

Research Article

EXPERTISE IN TACTILE PATTERN RECOGNITION

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Abstract—This article explores expertise in tactile object recognition. In one study, participants were trained to differing degrees of accuracy on tactile identification of two-dimensional patterns. Recognition of these patterns, of inverted versions of these patterns, and of subparts of these patterns was then tested. The inversion effect (better recognition of upright than inverted patterns) and the part-whole effect (better recognition of the whole than a part pattern), traditionally considered signatures of visual expertise, were observed for tactile experts but not for novices. In a second study, participants were trained as visual or tactile experts and then tested in the trained and non-trained modalities. Whereas expertise effects were observed in the modality of training, cross-modal transfer was asymmetric; visual experts showed generalization to haptic recognition, but tactile experts did not show generalization to visual recognition. Tactile expertise is not obviously attributable to visual mediation and emerges from domain-general principles that operate independently of modality.

For virtually every task, there are experts—bird-watchers, dog-show judges, car connoisseurs, and chess masters—and the psychological and neural mechanisms that mediate expertise in object recognition have been the focus of several recent studies. For example, compared with less skilled players, chess masters reproduce positions on a structured, but not random, chessboard more accurately (Chase & Simon, 1973), make fewer fixations per trial, fixate between rather than on individual pieces, and have larger visual spans (Reingold, Charness, Pomplun, & Stampe, 2001; Reingold, Charness, Schultetus, & Stampe, 2001). These perceptual advantages suggest that there may be a qualitative shift in the representation of information by experts compared with novices. Of particular interest is the implication that the visual system is plastic and may be optimized under conditions that are behaviorally relevant and meaningful.

Interestingly, by comparing the performance of experts and novices, it has been possible to track the emergence of several patterns associated with expertise. One such pattern is the downward shift to a more fine-grained representation; for example, Tanaka and Taylor (1991) observed that bird or car experts identified stimuli within their domain of expertise using subordinate-level labels (e.g., “robin”), but identified stimuli outside of their domain of expertise using basic-level labels (e.g., “bird”). The same downward shift is thought to apply to face recognition compared with nonface recognition—the former invokes subordinate individuation, whereas basic-level classification suffices in the latter case. The enhanced specificity that accompanies increasing experience is often attributed to the derivation of configural information—experts process not just the individual features but also the relations among them (Gauthier & Tarr, 2002; Maurer, Le Grand, & Mondloch, 2002). The claim that sensitivity to configural informa-

tion mediates expertise is supported by studies showing that children process faces in a part-based manner, whereas adults (as well as experts in their domain of expertise) process information in a more holistic fashion (Carey & Diamond, 1994; Diamond & Carey, 1986).

But the impact of expertise is not all positive, and there are two well-known conditions under which experts perform more poorly than novices. The first adverse impact of expertise is the *inversion effect*—poorer accuracy and longer reaction times when stimuli are presented upside down than when they are upright: This result is well established in the domain of face recognition (Yin, 1969) and is also observed for dog (Diamond & Carey, 1986) and Greeble (Gauthier, Williams, Tarr, & Tanaka, 1998) experts. The second adverse outcome is the *composite effect*. Experts process individual features of a stimulus more poorly than novices; when two parts of two different stimuli are presented as a composite, experts are slower and less accurate in recognizing one of the parts when the composite is upright or fused, compared with when the composite is inverted or the two parts are not fused (Hole, 1994; Young, Hellawell, & Hay, 1987). Note that these latter manipulations are thought to disrupt holistic or configural processing and, in so doing, reinstate access to the components of the display. Related to the composite effect, the *part-whole effect* refers to the finding that for items processed configurally (like faces), identifying a part, such as a nose, is facilitated when the part is presented in the context of the whole object, the face, compared with when it is presented in isolation (Tanaka & Farah, 1993, 2003). No such benefit is obtained for houses or scrambled faces, and the part-whole effect is reduced when the face is inverted or when competing flankers interfere with the holistic processing (Palermo & Rhodes, 2002).

As is apparent from these studies, the behavioral characteristics of expertise are now fairly well documented. It is critical to note, however, that these findings pertain only to visual expertise, and, in fact, there is a striking paucity of data on expertise in modalities other than vision. Our goal in the current investigation was to examine whether the signatures of expertise are emergent properties of the visual system per se, or whether they might reflect domain-general principles that subserve the emergence of expertise, independent of modality.

Whether or not one should expect to see the same benchmarks of expertise in the somatosensory as in the visual modality is controversial. On the one hand, there are major differences in the representation of geometric properties in these two sensory modalities, as well as in their mechanical aspects; whereas visual information may be captured in parallel by the receptors during a single fixation, tactile reception of objects is encoded more serially (Hamilton & Pascual-Leone, 1998) and generally entails a sequential contour-exploration strategy (Lederman & Klatzky, 1987; also, for differences in serial processing in the congenitally vs. adventitiously blind, see Kennedy, Gabias, & Nicholls, 1991). Haptic and visual object recognition also exploit different information: Whereas attributes pertaining to substance, such as surface roughness, compliance, and thermal properties, are critical for haptics, attributes relating to planar structure, such as size and shape, are more relevant for vision (Klatzky, Lederman, & Reed, 1987; Lederman, Thorne, & Jones, 1986). On the other hand, notwithstanding these dif-

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ferences, many studies have revealed cross-modal priming between vision and haptics, reflecting representational similarities across the domains. We pursue this topic further in the General Discussion.

To examine tactile expertise, we conducted two experiments using raised line patterns (see Fig. 1a). The patterns were designed to be encoded in a "haptic glance" (Klatzky & Lederman, 1995) and did not require sequential exploration, which is known to impair haptic performance on two-dimensional tasks (Lederman, Klatzky, Chataway, & Summers, 1990). In Experiment 1, we examined whether expertise effects emerge in the tactile modality by training individuals to differing degrees of accuracy (novice, expert) on these patterns, and then comparing recognition of the whole compared with inverted (Fig. 1b) and part (Fig. 1c) patterns. In Experiment 2, we gauged cross-modal transfer by training individuals as visual or tactile experts and comparing their recognition performance in both the trained and nontrained modalities.

EXPERIMENT 1

Method

Participants

Twenty-eight right-handed Carnegie Mellon University students consented to participate and were given course credit or paid for their participation in this study. No participant reported any loss of tactile or visual sensation nor any unusual experience with haptic input (e.g., none could read Braille). The data from 10 participants who did not complete both testing sessions ($n = 5$), had reaction times (RTs) greater than 16 s ($n = 3$), or did not reach criterion ($n = 2$) were excluded from the analyses.

Apparatus and materials

Six tactile patterns, each constructed from six pieces of balsa wood, were glued to cardboard bases. Each of the six segments of a

pattern was 2 mm high and 1 mm wide. The horizontal and vertical segments were 0.64 cm long, and the diagonal segments were 0.91 cm long. The cardboard bases were squares with 3.2-cm sides. Each pattern was no larger than a region 1.9×1.9 cm square and was coated with varnish to smooth the edges and fill the gaps between the segments.

Each of the six patterns was presented in three versions. The *whole* patterns (Fig. 1a) contained a three-segment portion that was common to all six patterns; in addition, each whole pattern contained a three-segment portion that was unique and, hence, diagnostic of the pattern's identity. The *inverted* patterns (Fig. 1b) were the whole patterns rotated 180° . The *part* patterns (Fig. 1c) were the unique three-segment portions of the whole patterns; these were centered on their own cardboard bases (which were the same size as the bases of the whole patterns). Participants were not told about the unique-nonunique composition of the stimuli. Each pattern was paired with a male name, such as "Steve" or "Tom." The pairing of pattern and name was randomized across subjects.

Procedure

Every participant completed two sessions, once as a novice and once as an expert (approximately 2 days later), with each session lasting between 30 min and 1 hr. Participants, who were blindfolded, sat at a table, and tactile patterns were placed in a frame, which secured the bases of the patterns and made the location of the patterns predictable.

Novice session. During the first session, participants were trained to associate a name with each of the whole patterns. On each trial, a single pattern was presented, and the corresponding auditory label was emitted by the computer (Macintosh G3 running Soundwave software). Participants felt the patterns by pressing an index finger directly downward and were given 5 s to associate the name and pattern on each trial. In each training block, each pattern was presented once, and participants completed six blocks, for a total of 36 training trials. Because both hands were used for the test phase, half the participants were trained with the left hand and half were trained with the right hand.

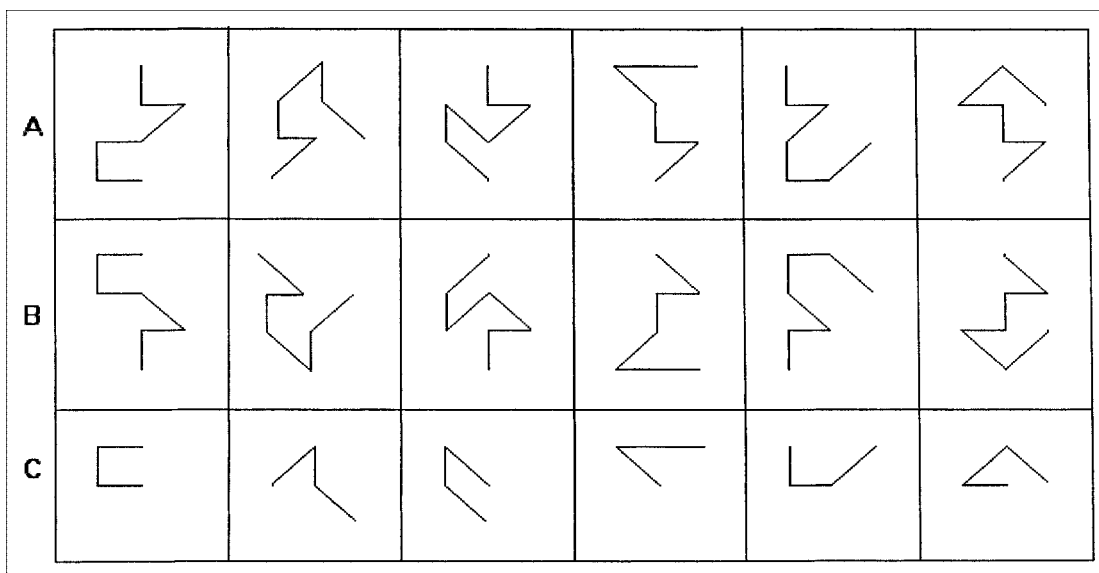


Fig. 1. Diagrams of the tactile patterns: (a) the six whole patterns, (b) the six patterns inverted, and (c) the six part patterns (unique three-segment portions of the whole patterns).

Tactile Expertise

After training, the participants completed three recognition tasks (whole, inverted, and part patterns), which were blocked. On each trial, the target and a foil (another trained pattern) were presented simultaneously. Once the patterns were in position, the digitized sound file of the name of one of the patterns was played and followed by a 450-ms beep. Participants were instructed that at the offset of the beep, they should use their left and right index fingers to touch the left and right patterns, respectively, and then indicate which pattern matched the auditory name by saying "left" or "right." Vocal RTs were measured via a lapel microphone, and accuracy was recorded manually. RT was defined as the time from the onset of the beep to the onset of the verbal response. The intertrial interval was approximately 4 s. For each task, each of the six patterns served as the target three times and as a foil three times, resulting in 18 trials per task. The order of the three tasks (whole, inverted, part) was counterbalanced across participants, and the placement (left, right) of the patterns was randomized within each task.

Expert session. In the second session, the training procedure from the novice session was followed, except that feedback was given and a criterion of 92% correct performance over two consecutive blocks of trials was set. If participants made an error, they were given the opportunity to associate the pattern with the correct name again. Subjects required, on average, nine training blocks (54 trials in total) to achieve criterion. Participants then completed the three recognition tasks using the procedure described for the novice session.

We predicted that recognition of the whole would be better for experts than novices, but that experts would show significantly poorer recognition of part and inverted than whole patterns.

Results and Discussion

A preliminary analysis revealed no significant effect of handedness (during training) nor any interaction of handedness with any other

variable; hence, the analyses presented here are collapsed across this factor. We conducted 2 (skill: novice, expert) \times 3 (recognition task: whole, inverted, part) analyses of variance (ANOVAs) for accuracy and then RT. Incorrect trials and trials on which the microphone misfired (2.1% of trials) were excluded from the RT analysis. Experts were significantly more accurate than novices, as shown in Figure 2 (experts: 91.3%, novices: 81.6%), $F(1, 17) = 68.7, p < .0001$, and also had significantly quicker RTs than novices, as shown in Figure 3 (experts: 7 s, novices: 9 s), $F(1, 17) = 19.7, p < .001$. There was a significant main effect of task for both accuracy, $F(2, 34) = 6.6, p < .005$, and RT, $F(2, 34) = 5.2, p = .01$. Critically, there was a significant Skill \times Recognition Task interaction for both accuracy, $F(2, 34) = 6.2, p = .005$, and RT, $F(2, 34) = 4.7, p < .01$. Tukey post hoc tests ($p < .05$) revealed no differences across the three tasks for novices. In contrast, experts performed more accurately and faster on the whole than on either the inverted or part tasks, which did not differ from each other.

These findings indicate that experts can identify haptic patterns better than novices. The long RTs even for experts are consistent with previous findings, confirming that haptic identification of two-dimensional patterns is challenging (Kilgour & Lederman, 2002; Lederman et al., 1990). The more pertinent result is that the two signatures of expertise, the inversion effect and the part-whole effect, are evident in the tactile domain: Experts, but not novices, exhibit better recognition of upright than inverted patterns, as well as better recognition of whole than part patterns.

EXPERIMENT 2

Given that the signatures of visual expertise are also present in the tactile modality, it is important to determine the source of the tactile expertise. One obvious possibility is that tactile expertise recruits the

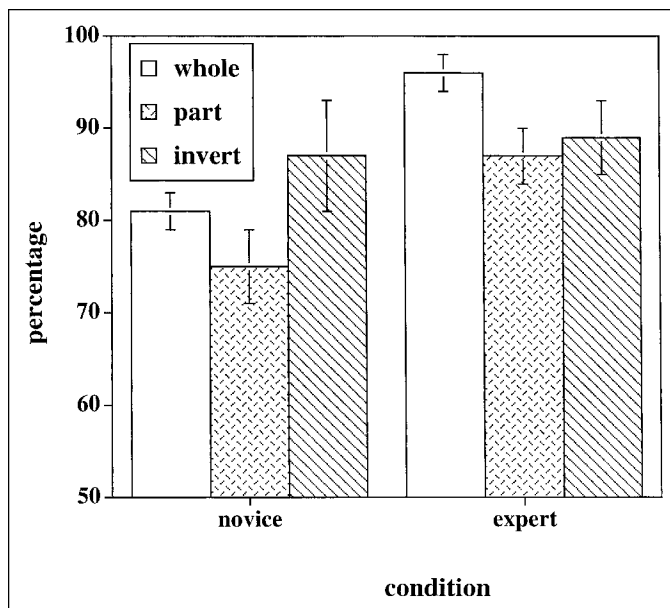


Fig. 2. Mean percentage accuracy (± 1 SE) for whole, part, and inverted patterns in Experiment 1. Results are shown separately for novice and expert participants, all of whom were trained tactily.

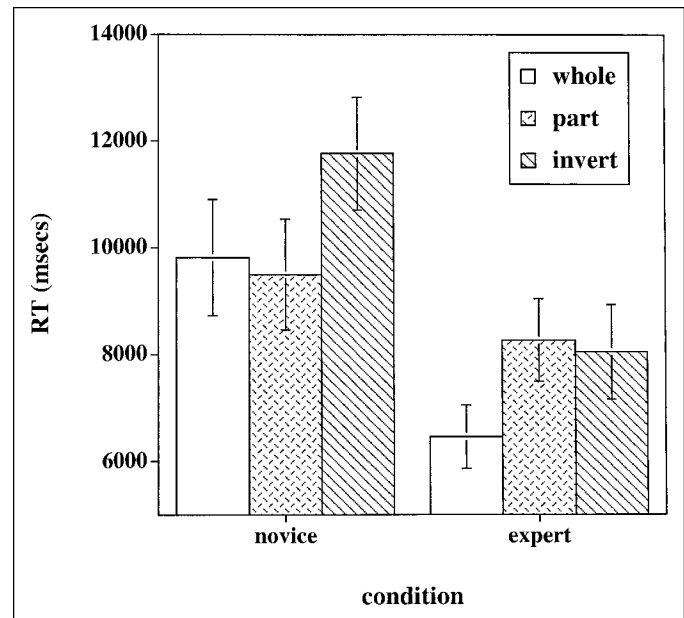


Fig. 3. Mean reaction time (RT; ± 1 SE) for whole, part, and inverted patterns in Experiment 1. Results are shown separately for novice and expert participants, all of whom were trained tactily.

expertise of the visual system: In the course of tactile training, people may form a visual image from the haptic input, and this visual image may then be processed by the visual system. In this case, the expertise effects are mediated not by tactile representations per se but by visual representations. There is considerable evidence to support this view; for example, Lederman et al. (1990) showed that haptic recognition of raised line drawings is even poorer in congenitally blind than in blindfolded sighted individuals, presumably because of the absence of visual image mediation in the former group (but see D'Angiulli, Kennedy, & Heller, 1998, for different results). These authors also reported that haptic recognition speed and accuracy were correlated with imageability ratings, lending further credence to their visual-mediation view. In addition, several recent functional magnetic resonance imaging studies have shown that haptic exploration of novel, three-dimensional objects produces activation not only in somatosensory areas of cortex, but also in areas of occipital cortex standardly associated with visual object processing (Amedi, Malach, Hendler, Peled, & Zohary, 2001; Deibert, Kraut, Kremen, & Hart, 1999; James et al., 2002).

If tactile expertise is a consequence of visual mediation, we would expect to observe expertise effects at test in both the tactile and visual domains, independent of modality of training. It is also possible, however, that tactile expertise is not dependent on visual expertise. According to this alternative account, the haptic and visual systems are separate and independent but utilize similar computations to achieve expertise. Thus, there is not direct transfer between training and test across the different sensory modalities. Results of a recent study are consistent with this account. Kilgour and Lederman (2002) found no correlation between the ability to use visual imagery and haptic recognition of faces. Such a finding undermines the notion of general use of visual mediation in haptic recognition and supports the notion of visual-haptic independence.

Method

Participants

Thirty-nine participants (22 male, 17 female) from Carnegie Mellon University, selected using the same criteria as in Experiment 1, consented to participate in the experiment for course credit. Data from 3 participants who did not reach criterion (all 3 received the tactile training) were excluded.

Apparatus and materials

The stimuli used in Experiment 1 were used for this study as well. In addition, visual counterparts of the patterns were drawn up using a Macintosh G3 Powerbook with an 11- × 8.5-in. monitor. The maximum horizontal and vertical visual angles for the whole (and inverted) patterns were 1.73° and 2.64°, and the corresponding values for the parts were 0.87° and 1.41°. The visual angle of the display when two patterns were presented simultaneously at visual test was 13.47°.

Procedure

Subjects completed this experiment in a single session. Half the subjects were trained visually and half tactilely. The tactile training replicated the expertise training procedure of Experiment 1, and subjects took, on average, 10 blocks (60 trials) to achieve the 92% criterion level on whole pattern recognition. Visual training was conducted

on a computer screen but was identical to the tactile training except that subjects were not blindfolded and it took, on average, 5 blocks for subjects to achieve the 92% accuracy level. As in the tactile training, a sound file containing the name of the pattern was emitted, followed by a beep that lasted for 450 ms. Immediately thereafter, the visual pattern appeared and participants had 5 s to associate the name and pattern.

The tactile testing procedure was the same as in Experiment 1. Visual testing followed the same procedure except that the two patterns were presented visually on a computer screen. Participants were always tested first in the modality in which they were trained and then in the nontrained modality. The order of tests (whole, inverted, part) was counterbalanced across modality and across subjects. Note that subjects had no direct experience with the patterns in the nontrained modality until the start of testing in that modality.

Results and Discussion

An ANOVA with training modality (visual, tactile) as a between-subjects factor and testing modality (visual, tactile) and recognition task (whole, inverted, part) as within-subjects factors was conducted on accuracy and then RT. The ANOVA on accuracy (see Fig. 4) revealed, at most, a very small but nonsignificant benefit for visual (91.3%) over tactile (87.2%) training, $F(1, 34) = 3.4, p = .073$. Irrespective of training modality, performance was better when testing was conducted visually (92.4%) than tactilely (87%), $F(1, 34) = 4.4, p < .05$. There was also a significant main effect of recognition task, $F(2, 68) = 13.2, p < .001$, but recognition task interacted with testing modality, $F(2, 68) = 4.2, p = .019$, as follows: With visual testing, whole pattern recognition was better than either part or inverted pattern recognition, which did not differ from each other, but with tactile testing, whole pattern recognition was better than both part and inverted pattern recognition, and inverted recognition was better than part recognition. The presence of all the segments in the stimuli may have given rise to the benefit in the inverted over the part recognition task. There were no other significant effects.

The findings are even clearer in the RT analysis. Participants trained tactilely responded significantly more slowly (4,689 ms) than those trained visually (3,759.5 ms), $F(1, 34) = 6.8, p = .01$. RTs were also shorter for visual (2,246 ms) than tactile testing (6,202 ms), $F(1, 34) = 198.6, p < .0001$. As expected, there was a significant effect of recognition task, $F(2, 68) = 17.4, p < .0001$, with fastest recognition on whole patterns (3,724 ms), and no difference between part (4,467 ms) and inverted (4,480 ms) patterns. All two-way interactions were also significant—Training Modality × Test Modality: $F(2, 68) = 8.5, p < .01$; Training Modality × Recognition Task: $F(2, 68) = 8.9, p < .001$; Test Modality × Recognition Task: $F(2, 68) = 19.8, p < .0001$. Of most relevance is the presence of the three-way interaction, $F(2, 68) = 3.4, p < .05$. The essence of the interaction is as follows: In individuals trained visually (Fig. 5b), RTs were faster for the whole than for either part or inverted patterns, which did not differ in the tactile modality, but part recognition was faster than inverted recognition in the visual modality. Individuals trained tactilely (Fig. 5a) showed the expertise effects when tested in the tactile modality, with whole recognition faster than either inverted or part recognition, but not when tested in the visual modality, for which there were no significant differences between the three recognition tasks.

The first major result is that we replicated Experiment 1. An ANOVA with experiment (1, 2) as a between-subjects factor and rec-

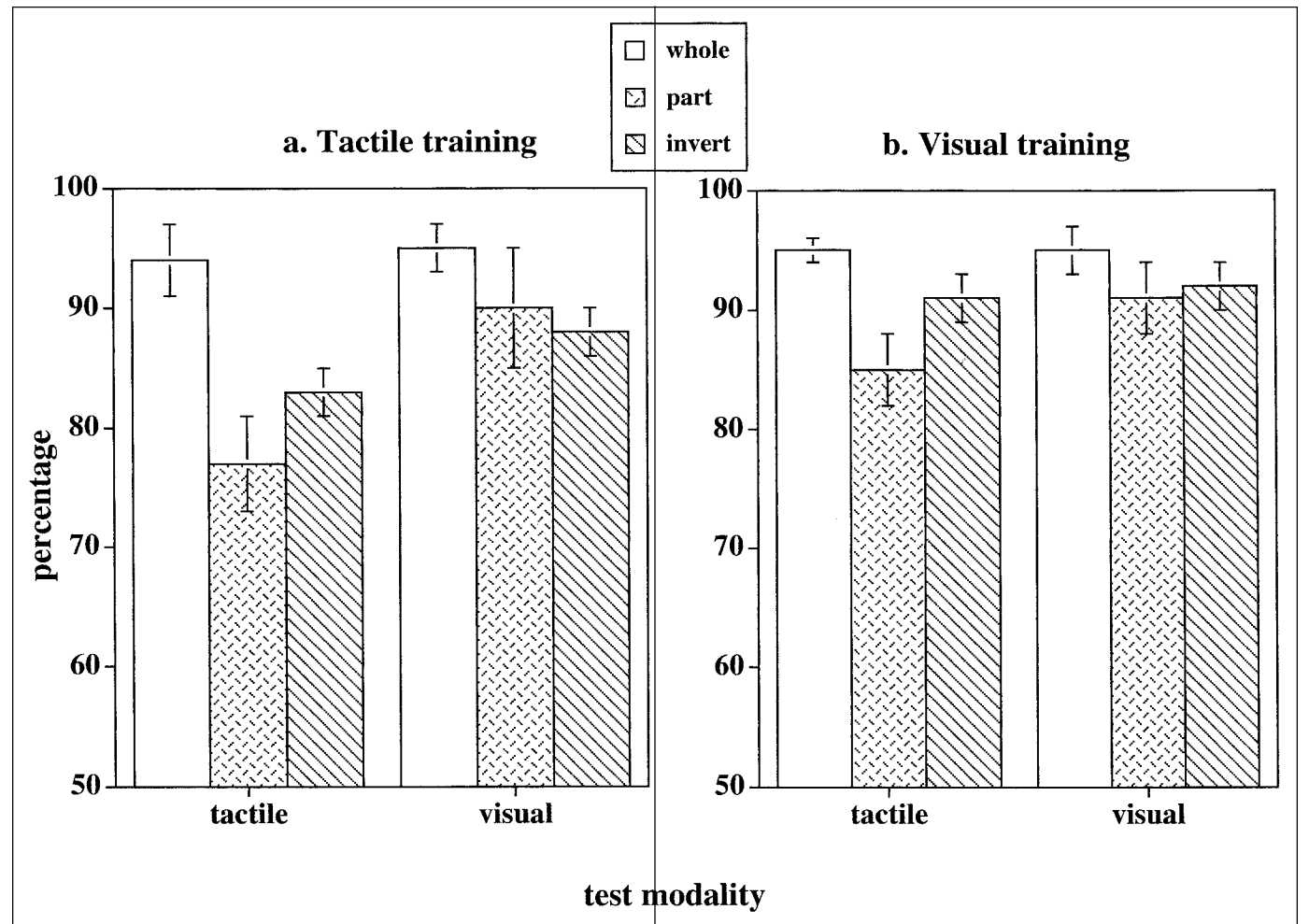


Fig. 4. Mean percentage accuracy (± 1 SE) for whole, part, and inverted patterns in Experiment 2. Results are shown separately for participants trained (a) tactilely or (b) visually and tested in the trained and nontrained modality.

ognition task as a within-subjects factor (tactile training only) showed no interaction, $F(2, 68) = 1.8$, $p > .05$, although accuracy was higher (but RT slower) in Experiment 1 than Experiment 2, $F(1, 34) = 11.03$, $p < .005$. The ordering of the recognition tasks was also replicated, $F(2, 68) = 13.4$, $p < .0001$, with higher accuracy (and faster RT) on the whole than on the other recognition tasks. The same expertise effects were observed in Experiment 2 for individuals trained and tested in the visual modality.

The novel and important contribution of this experiment is the cross-modal asymmetry between individuals trained in the two modalities. Despite the fact that they had no prior experience with the tactile patterns, individuals trained visually exhibited the expertise effects at test independent of modality. In contrast, individuals trained tactilely showed the expertise effects at test only in the tactile modality and did not show the generalization to the untrained, visual modality.

GENERAL DISCUSSION

Two general conclusions can be drawn from our studies. First, as is true of visual object recognition, tactile object identification can be

modified by experience and learning. Moreover, expertise appears to manifest itself in the two modalities in a qualitatively similar fashion. It is well established in vision that with expertise comes increased configural processing such that the interrelations between parts of an object become more accessible and the parts less accessible (Diamond & Carey, 1986; Gauthier & Tarr, 2002); the present results indicate that this appears to be true in the somatosensory modality, too. Thus, identifying a familiar shape tactilely when it is inverted and accessing its parts are both adversely affected as experience with the intact, upright pattern increases.

Second, there is an asymmetry in the cross-modal transfer of visual and haptic representations during object recognition. Visual information is acquired fast and relatively effortlessly, and it can be exploited for the purpose of haptic recognition: Not only are individuals trained visually faster at tactile identification than those trained tactilely, but they also show the inversion and part-whole effects despite the fact that they have not experienced the patterns tactilely prior to test. Information acquired haptically, however, is not transferred to visual identification; individuals trained tactilely exhibit the benchmarks of expertise only in the trained tactile domain, but not in the visual domain. This

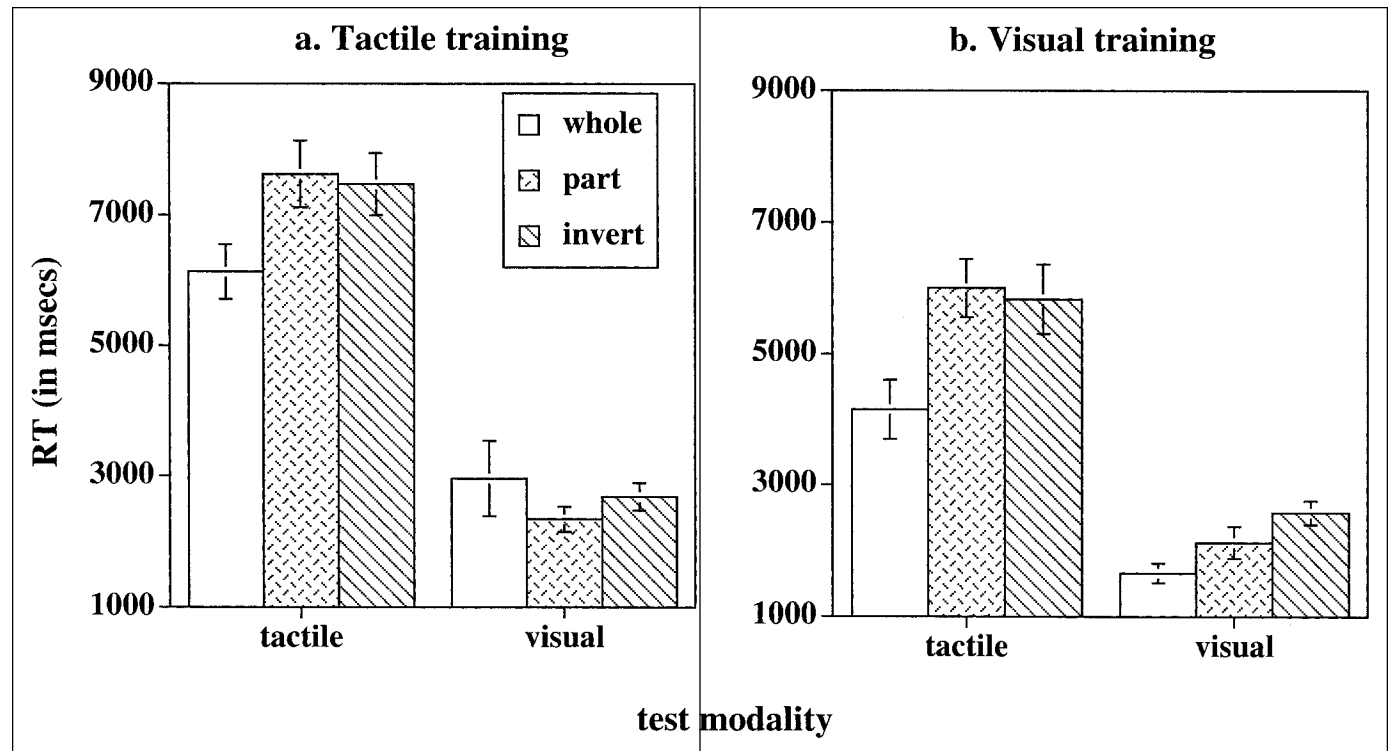


Fig. 5. Mean reaction time (RT; ± 1 SE) for whole, part, and inverted patterns in Experiment 2. Results are shown separately for participants trained (a) tactiley or (b) visually and tested in the trained and nontrained modality.

asymmetry in cross-modal generalization indicates that there is not a single, shared representation for visual and tactile expertise. However, the modalities are not entirely independent either, and so both the apparent independence and the cross-modal asymmetry require explanation.

Consistent with our findings, many studies using two-dimensional form discrimination have demonstrated an asymmetry in cross-modal transfer of haptic and visual representations during object identification (Jones, 1981; Lobb, 1965, 1970), and investigators have argued for their independence. Despite the apparent independence, however, similar computational principles appear to constrain the two modalities. In our case, expertise, reflected by the inversion and part-whole effects, which are well established in vision, also emerges in the tactile domain. Other studies have also shown that even if the underlying visual and haptic representations are not identical, the same computational processes are operational. For example, Newell, Ernst, Tjan, and Bühlhoff (2001) have shown that tactile object recognition, like visual object recognition, is viewpoint-specific; however, whereas the visual system appears to prefer the front of the object, haptic recognition favors the back. Likewise, on the basis of similar confusion matrices in the two modalities, Loomis (1982) has argued that vision and haptics are functionally similar but not identical. Other researchers have found that raised line depictions of visual illusions such as the Müller-Lyer figure yield similar but not identical haptic illusions in blindfolded individuals (Heller & Joyner, 1993) and that touch, like vision, shows sensitivity to Gestalt principles such as symmetry (Ballesteros, Millar, & Reales, 1998; Reales & Ballesteros, 1999). These studies support the apparent independence of touch and vision. The

asymmetry in cross-modal generalization, then, is likely attributable to the well-known dominance of the visual modality (Lobb, 1970) in capturing the independent haptic processing.

We have suggested that the two modalities are independent but obey similar operating principles. What remains to be accounted for is the widespread finding of symmetric cross-modal transfer (Easton, Green, & Srinivas, 1997; Macaluso, Frith, & Driver, 2000). Most studies documenting symmetric transfer have utilized three-dimensional objects, which are sequentially explored haptically. Information concerning object structure, topography of spatial relations, and surface features must be derived under these conditions; additionally, objects must be situated in a three-dimensional reference frame, which is object-centered. It is under these circumstances that the haptic system may recruit processes of the visual system, and these processes, in turn, give rise to activation in extrastriate visual cortex (Amedi et al., 2001; James et al., 2002). We suggest, then, that the apparent cross-modal symmetry is a function of the stimuli and the task being performed and is not a necessary and fundamental characteristic of visual-haptic processing.

Before we conclude, one remaining issue requires discussion, and it concerns the definition of expertise. In the present study, subjects undertook, at most, 2 hr of training. In contrast, in most studies of expertise, many hours are devoted to the critical task. We suggest that the experience effects we report here lie along a continuum with true mastery and that the effects we observed may be exaggerated with further experience. Moreover, other markers of expertise, such as the composite effect, might also emerge with further experience.

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REFERENCES

- Amedi, A., Malach, R., Hendler, T., Peled, S., & Zohary, E. (2001). Visuo-haptic object-related activation in the ventral visual pathway. *Nature Neuroscience*, *4*, 324–330.
- Ballesteros, S., Millar, S., & Reales, J.M. (1998). Symmetry in haptic and in visual shape perception. *Perception & Psychophysics*, *60*, 389–404.
- Carey, S., & Diamond, R. (1994). Are faces perceived as configurations more by adults than by children? *Visual Cognition*, *1*, 253–274.
- Chase, W.G., & Simon, H. (1973). Perception in chess. *Cognitive Psychology*, *4*, 55–81.
- D'Angiulli, A., Kennedy, J.M., & Heller, M.A. (1998). Blind children recognizing tactile patterns respond like sighted children given guidance in exploration. *Scandinavian Journal of Psychology*, *39*, 189–190.
- Deibert, E., Kraut, M., Kremen, S., & Hart, J. (1999). Neural pathways in tactile object recognition. *Neurology*, *52*, 1413–1417.
- Diamond, R., & Carey, S. (1986). Why faces are not special: An effect of expertise. *Journal of Experimental Psychology: General*, *115*, 107–117.
- Easton, R.D., Green, A.J., & Srinivas, K. (1997). Transfer between vision and haptics: Memory for 2-D patterns and 3-D objects. *Psychonomic Bulletin & Review*, *4*, 403–410.
- Gauthier, I., & Tarr, M.J. (2002). Unraveling mechanisms for expert object recognition: Bridging brain activity and behavior. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 431–446.
- Gauthier, I., Williams, P., Tarr, M.J., & Tanaka, J. (1998). Training “Greeble” experts: A framework for studying expert object recognition processes. *Vision Research*, *38*, 2401–2428.
- Hamilton, R.H., & Pascual-Leone, A. (1998). Cortical plasticity associated with Braille learning. *Trends in Cognitive Sciences*, *2*, 168–174.
- Heller, M., & Joyner, T. (1993). Mechanisms in the haptic horizontal-vertical illusion: Evidence from blind and sighted individuals. *Perception & Psychophysics*, *53*, 422–428.
- Hole, G. (1994). Configurational factors in the perception of unfamiliar faces. *Perception*, *23*, 65–74.
- James, T.W., Humphrey, G.K., Gati, J.S., Servos, P., Menon, R.S., & Goodale, M.A. (2002). Haptic study of three-dimensional objects activates extrastriate visual areas. *Neuropsychologia*, *40*, 1706–1714.
- Jones, B. (1981). The developmental significance of cross-modal matching. In R.D. Walk & H.L. Pick (Eds.), *Intersensory perception and sensory integration* (pp. 109–132). New York: Plenum.
- Kennedy, J.M., Gabias, P., & Nicholls, A. (1991). Tactile pictures. In M.A. Heller & W. Schiff (Eds.), *The psychology of touch* (pp. 263–300). Hillsdale, NJ: Erlbaum.
- Kilgour, A.R., & Lederman, S.J. (2002). Face recognition by hand. *Perception & Psychophysics*, *64*, 339–352.
- Klatzky, R.L., & Lederman, S.J. (1995). Identifying objects from a haptic glance. *Perception & Psychophysics*, *57*, 1111–1123.
- Klatzky, R.L., Lederman, S.J., & Reed, C. (1987). There's more to touch than meets the eye. *Journal of Experimental Psychology: General*, *116*, 356–369.
- Lederman, S.J., & Klatzky, R.L. (1987). Hand movements: A window into haptic object recognition. *Cognitive Psychology*, *19*, 342–368.
- Lederman, S.J., Klatzky, R.L., Chataway, C., & Summers, C. (1990). Visual mediation and the haptic recognition of two-dimensional pictures of common objects. *Perception & Psychophysics*, *47*, 54–64.
- Lederman, S.J., Thorne, G., & Jones, B. (1986). Perception of texture by vision and haptics: Multidimensionality and intersensory integration. *Journal of Experimental Psychology: Human Perception and Performance*, *12*, 169–180.
- Lobb, H. (1965). Vision versus touch in form discrimination. *Canadian Journal of Psychology*, *19*(3), 175–187.
- Lobb, H. (1970). Asymmetrical transfer of form discrimination across sensory modalities in human adults. *Journal of Experimental Psychology*, *86*, 350–354.
- Loomis, J. (1982). Analysis of haptic and vision confusion matrices. *Perception & Psychophysics*, *31*, 41–52.
- Macaluso, E., Frith, C., & Driver, J. (2000). Selective spatial attention in vision and touch: Unimodal and multimodal mechanisms revealed by PET. *Journal of Neurophysiology*, *83*, 3062–3075.
- Maurer, D., Le Grand, R., & Mondloch, C.J. (2002). The many faces of configural processing. *Trends in Cognitive Sciences*, *6*, 255–260.
- Newell, F.N., Ernst, M.O., Tjan, B.S., & Bühlhoff, H.H. (2001). Viewpoint dependence in visual and tactile object recognition. *Psychological Science*, *12*, 37–42.
- Palermo, R., & Rhodes, G. (2002). The effect of divided attention on holistic face perception. *Cognition*, *88*, 225–257.
- Reales, J.M., & Ballesteros, S. (1999). Implicit and explicit memory for visual and haptic objects: Cross-modal priming depends on structural descriptions. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 644–663.
- Reingold, E.M., Charness, N., Pomplun, M., & Stampe, D.M. (2001). Visual span in expert chess players: Evidence from eye movements. *Psychological Science*, *12*, 48–55.
- Reingold, E.M., Charness, N., Schultetus, R.S., & Stampe, D.M. (2001). Perceptual automaticity in expert chess players: Parallel encoding of chess relations. *Psychonomic Bulletin & Review*, *8*, 504–510.
- Tanaka, J.W., & Farah, M.J. (1993). Parts and wholes in face recognition. *Quarterly Journal of Experimental Psychology*, *46A*, 225–245.
- Tanaka, J.W., & Farah, M.J. (2003). The holistic representation of faces. In M.A. Peterson & G. Rhodes (Eds.), *Perception of faces, objects and scenes: Analytic and holistic processes* (pp. 53–74). New York: Oxford University Press.
- Tanaka, J.W., & Taylor, M. (1991). Object categories and expertise: Is the basic level in the eye of the beholder? *Cognitive Psychology*, *23*, 4457–4482.
- Yin, R.K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology*, *81*, 141–145.
- Young, A.W., Hellawell, D., & Hay, D.C. (1987). Configurational information in face perception. *Perception*, *16*, 747–759.

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