Central and peripheral influences on tactual reading

MORTON A. HELLER

Winston-Salem State University, Winston-Salem, North Carolina

Subjects attempted to read two-, three-, or four-letter words printed on their palms, wrists, or fingers. Successive letters were either drawn over each other at the same location or were spatially separated on skin surfaces. A peripheral source of masking was suggested, since reading was aided by writing letters at different cutaneous locations. Two-letter words were easy to read when two palms or the palm and wrist were used. Due to interdigit masking, however, spatial separation of letters did not help when they were printed on the fingers of one hand. Central contributions to tactual reading were indicated, since categorical information aided reading, as did knowledge of (constant) orientation. The difficulties found in reading Print-On-Palm (POP) were ascribed to aftersensations derived from drawing a point across the skin, a passive form of touch. It was proposed that passive touch may be limited in performance when memory is severely loaded. However, passive touch may suffice for simple patterns, since passive POP was better than active touch for letter recognition.

Drawing on the skin is a form of tactual experience that poses significant practical and theoretical problems, yet has only recently begun to prompt systematic inquiry. Deaf-blind individuals are trained to read printing on the skin of the palm, or Print-On-Palm (POP), with varying degrees of success (R. J. Smithdas, personal communication, July 6, 1983). Neurologists, however, take the skill for granted in normals and evaluate the status of one's parietal lobe by drawing symbols on the skin (Critchley, 1953; Harley & Grafman, 1983). To add further confusion to the picture is Diderot's claim (cited in Morgan, 1977) that a blind mathematician named Saunderson could recognize the face of a friend from images drawn on the palm. Diderot suggested, "The blind could thus have their own kind of painting, in which the skin would serve as their canvas." His comments are remarkable, given the tendency of observers to describe straight tracks on the forearm as curved (Langford, Hall, & Monty, 1973). Moreover, subjects are poor at reproducing shapes that are drawn on the palm, often perceive closed forms as open (Heller, 1980a), and make errors in detecting direction (Dreyer, Hollins, & Whitsel, 1978).

The present investigation is relevant to the theoretical distinction between active and passive touch (Gibson, 1962, 1966; Revesz, 1950). Drawing on the skin qualifies as passive touch, since the observer is immobile during cutaneous stimulation. In active touch, a more "nor-

mal" tactual experience, self-produced movement presumably leads to information pickup. Although active touch is often assumed to be superior to passive touch (Gibson, 1962; Heller, 1980a, 1980b, 1984), the data are inconclusive. Schwartz, Perey, and Azulay (1975) failed to find an advantage for active over passive touch when both methods used the fingertip. Furthermore, Magee and Kennedy (1980) reported a superiority for passive touch in the identification of large, raised-outline drawings of common forms. Heller and Boyd (1984) have found active touch to be inferior to passive exploration of hollow, template patterns with a pen-like wand.

Heller (1980b) suggested that passive touch might promote aftersensations and consequent masking effects as observers attempted to read POP. In his study, individuals were required to read random sequences of letters, numbers, or individual words drawn on their palms. Retention of sequences was poor when the stimuli were presented at interstimulus intervals (ISIs) of 1 sec. Slower rates aided recall, with significant gains being obtained for ISIs of 3 and 5 sec. It was proposed that tactile retention was limited by passivity. In a related study, Manning (1980) found evidence for tactual sensory memory in a demonstration of suffix effects while letter sequences were being drawn on the skin. She found that a decrement in the recall of a sequence of tactual stimuli was produced by a "not-to-be-remembered" item added to the end of a list.

The purpose of the present study was to isolate the causes of impaired tactile reading and retention. It was hoped that the best method for printing on the skin would be discovered. Prior research on POP had presented letters sequentially at the same location on the skin. Thus, a form of overwriting probably took place with a possible cutaneous source of interference. It seemed plausible that

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The author's mailing address is: Department of Psychology, Winston-Salem State University, Winston-Salem, NC 27110.

such masking effects might be minimized by drawing successive letters on different skin surfaces.

A number of experiments were performed to identify central and peripheral influences on tactual reading. Experiments 1-4 sought to determine whether tactual reading would be aided by the printing of letters at different locations; if it were, tactual interference effects might be partially derived from peripheral masking. The last two experiments examined the variables of categorical information (Experiment 6) and orientation (Experiment 7).

EXPERIMENT 1

The first experiment was designed to investigate the role of peripheral factors in masking in POP. Two-letter words were printed with both letters in the same or different locations. Superior word recognition in conditions in which letters were drawn on distinct surfaces would suggest a peripheral contribution to masking.

Method

Subjects. There were 42 undergraduate student volunteers. Half were males and half were females.

Stimuli and Apparatus. Printed capital letters were drawn on the subjects' palms or wrists. The standardized procedure for POP was used; this is described in the "Guidelines for Helping Deaf-Blind Persons" provided by the Helen Keller Center (R. J. Smithdas, personal communication, July 6, 1983). The letters were approximately 4 cm high¹ and were drawn freehand with the aid of a Lucite rod with a .16-cm rounded tip. All subjects were required to read 26 two-letter words: LA, AT, BY, DO, UP, TO, MA, LO, IS, HI, HO, PA, ON, WE, SO, MY, IT, ME, IN, HA, GO, BE, AM, OF, AX, and NO. The letters were drawn at a rapid rate with ISIs of 1 sec in the present and subsequent experiments. The stimuli were presented in an upright orientation for the subjects, and vision of the skin was blocked by a Masonite screen.

Design and Procedure. The experimental variable was the locus of presentation of successive letters. The letters were either printed over each other at the same location on the palm (same palm condition), or were presented with the second letter of each word at a different location. There were two different-location conditions. In the first, the two-palms condition, one letter was drawn on the left palm and the second letter of each word was drawn on the right palm. With their vision obscured, subjects in this condition had their hands flat on a pad before them. The letters were drawn so that the tops of the letters were farther from the subjects (in the horizontal plane) than the bottoms. Subjects in the palm-wrist condition experienced the letters on their palms and wrists, with the bottoms of the letters oriented toward the fourth-finger edge of the hand and with the arm turned to allow the letters to be in a vertical, upright position with respect to the subject. For the right arm, the first letter of a word was drawn on the palm and the second letter was drawn on the wrist (see Figure 1); for the left arm, the first letter was drawn on the wrist and the second was drawn on the palm. Thus, in both cases, the letters were read from left to right. Half of the subjects in the same-palm and palm-wrist groups started with the left limb for one half of the words and completed reading with the right limb. The rest of the subjects in these two conditions began with the right hand. All subjects were instructed to identify the two-letter words after they were printed and to guess if uncertain; feedback was not given.

Results and Discussion

Tactual reading was best when successive letters were drawn on separated skin surfaces (see Table 1). A sim-

Figure 1. The top portion shows the printing method used in Experiment 2. The bottom portion illustrates the print-on-palm-and-wrist procedure used in Experiment 1.

ple analysis of variance performed on the number of words correct showed that the effect of locus was highly significant [$F(2,39) = 6.31, p < .01$]. A Newman-Keuls test indicated that mean performance for both the separate-palms condition and the palm-wrist condition was superior to that obtained when successive letters were drawn on the same palm ($p < .05$ for both comparisons). The two separate-location means, however, were not significantly different in accuracy ($p > .05$). Same-palm performance (62% correct) was similar to that reported by Heller (1980b) for two-letter words (59% correct).

The results, showing that physical separation of letters on the skin aided reading, support the notion that a peripheral source of masking contributes to impairment

Table 1
Mean Number Correct and Standard Deviations for Words
Printed on the Palm, on the Palm and Wrist, or on Two Palms

Mode of Presentation of Successive Letters	Mean Number Correct	Standard Deviation
Same Palm	16.4	4.6
Different Palms	19.7	4.0
Palm and Wrist	21.4	2.7

Note—The maximum score possible = 26 correct.

in the reading of POP. It is not known, however, which explanation of masking is most appropriate. Masking might develop because of limited temporal resolution to aftersensations, or to attentional disturbances (Loomis, 1981) or lateral inhibition (see Crowder, 1978).

EXPERIMENT 2

The purpose of the second experiment was to test the generality of the effect of letter separation on the decoding of POP. Three- and four-letter words were printed on the palms and wrists of subjects. The letters were drawn successively on the same palmar surface, on the same place on the wrist, or on separated areas. It was expected that fewer identification errors would occur with shorter words and when letters were printed on separated skin locations.

Method

Subjects. Thirty-six naive subjects served in the second experiment. Equal numbers of males and females were assigned to each condition.

Stimuli. Fourteen three- and four-letter words were taken from Christian, Bickley, Tarka, and Clayton (1978). All words, with capital letters printed as in the first experiment, had high recall scores. The three-letter words were: FUN, BOY, ARM, JOY, NUN, SKY, ROD, KEG, LIP, GEM, FOX, BAR, AIR, and CAR. The four-letter words were: ARMY, FROG, JURY, CORN, DUTY, BABY, CAMP, MULE, STUB, TIME, HALL, BOWL, GIFT, and IRON.

Procedure. Subjects placed both arms through a cloth-covered opening in a Masonite screen, and rested them, parallel to each other, flat on a pad. The first two letters of each word were printed on the left arm, with the first letter on the palm and the second on the wrist. The last letter or letters were printed on the right arm: the last letter of a three-letter word was drawn on the palm; the third letter of a four-letter word was drawn on the palm and the fourth was drawn on the wrist (see Figure 1). With this arrangement, the observer faced the upright letters and read them from left to right. Individuals were given prior information about word length, but, as in the first experiment, feedback was not given. The three-letter words were presented first, the four-letter words next.

Results and Discussion

Table 2 summarizes the results of the second experiment and shows that reading was aided overall by printing the letters on distinct, separate locations. A detailed examination of the data, however, displays a more complex picture. A mixed-factor analysis of variance revealed that the effect of method of printing (location) was significant [$F(2,33) = 5.1, p < .05$], as was the effect of

word length [$F(1,33) = 4.6, p < .05$], but that the interaction was also significant [$F(2,33) = 5.0, p < .05$]. Tests on simple main effects exhibited a significant effect of word length, but only when letters were printed on different locations [$F(1,33) = 10.57, p < .01$]. Word length had no effect on performance when successive letters were printed on the same palm [$F(1,33) = 2.6, p > .05$] or the same wrist [$F(1,33) = 1.3, p > .05$] location. Moreover, the effect of location was significant when the words had three letters [$F(2,33) = 8.4, p < .01$] but not when they had four letters [$F(2,33) = 1.7, p > .05$]. Individual F tests showed that presentations of letters on different surfaces produced better reading than did presentations of the three letters of a three-letter word on the same palmar skin [$F(1,33) = 8.4, p < .01$] or the same wrist [$F(1,33) = 15.7, p < .01$]; the palm and wrist conditions did not differ significantly [$F(1,33) = 1.1, p > .05$].

Peripheral contributions to tactile interference in reading POP are indicated by the benefits obtained when reading successive letters of three-letter words on spatially distinct skin surfaces. Because of the lingering of sensory images from prior stimulation, it may be difficult to attend to a stimulus drawn on the skin. Unfortunately, spatial separation failed to aid in the reading of longer words. Although it seems reasonable to suppose that the effect of spatial separation should be evident with longer words, memory may become easily overloaded when touch is passive (Heller, 1980b). The helpful effects of spatial dissociation are apparently insufficient to overcome the limitations imposed by 1-sec ISIs. Moreover, it is possible that there were order effects in Experiment 2; that is, four-letter words may have suffered by always being second.

EXPERIMENT 3

Experiment 3 investigated the feasibility of printing letters on the fingers of individuals. "Print-On-Finger" might have advantages over POP, since fingers are more sensitive than the palm or wrist (Sinclair, 1967). Forms are perceived more accurately when explored with fingers

Table 2
Mean Number Correct and Standard Deviations for
Three- and Four-Letter Words Printed on the
Palm, the Wrist, or the Palm and Wrist

Location of Successive Letters	Word Length	Mean Number Correct	Standard Deviation
Same Palm	3	5.8	2.3
	4	4.7	2.8
	Overall	10.5	4.6
Same Wrist	3	4.7	2.5
	4	5.5	2.7
	Overall	10.2	4.6
Palms and Wrists	3	9.0	2.5
	4	6.7	3.2
	Overall	15.7	5.0

than when explored by the palm (Gibson, 1962), and neurologists print numerals on fingers to evaluate parietal integrity (Harley & Grafman, 1983). In the third experiment, letters were printed successively over each other on the end of the index finger or were drawn sequentially, with each letter on a different finger of the preferred hand. On the assumption that peripheral, local interaction is responsible for failures to comprehend POP, it was expected that spatial separation would facilitate performance.

Method

Subjects. The subjects were 28 volunteers, none of whom had participated in any previous experiment on tactual reading. Equal numbers of males and females were assigned randomly to each condition.

Stimuli and Apparatus. The approximately 1.3-cm-high letters were drawn on the fingerprint skin of the preferred hands of subjects. Two-, three-, and four-letter words were printed in capitals in an upright orientation for participants. The words were: AT, BY, DO, UP, TO, MA, LO, IS, HI, HO, FUN, BOY, ARM, JOY, NUN, SKY, ROD, KEG, LIP, GEM, ARMY, FROG, JURY, CORN, DUTY, BABY, CAMP, MULE, STUB, and TIME. The three- and four-letter words were taken from Christian et al. (1978). Vision of the letters was prohibited, as in Experiments 1 and 2.

Design and Procedure. The experiment took the form of a mixed-factor analysis of variance, the variables being location of stimulation (same or different) and word length, with repeated measures on word length. All subjects were exposed to 10 two-letter words, then to 10 three-letter words, and finally to 10 four-letter words. The subjects were informed about word length prior to stimulation, but feedback was not given. In one condition, the letters were printed at the same place on the fingerprint skin of the index finger. In a second condition, two-letter words were printed on the index and middle fingers; three-letter words were written with successive letters on the index, middle, and ring fingers; four-letter words were presented with the letters on the index, middle, ring, and fourth fingers of the preferred hand. The letters were drawn so that for right-handed individuals the last letter was on the index finger and for left-handed individuals the first letter was on the index finger, thus allowing the words to be read from left to right. It should be noted that there is a possible confound in this experiment between fingers used and word length. Two-letter words were always drawn on the index and middle fingers, but longer words used other fingers, for example, the ring finger.

Results and Discussion

Table 3 gives means and standard deviations for words with letters printed over each other or on different fingers of the same hand. Performance was better for two-letter words than for longer words, but the separation of letters did not seem to improve reading. It was interesting that POP was more suitable for tactual reading than was writing on the fingers. The palm-and-wrist printing in Experiment 1 produced 82.3% correct readings for two-letter words, whereas the finger printing of the present experiment produced 50% correct readings.

A mixed-factor analysis of variance showed that shorter words were read more easily than longer words [$F(2,52) = 19.8, p < .01$], but the main effect of locus was not significant ($F < 1$), as was the interaction ($F < 1$). A Newman-Keuls test (with the data collapsed over the location variable) indicated that two-letter words were read more easily than were longer words ($p < .01$). Four-

Table 3
Mean Number Correct and Standard Deviations for Two-, Three-, and Four-Letter Words Printed on the Index Finger or on Two, Three, or Four Fingers

Location	Word Length	Mean Number Correct	Standard Deviation
Index Finger	2	5.0	3.0
	3	2.6	2.3
	4	2.4	2.3
Separate Fingers	2	5.0	2.5
	3	3.0	1.5
	4	3.1	2.0

letter words, however, were no more difficult to read than were three-letter words ($p > .05$).

The failure of the use of multiple fingers of one hand to aid reading is consistent with the findings of Lappin and Foulke (1973). They found that two fingers on two hands were better than two fingers on the same hand for reading punctiform patterns.

EXPERIMENT 4

The fourth experiment examined the possibility that tactual reading of printed symbols would benefit from the use of fingers on two hands, just as two palms had aided reading in Experiment 1.

Method

Subjects. There were 20 subjects.

Stimuli and Apparatus. The 26 two-letter words were the same as those used in the first experiment, but the letters were only approximately 1.8 cm high.

Design and Procedure. The words were drawn on the fingerprint skin. Same-location subjects had the second letter of each word drawn over the first on the index finger. Half the words were printed on the left hands of these subjects and half were drawn on the right. Different-location subjects had the first letter of each word printed on the left index finger and the second on the right index finger.

Results and Discussion

Performance was better when two hands were used [$t(18) = 2.29, p < .05$]. The mean number of words read correctly was 17.6 (SD = 5.4) for the same-location condition and 21.9 (SD = 2.4) for the different-location condition. This finding provides further evidence for a peripheral contribution to tactual masking effects.² The higher level of performance for the fingers in Experiment 4 was similar to the level of accuracy obtained for two palms in Experiment 1. Subjects in both conditions of the present experiment outperformed the single-finger subjects of Experiment 3, perhaps because of the larger size of the stimuli (1.8 vs. 1.3 cm).

EXPERIMENT 5

The purpose of Experiment 5 was to compare the accuracy of active and passive letter recognition. The mediocrity of tactual reading could result from inefficient let-

ter recognition when symbols are printed on the skin (although this would seem to be unlikely on the basis of neurological reports) or be due to memorial factors. Active tracing of outline letters produces recognition accuracy of over 90% correct for most letters (Austin & Sleight, 1952; Seminara, 1960). Moreover, Seminara's report that haptic exploration of 1.7-cm-high raised letters yielded accuracy scores of at least 95% for long words suggests that active tactual reading of words is superior to passive reading. Subjects in the present experiment identified letters drawn on their palms, or used their index fingers to trace large letters grooved in plastic. It was not known which condition would prompt better performance, since prior research had used patterns of different sizes, and direct comparisons of active and passive shape recognition had been limited to geometric forms and simple patterns (Heller, 1984) or other nonverbal material (Magee & Kennedy, 1980).

Method

Subjects. Twelve subjects were used in Experiment 5.

Stimuli and Apparatus. The 26 letters were presented twice each, in a random sequence, for a total of 52 trials per mode. A different random arrangement of stimuli was prepared for the active and passive recognition conditions. The letters were drawn approximately 6.0 cm high on the palm and were oriented in an upright position for the subjects. For active touch, the stimuli consisted of 6-cm-high patterns grooved into acrylic. The grooves were 6 mm wide and approximately 1 mm deep.

Procedure. Active touch entailed tracing the grooved letters with the tip of the index finger of the preferred hand. Half of the subjects first attempted to recognize 52 letters using active touch and then were exposed to passive touch with the letters drawn on the palm. The sequence was reversed for the rest of the observers. All individuals were permitted up to 15 sec of exposure to each letter before a response was required, but were asked to respond as soon as they knew what the letter was. In the passive condition, with a maximum of 15 sec of exposure time, each letter was redrawn if the subject requested it. Although the observers were told that they would be timed with a stopwatch, they were asked to strive for accuracy. In the active condition, the clock was started when the active finger first contacted the top of each letter; in the passive condition, the clock was started as the experimenter first began to draw each symbol. Feedback was not given.

Results and Discussion

Letter recognition was better in the passive condition. The mean number correct was 45.3 ($SD = 4.3$) for POP and 37.3 ($SD = 7.6$) for active touch. The effect of perceptual mode was significant [$t(11) = 4.5, p < .01$]. Subjects required significantly less exposure time in the passive condition than in the active condition [$t(11) = 12.4, p < .01$]. The mean exposure time was 9.43 sec for active touch and only 4.0 sec for POP.

The difficulties found with passive retention cannot be ascribed to problems in the registration or detection of form per se, since individual letter recognition was good in the present experiment. These results are consistent with Piaget and Inhelder's (1967) suggestion that passive touch may be poor only when patterns are complex and place a substantial load on memory. Thus, the difficul-

ties encountered with POP stem not from any difficulty in reading individual letters, but from subjects' inability to recall sequences of drawn letters and integrate them into words. It is easy to actively read words consisting of raised-outline letters (Seminara, 1960),³ and thus active touch may be superior to passive touch when memory is strained.

EXPERIMENT 6

Experiment 6 was designed to see if a central factor, categorical information, would have an impact on pattern recognition. Independent groups of subjects either were told that shapes, letters, or numbers would be drawn or were provided categorical information prior to the presentation of each stimulus configuration. The importance of categorical information would be shown by lower recognition scores when subjects were not given prior information about the classification of each of the patterns.

Method

Subjects. There were 20 naive subjects in Experiment 6.

Stimuli and Apparatus. The stimuli were printed capital letters, numbers, or familiar, nameable geometric shapes. The letters were A-H, the numbers were 2-9, and the shapes were a rhombus, a square, and a triangle. These patterns were chosen to preclude certain types of categorical errors; that is, "O" and "I" were not studied since they could easily be mislabeled even when correctly perceived. A random arrangement of the stimuli employed each pattern twice, for a total of 38 trials per subject. The forms were drawn approximately 6 cm high in an upright orientation on the preferred palm.

Design and Procedure. The experiment was a mixed-factor design with repeated measures on type of pattern. The independent factor was the provision of categorical information. The patterns were drawn just once per judgment. Observers in the prior-information condition were told the classification of each pattern before it was drawn. Control subjects were informed that the patterns would be upright geometric forms, printed capital letters, or numbers; they were not told anything else about the forms. This information was provided to the control subjects only at the start of the experimental session. The observers were instructed to name the stimuli after they were drawn. Feedback was not given.

Results and Discussion

Recognition was impaired when categorical information was not available prior to the presentation of each stimulus. A mixed-factor analysis of variance performed on the data for numbers and letters showed that the effect of categorical information was highly significant [$F(1,18) = 6.4, p < .02$]. Item type had no effect on recognition [$F(1,18) = 1.7, p > .05$], and the interaction was not significant [$F(1,18) = 3.3, p > .05$]. Mean percent correct responses (with the data collapsed over item type) for the prior-information and control conditions were 90.3% and 72.5%, respectively. Performance was lower for shapes overall, with 53.3% correct. The limited number of observations with shapes did not permit meaningful statistical tests.

The results of the present experiment suggest that high levels of tactual reading accuracy may demand prior in-

struction in symbol classification. Subjects do not seem to have an immediate comprehension of a pattern's category when different types of symbols are presented. The lower level of performance for highly familiar shapes is consistent with the findings of prior research done with drawn forms (Heller, 1980a). Form perception may require more precise spatial understanding than letter recognition and may place a greater burden on memory with sequential presentation methods. If an observer knows a letter will be drawn, detection of the number of component lines could serve to distinguish, say, a letter F from an E. A discrimination based on such an analysis of stimulus features is less likely to be successful when categorical status is ambiguous.

A central contribution to tactual reading is implicated by the significant effect of categorical information. Subjects engage in a conscious process of hypothesis testing when forms or symbols are traced with a moving point on the skin, and use decisions about stimulus characteristics to label them. For example, most observers report counting lines as the letters are drawn. The next experiment was designed to investigate other central influences on tactual reading.

EXPERIMENT 7

The purpose of this experiment was to determine if knowledge of the orientation of patterns would be important for efficient and adequate tactual reading. Earlier research had failed to show an effect of orientation on symbol recognition when letters or numbers were drawn on the palm (Heller, 1980b, 1981). Subjects in those experiments, however, were always informed about orientation; that is, they were told when letters were to be inverted. Rock (1973) reported that tactual recognition of familiar forms was disrupted when no information about figure tilt was provided and orientation was varied. The present experiment investigated the influence of knowledge of orientation on the accuracy of tactual reading of two-letter words.

Method

Subjects. Forty undergraduate students participated in this experiment.

Stimuli. The stimuli were 27 two-letter words drawn from the first experiment, with the addition of PI.

Design and Procedure. The method of drawing was similar to the palm-and-wrist procedure of Experiment 2. Subjects in three of the independent groups were given prior information about the orientation of the letters. The words were upright for the subjects in one group, inverted for a second, and perpendicular to the arm axis for a third group (the experimenter sat to the left of the subjects in the perpendicular group and drew letters toward the experimenter). Orientation of the letters varied from trial to trial in the variable-orientation condition. The two letters of each word were always presented in the same orientation, but one third of the words were upright, one third were inverted, and the rest were perpendicular to the arm axis, in a random arrangement. Variable-orientation subjects were told, at the start of the session, that words would be printed in these assorted orientations, but were not in-

formed about the orientation of individual words. The first letter of each word was always drawn on the horizontal palm.

Results and Discussion

Tactual reading was very poor when orientation was variable and subjects had to "guess" where the top of each form was. The mean number of words correctly identified for the variable, perpendicular, upright, and inverted orientations were 10.4, 21.1, 20.2, and 19.5, respectively. The effect of orientation was significant [$F(3,36) = 15.7$, $p < .01$], but only because of poor performance in the variable condition. A Newman-Keuls test indicated that orientation per se had no effect on performance, since tactual reading was comparable in the perpendicular, inverted and upright conditions ($p > .05$ for all comparisons) when subjects were told about the orientation of the words. Performance was significantly worse in the variable condition than in all the other conditions ($p < .01$ for all comparisons).

The subjects were poor at tactual reading when orientation was not known, a finding that is consistent with Rock's (1973) assertion that a form's appearance depends upon orientation. The present results do not, however, permit ready speculation on the phenomenal qualities of shapes. It is merely apparent that letters are confusable when directional information is withheld. The letters W and M, for example, differ mainly in orientation (see Reiser & Pick, 1976).

Unfortunately, there are two differences between the variable condition of Experiment 7 and the other conditions, and either factor could have contributed to impaired performance. The variable-orientation procedure may have reduced performance because observers were not provided with knowledge of the orientation of patterns or because the orientation of the patterns was changed from trial to trial. Both of these factors could jointly or individually modify perception. To shed further light on this problem, two additional groups were run with the stimuli of the seventh experiment. In one group, the orientation of the words was shifted from trial to trial, but the subjects were always told what the orientation of each word was. In a second condition, all the letters of the words were inverted, but the subjects were given no information about the true orientation of the letters as the experimenter sat to the left of the subject. Performance was equally poor in these two groups ($t < 1$). The mean number correct was 12.7 when orientation was variable and orientation instructions were given, and only 10.1 for the inverted condition without information on orientation. Prior knowledge about orientation clearly matters: subjects in the inverted condition of Experiment 7 performed significantly better than did subjects in the inverted-letters condition in which orientation information was denied. When asked, after the experiment, most subjects in the inverted-letters condition said they thought the letters were printed facing toward the experimenter, that is, in the perpendicular orientation. The fact that

variability of orientation degrades performance is shown by the finding that information on orientation had no effect on accuracy in a comparison of mean performance for the variable conditions with and without prior information ($t < 1$). It is apparently difficult to adjust to rapid fluctuations in orientation, a process that takes some time. The results demonstrate that tactual form perception depends upon knowledge of orientation and its constancy.⁴

GENERAL DISCUSSION

The results of the experiments suggest that tactual reading is influenced by both central and peripheral factors. Sensory and perceptual variables act in concert to modify the pickup of pattern information by the skin. The benefits of spatial separation of letters imply that sensory persistence may impede tactual reading. These results are consistent with the effect of rate of presentation on detection of sequences of patterns (Craig & Sherrick, 1982; Heller, 1980b). The effects of categorical information (Experiment 6) and knowledge of orientation (Experiment 7) implicate postsensory, central factors. The expectations of observers have an obvious impact on tactual reading.

The experiments that show improvement in tactual reading as a result of spatial separation support a peripheral explanation of reading limitations. The positive effects of separation were found for two palms and the palm and wrist (Experiments 1 and 2), the fingers of two hands (Experiment 4), and two wrists (Footnote 2). Separation failed to help when words were longer than three letters, indicating that passively generated memory traces may show severe capacity limitations for rapid presentation rates with 1-sec ISIs. This outcome is consistent with the findings of prior research by the present author (Heller, 1980b), and is supported by the introspections of subjects. One individual in a palm-wrist condition (see Footnote 4) asserted that he sometimes did not feel two separate letters on his palm and wrist, but rather experienced a large letter that spanned the intermediate skin surface between these two loci. Under other circumstances, of course, sensory persistence might aid retention.

Passive drawing on the skin may produce after sensations and consequent masking effects for sequences of letters (see Heller, 1980b). These after sensations could be distracting, even when letters are printed on separate locations, producing trace aggregation. The effects of sensory persistence are likely to become intensified as word length increases, leading to a limit in a space/time tradeoff. Slower rates are probably needed for optimal performance with long words (Heller, 1980b). After sensations could be produced via active touch when excessive force is applied to surfaces, but are uncommon for moderate levels of force. Active touch may thus facilitate attention to stimulus configurations, and minimize the intrusion of distracting and attention-demanding after sensations by allowing appropriate force levels.

It is proposed that the problems frequently found with passive tactile reading represent a difficulty in integrating sequences of memory traces, and not with the perception of individual, simple patterns. This conclusion is supported by the results of Experiment 5 (and Footnote 3), which showed that recognition of individually drawn letters can be highly accurate. These accuracy levels were similar to those found in prior research in which letters were drawn without repetition, and they indicate that, with short recognition latencies, letter recognition is efficient. In any case, passive letter recognition was at least as good as with active touch recognition.⁵ Clearly, reading long words in POP is much more difficult than reading single letters, as any reader of POP can attest. This is not true, however, for active touch (Seminara, 1960).

Explanations have been proposed that suggest that the weaknesses of passive tactile pattern recognition derive from task novelty. Sherrick (1974) has cogently argued that much of the difficulty with passivity may stem from a relative lack of familiarity with the passive mode. Moreover, with passive drawing, sensory input is limited to the skin (Loomis, 1984), and people may be more familiar with multimodal haptic input that has a kinesthetic component. Although a familiarity explanation is plausible, it does not explain why letter recognition was found to be very accurate despite the fact that many subjects did not recall having had prior experience with POP or any related tasks. It is possible, of course, that what is needed is familiarity with passively perceived, sequentially organized material, and that this kind of experience is lacking in most observers.

Subjects must be informed about orientation for optimal performance. Words (Experiment 7), letter sequences (Heller, 1980b), and individual letters (Heller, 1981) printed on the skin in different orientations were all found to be legible when those orientations were known and constant. Tactual reading was poor in Experiment 7 when orientation was varied, even when the orientation was announced before each trial. It is interesting that a constant, upright orientation produced low performance when orientation information was withheld (Footnote 4). When asked after the experimental session, most observers said they initially thought the letters faced the experimenter and not themselves. This suggests that observers need not adopt an egocentric attitude at the start of the experimental session (see Oldfield & Phillips, 1983). Subjects also required knowledge about the orientation of forms. Constancy of orientation was clearly insufficient.

Finally, the expectations of observers have a profound influence on passive tactual pattern perception. This was demonstrated by poorer performance in symbol naming when category information was omitted in Experiment 6. Reading words printed on the skin is a complex cognitive skill that depends upon sensory factors, spatial frames of reference, and one's anticipation about the realm of possible configurations.

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NOTES

1. An experiment was performed in which 14 subjects were required to read the letters of the alphabet, printed twice each in a random sequence. The 52 approximately 1.3- or 4-cm-high stimuli were printed on the subjects' palms, perpendicular to the arm axis. The large letters were recognized more frequently ($M=41.3$) than the small letters ($M=25.9$), $t(13) = 10.0$, $p < .01$.
2. Twenty-six two-letter words were printed on the wrists of 28 subjects. The words were written either with the second letter printed over the first or with the first letter of each word on the observer's left wrist and the second letter on his or her right wrist. The 4-cm-high letters were printed in an upright orientation for the subjects. The mean numbers correct for the same-wrist and separate-wrist conditions were 13.6 and 17.9, respectively. Reading was significantly easier in the separate-location condition [$t(26) = 2.22$, $p < .05$], providing further evidence for peripheral interference effects.
3. An additional experiment compared active touch using fingers and passive recognition of letters drawn on the index finger of the preferred hand. It was just as easy to name 2.5-cm solid plastic letters with active exploration (88.8% correct) as it was to name 1.8-cm-high letters drawn on the finger (86.5%), a nonsignificant effect of perceptual mode ($t < 1$). The superiority of active touch in this experiment over performance in Experiment 5 could have resulted from the restriction of active touch to the use of just one finger, a procedure that impoverishes stimulation. Furthermore, incised patterns may not be as discriminable as raised outlines (Berla & Butterfield, 1977). Moreover, differences between active and passive touch may be linked to the size of the stimuli (Loo, Hall, McCloskey, & Rowe, 1983).
4. A further 10 subjects were exposed to the words used in Experiment 7 printed in an upright orientation. The observers were not, however, informed about the orientation of the letters. Lack of information on orientation degraded reading performance; the mean number correct was only 13.1, which was not significantly different from the mean (10.1) obtained in the inverted condition with no prior orientation instruction [$t(18) = 1.03$, $p > .05$]. Individuals did not automatically assume the letters were upright for them. When asked after the experiment was over, most subjects remarked that they initially assumed that the experimenter wrote the letters in an upright orientation with respect to the writer, that is, in the perpendicular orientation. Individuals may typically adopt the point of view of the writer, unless instructed differently. Of course, subjects in Experiments 1-6 were always informed about orientation.
5. The present supposition that memory may be easily overloaded when touch is passive is at variance with Magee and Kennedy's (1980) suggestion that active touch may load memory with planning and execution of movements. They found that memory might be less loaded when touch was passive. Active touch can suffer when movement control is difficult (as with the incised patterns of Experiment 5).