$ and field size $(F_{1,22} = 16.48, p < 0.001)$.

Table 1 gives the number of correct responses (out of six) and the average response latencies as a function of picture and modality, for the narrow field condition only. Within each modality, recognition accuracy and response latency are highly negatively correlated $(r = -0.83$ for vision and $r = -0.84$ for touch). When compared across modalities, response latency for touch correlates significantly with latency for vision $(r = 0.45, p < 0.025)$; the corresponding correlation for recognition accuracy is lower $(r = 0.28)$. These correlations, though based on data of limited reliability, provide additional evidence for some degree of similarity between tactual and visual processing with the narrow field of view.

In a control condition, five additional subjects were tested for visual recognition of the pictures in the absence of a restricted field of view. The diffuser was set at the greatest value of blur used by any of the subjects in the main experiment. Recognition accuracy was 100% with the response latency averaging 1.3 s. This control condition shows that the difficulties subjects had in recognizing pictures both in the visual and in the tactual conditions of the main experiment cannot be due to poor depiction or to the limited spatial resolution produced by blurring.

Table 1. Number of correct responses (out of six) and average response latencies for visual and tactual recognition with the narrow field condition.

Picture	Vision		Touch	
	correct responses	response latency/s	correct responses	response latency/s
Lightbulb	6	65	4	82
Pencil	6	27	4	68
Envelope	2	94	3	102
Glove	3	99	4	92
Hanger	1	107	5	70
Screw	4	62	2	120
Sweater	2	105	0	118
Key	3	109	2	102
Spoon	2	85	5	62
Clothespin	1	115	0	120
Carrot	1	114	4	104
Comb	5	66	4	68
Knife	1	77	2	97
Sock	1	101	1	112
Glasses	5	79	2	106
Scissors	6	42	4	89
Screwdriver	4	67	1	113
Ashtray	0	120	1	120
Candle	6	72	1	110
Whistle	1	118	0	120
Cup	5	83	2	83
Bowl	4	89	6	66
Hammer	2	111	5	99
Lock	0	120	1	120

3.2 Subsidiary experiment

For the stationary-aperture mode, mean recognition accuracies were 38% and 71% for the narrow and wide apertures, respectively; the corresponding mean response latencies were 106 s and 68 s. Both sets of measures are in reasonable agreement with the values obtained in the main experiment for vision (figure 4). For the moving-aperture mode, the recognition accuracies were 71% and 75% for the narrow and wide apertures, respectively; the corresponding response latencies were 74 s and 55 s.

A two-way repeated-measures ANOVA (mode by field size) on the recognition accuracies showed significant main effects of mode ($F_{1,7} = 17.93$, $p < 0.01$) and field size ($F_{1,7} = 15.2$, $p < 0.01$), and a significant mode by field size interaction ($F_{1,7} = 7.4$, $p < 0.05$). Similarly, an ANOVA on response latencies showed a significant main effect of mode ($F_{1,7} = 37.7$, $p < 0.001$), a marginal effect of field size ($F_{1,7} = 5.5$, $p = 0.051$), and a significant mode by field size interaction ($F_{1,7} = 8.8$, $p < 0.05$).

The results of the subsidiary experiment clearly show that the moving-aperture mode results in better performance than the stationary-aperture mode. This superiority might be expected on the grounds that the moving aperture provides an additional source of overall spatial layout that is not available in the stationary-aperture mode or in tactual scanning. However, we note that the moving-aperture results, though better than those obtained with a stationary aperture, also support our claim that viewing with a narrow aperture is far more difficult than full-field viewing. We also note that although doubling the field size in the moving-aperture mode produced little improvement in recognition accuracy, it did produce a significant reduction in response latency ($t_7 = 3.1$, $p < 0.01$); thus, the finding that doubling the field of view had a significant effect for vision but not for touch is true whether one considers the moving-aperture or stationary-aperture mode.

4 Discussion

When care was taken to match active visual exploration and active tactual exploration in terms of effective information (main experiment, see section 3.1), mean recognition performance, assessed in terms of both accuracy and latency, was essentially the same for both sense modalities with the smaller field size. Because tactual performance showed little improvement when the field size was doubled, it would appear that the effective tactual field of view is limited to one finger and that much of the difficulty subjects have in recognizing raised pictures can be ascribed to this narrow effective field of view. At the very least, the near equivalence of vision and touch for the narrow field size rules out the possibility that poor tactual picture perception can be ascribed solely to subjects' inexperience with tangible graphics displays.

It seems unlikely that the narrowing of the field size exerts its influence simply by limiting the amount of stimulus information sampled within a given time interval because, during the allowable two minutes of exploration, subjects were easily able to sample all picture information even with the narrow field size. It seems much more likely that restricting the field of view, which necessitates sequential sampling of the pattern, gives rise to difficulties at higher levels of perceptual processing. As indicated earlier, subjects depend more on working memory and some process of integration when interpreting patterns scanned with a narrow field of view. Thus, a reasonable hypothesis is that recognition performance when the field of view is restricted is impeded by limitations in working memory or in the integration process.

With regard to the possibility that sighted observers are less able to make use of pictorial conventions when sensing by touch rather than vision (Lederman et al 1990), the evidence is not compelling. Comparing the pictures in figure 1 with the results

given in table 1, it is far from obvious that pictures employing 3-D conventions are selectively more difficult to recognize by touch than by narrow-field vision. For example, whereas the glasses and candle make use of such conventions and were easily recognized by vision and poorly recognized by touch, the hammer and bowl constitute counterexamples. Thus, based on these data, one cannot argue forcefully that touch is at a disadvantage relative to vision in its capacity to use pictorial conventions, at least for subjects with visual experience. A more decisive experiment on this point would involve the deliberate selection of pictures employing more salient perspective and occlusion cues and of pictures lacking such cues and the presentation of these pictures to the two senses under conditions of equivalent information availability, as in the present experiment.

The second important result is the differential effect that increasing the field of view had for the two senses. Doubling the width of the field produced a substantial increment in visual recognition performance, measured in terms of both accuracy and latency, but virtually no change in tactual recognition performance. The improvement in visual performance implies that subjects were able to integrate information across the double aperture, although not necessarily perfectly. In addition, the fact that the larger aperture, though still constituting only a small fraction of the total picture extent, permitted nearly 80% correct recognition, implies that subjects were using kinesthetic information from the arm and hand quite effectively in temporally integrating the successive images appearing in the visual aperture. This rules out the possibility that poor arm/hand kinesthesis accounts for the difficulty of tactual picture perception.

The finding that doubling the tactual field of view resulted in little improvement in performance is consistent with the results of Craig (1985) and of Lappin and Foulke (1973). However, the failure of Lappin and Foulke to find evidence of integration across the index and middle fingers in a task involving downward scanning of parallel columns of braille characters could be attributed to a central limitation—because the subject was being asked to identify two different characters on the two fingers at the same time, one could hypothesize that there was parallel perceptual processing up to a serial process of identification. In contrast, Craig (1985) found that even when a single pattern was spread across two fingers of the same hand, subjects seemed unable to fully integrate the distributed information while attempting to recognize the pattern. His task is thus much more similar to the present task in which information about a single pattern is available to two adjacent fingers.

Why might it be so difficult for subjects to integrate 2-D pattern information over adjacent fingers? One reason suggested to us by J C Craig (personal communication, November 1988) is that when we normally explore with our hands, the changing relative positions of the fingers imply a lack of invariance in the spatiotemporal stimulation in the somatosensory cortex; this lack of invariance might make integration of pattern information across the somatosensory cortex difficult even under temporary circumstances where spatiotemporal stimulation is invariant (ie with fingers abutting). Arguing against this idea are some other results of Craig (1985) showing that integration across the fingers is improved somewhat when the pattern information is distributed across the index fingers of the two hands. This result suggests that the difficulty in integrating over the two fingers of one hand might be the result of between-finger masking or inhibition (Craig 1985) rather than an inability to spread attention.

The failure to find across-finger integration for pictures of objects is counter-intuitive, for one certainly would expect such integration in the active exploration of 3-D objects. However, if five-finger exploration of 3-D objects should prove superior

to one-finger exploration, the advantage of the former might be the result of shape information provided by hand kinesthesis rather than the enlarged cutaneous field of view for pattern information. An experiment to clarify this issue is now in progress.

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