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Identifying objects by touch: An "expert system"

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How good are we at recognizing objects by touch? Intuition may suggest that the haptic system is a poor recognition device, and previous research with nonsense shapes and tangible-graphics displays supports this opinion. We argue that the recognition capabilities of touch are best assessed with three-dimensional, familiar objects. The present study provides a baseline measure of recognition under those circumstances, and it indicates that haptic object recognition can be both rapid and accurate.

Many of you may remember a children's game in which the goal is to identify, by touch alone, several common objects plucked from a bag or a tray. The joy of playing lies in the discovery that success is possible. For those of us who have played the game and experienced that success, it may not be surprising that objects can be identified through tactual exploration. However, the present report documents that this is no trivial observation. In a systematic study of haptic object identification, it was found that people are highly accurate and quite fast at identifying a large number (100) of objects.

We deem this observation surprising, because it has often been argued, both empirically and theoretically, that the haptic system (i.e., purposive touch, as defined in Gibson, 1966) is inadequate for object identification, especially when compared with vision. Two lines of research are used to support this claim. One compares haptic and visual identification of raised two-dimensional (and sometimes fully three-dimensional) nonsense shapes (e.g., Bryant & Raz, 1975; Cashdan, 1968; Rock & Victor, 1964). The second uses tangible graphics displays—raised line drawings of objects, maps, graphs, etc.—in which raised symbols represent spatial and structural information (e.g., Lederman & Campbell, 1982; Lederman, Klatzky, & Barber, 1985; Magee & Kennedy, 1980). Such displays are intended to be read by hand rather than by eye. Although the research assesses the level of performance that can be achieved by touch alone, comparisons with vision are nevertheless implicit. These studies demonstrate either that touch is ineffective for reading and identification or that touch is so dominated by vision that its contribution to pattern perception is minimal.

However, we will suggest reasons why performance with arbitrary, unfamiliar three-dimensional or raised two-dimensional stimuli might underestimate the capacity for haptic object recognition. Further, we offer the present study as an "existence proof" that haptics *can* be highly effective for object identification. Our argument is similar to one made by Reed, Durlach, and Braida (1982), who have been developing a sensory substitution system for the deaf. They suggest that the success of "Tadoma"—a method of understanding speech in which the "listener's" fingers and thumb(s) are placed on the cheeks, lips, and jaws of the speaker—is proof that the tactual system can process complex spatiotemporal patterns at rates close to those of auditory speech perception. Similarly, we argue by demonstration that touch can perform a very common identification task with considerable competence, despite its poor performance in other tasks (particularly those with less naturalistic stimuli).

One reason for caution in generalizing results from studies with artificial objects or raised graphics displays to haptic performance as a whole is that such studies generally require pattern "apprehension"—obtaining information about volumetric, topographical, and other attributes of the stimuli—as opposed to categorization. Even when artificial displays depict real objects and a categorical response is required, the stimuli generally fail to retain many of the properties of the objects themselves, such as temperature, size, or texture. The cues that these displays do provide are usually dictated by the original visual master from which a raised replica was derived. It therefore becomes necessary to determine the shape of the stimulus, perhaps even to form a visual image, in order to identify it. In contrast, real objects might be recognized on the basis of nonstructural cues. A kitchen sponge, for example, could be identified by its texture, without regard for its shape or size.

As mentioned above, vision-touch comparisons have often been interpreted as evidence that haptic performance

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is poor. Several considerations, however, suggest that these comparisons are inappropriate to assess haptic object recognition. One concern is the degree of practice, which has been found to improve haptic discrimination performance (Gibson, 1966; Simons & Locher, 1979). A lack of familiarity with haptic identification of artificial displays might be critical to its inferiority relative to vision. Another issue is whether the displays that have been used in previous research adequately allow for fundamental differences between the visual and haptic sensory systems (Berla, 1982; Ikeda & Uchikawa, 1978; Lederman, 1979). For example, the resolving power of the fingertip is much less than that of the eye (Weinstein, 1968), and the tactile system may have inherent difficulty in representing stimulus orientation (Pick, Klein, & Pick, 1966). Both of these factors could influence haptic performance profoundly; yet stimulus construction cannot easily compensate for either. Consider that changing the size of a stimulus to accommodate the poor resolution of touch also changes the rate at which it can be explored and, accordingly, changes the temporal-integration and memory demands of the task (Berla, 1982). Similarly, using explicit orientation cues may aid tactual apprehension (Lederman, 1979; Lederman & Campbell, 1982), but may also add irrelevant information that interferes with the perception of structural properties of the display.

The foregoing suggests that in order to assess haptic object identification, one should avoid artificial objects or two-dimensional displays and, instead, use real objects. The cues that real objects provide are ecologically determined, rather than based on a visual replica. Haptic manipulation of objects is commonplace and therefore familiar. Real objects maintain in full scale the attributes that contribute to haptic identification, and their proper orientation is determined by such intrinsic characteristics as principal axes, flat surfaces, and center of gravity. Thus, objects seem ideally suited to recognition through haptic exploration.

Some extant studies suggest, in agreement with this reasoning, that haptic identification of common objects is quite accurate (Bigelow, 1981; Hoop, 1971; Schiff & Dytell, 1972; Simpkins, 1979). However, those investigations do not provide a general assessment of haptic identification capabilities, because of various limitations—using very young subjects, a small sample of objects, or a task other than identification per se. The present study directly assessed adults' haptic identification of hand-size common objects that were readily identifiable through vision. Its goal was to provide baseline measures of speed and accuracy.

METHOD

The subjects were students at Queen's University, 20-23 years of age. Three females and 2 males took part in a visual identification task, and 10 females and 10 males participated in a haptic identification task.

The stimuli were 100 common objects, of a size that could be held within the hands (see Appendix). None made a noise, either functionally or in the course of manual exploration, and none had a clear identifiable odor. Forty-one of the stimuli were selected from a list of objects (Snodgrass & Vanderwart, 1980) as having high (>70%) name agreement when they were presented pictorially; the remainder were selected by the experimenters as being unambiguously identifiable by name. The objects were roughly classifiable as personal articles, articles for entertainment, foods, clothing, tools, kitchen supplies, office supplies, and household articles. There were from 8 to 23 items in each class.

The visual identification task served as a pretest for verifying the nameability of the stimuli by sight. In addition to the 100 stimuli described above, an additional 10 were included, but were discarded when they were incorrectly named by a subject. A name was considered correct if it was commonly applied to objects of the given type, was not commonly applied to distinctly different objects, and was not the name of a relatively abstract category. (Thus, for example, "thread" or "spool" would be acceptable for that object, but "dowel" or "sewing implement" would not.) Each object was placed, in turn, on a table before the subject, who was asked to name it. All of the stimuli ultimately used were named correctly by all five subjects. Although reaction times were not measured, they were generally brief, on the order of a second.

For the haptic identification task, each subject sat at a table that had been padded with a towel to reduce noise. He or she was blindfolded and wore headphones through which white noise was delivered, in order to mask inadvertent noise from the exploration. The subject's chin was placed in a chinrest clamped to the table, and he or she made responses into a microphone that triggered a voice key for purposes of timing responses. The subject was free to use both hands and to pick up the objects while exploring.

On each trial, the experimenter set an object on the padded table and turned on a tape recorder. (The order of objects was determined randomly for each subject.) She then tapped the subject's hand, to indicate that the object was available for exploration. When the subject first touched the object, the experimenter pressed a finger switch, starting a timer that terminated with the subject's vocal response. The subject's task was to identify each object as quickly and accurately as possible, or, if he or she could not do so, to say, "I don't know." In addition, following vocalization of a name, the subject was asked to describe the properties that had been used to identify the object.

RESULTS

The principal dependent variables were reaction time (between the first tactile contact with the object and vocalization) and errors, either misnaming or omission ("I-don't-know" responses). Misnaming errors were further categorized as superordinate (giving the name of a higher order category, e.g., "vegetable" for a pumpkin), categorically related (e.g., "sock" instead of "sweater"), corrected superordinate or related (following an initial superordinate or categorically related name with a correct response, e.g. "clothing ... sweater"), and categorically unrelated (e.g., "rock" for a potato).

Of the 2,000 responses, only 83 (4.2%) were errors. Four errors were omissions. There were 22 superordinate errors, 29 categorically related, 14 corrected superordinate or related, and 14 unrelated. Males and females did not differ in their error rates, by t test.

Analysis of the reaction times for correct responses indicated that the model response latency was 1-2 sec and that 68% of responses occurred within 3 sec of contact. Only 6% of responses took longer than 5 sec of contact.

These data differed little by gender of subject. When mean response latencies were computed for each stimulus, all but two items had mean values of 5 sec or less. The deviant items were rice (mean latency = 6.6 sec) and T-shirt (mean latency = 10.6 sec). These items also accounted for relatively high proportions of the errors (6 per object).

Another type of data was subjects' phenomenological reports of the object properties that had led to their identifications. These were divided into 16 categories, derived from an initial sampling of the data, which distinguished among reports of a distinctive component and of the size, shape, texture, temperature, and function of the whole object or a component. Two independent raters assigned the reports to the 16 categories, with 85% agreement.

An average of 1.9 comments was made about each item. Global shape (e.g., of a whistle), global texture (e.g., of sandpaper), and presence of a distinct component (e.g., cap on a pen) were predominantly mentioned as the basis for identification (on 46%, 36%, and 35% of trials, respectively), with component texture (16%), global size (15%), and component shape (7%) next most often reported.

DISCUSSION

The principal finding from this study is that haptic identification of a wide range of objects can be remarkably fast and accurate. Given the present scoring system, 96% of the naming responses were correct. With a more lenient system, allowing superordinate category names and related categorical responses, and permitting false starts, the accuracy rate would be 99%. Moreover, 94% of correct (under strict scoring) names were given within a 5-sec interval. This performance is all the more remarkable when it is compared with haptic reading and identification performance observed in past research. Difficulties with raised drawings are informally confirmed in our laboratories as well; frequently, people are unable to identify even simple outlines after 2-3 min of exploration!

The observed levels of haptic identification are also considerably better than the level of identification of common odors (Cain, 1979, 1982; Desor & Beauchamp, 1974; Engen & Ross, 1973)—generally estimated at about 40%-50%. An important factor underlying the relatively low level of identification by odor is label availability; thus, performance is subject to considerable improvement with practice (Cain, 1979; Desor & Beauchamp, 1974). One might argue, then, that by equating stimuli for the natural-language frequency of their labels, identification rates for touch and olfaction would be comparable. However, even after accounting for difficulties in associative retrieval of names, a residual error in odor identification remains, apparently reflecting discrimination failures imposed by the sensory system itself (Cain, 1979). Odor identifications also have considerably longer latencies than the responses in the present experiment. In the Desor and Beauchamp study, unpracticed subjects took approximately 10 sec to give correct responses and highly practiced subjects still averaged over 2.5 sec to respond. The rapid and accurate responses by unpracticed subjects in the present experiment suggest that the superiority of haptic over olfactory identification cannot be explained solely by superior accessibility to labels.

Earlier it was suggested that studies with arbitrary configurations or two-dimensional simulations might underestimate the capacity for haptic object identification, because these types of stimuli deprive the haptic system of some of its most effective cues. The present data provide support for this suggestion. Most bases for identification that are emphasized in the phenomenological reports of these subjects—global shape, texture, and size cues—are not readily available with simulated objects. Raised-line drawings might appear to provide shape information, but the usual nature of that information is a projection to the retinal plane, not the tangible, grasped shape of haptic exploration. Texture cues in raised drawings are normally minimal and usually arbitrarily assigned to the concepts they are intended to represent. Moreover, often only relative size can be portrayed.

Also relevant to this argument is a study (Krantz, 1972) that used factor analysis to assess the basis for haptic object identification. It identified five factors—amount of exertion needed to explore (related to compliance), roughness, size, temperature, and sharpness—none of which is adequately represented by raised-line drawing techniques in current use.

Although we have argued that the haptic system is well equipped to identify familiar objects, we do not mean to claim that the perception of form through touch is generally accurate and efficient. It is one thing to assign an object to a known category and quite another to apprehend its structural characteristics. Studies using artificial objects and graphics displays appear well suited to assess haptic perception in this latter sense—and they assess it as poor. In contrast, past experience with objects—visual as well as tactual—might enable categorization on the basis of minimal cues, without full apprehension of surface and shape. The present study indicates that, in this latter task, the haptic system can be very competent indeed, more competent than might be expected from intuition or extrapolation from experiments on haptic perception of form. We see the results of the current study as a necessary first (phenomenological) step towards developing a model of haptic object identification, one component of which may be a representation that is readily accessed by both haptics and vision (as suggested by Garbin & Bernstein, 1984; Gibson, 1966).

The present work also has implications for applied concerns. One application that motivated this research was the design of effective tangible graphics for the visually handicapped. Our study suggests that effective graphic aids should eschew simple mimicry of two-dimensional visual displays. Instead, they might incorporate the three-dimensionality of real objects and retain critical properties such as texture. A rather different area in which research on haptic object identification might be applied is the development of intelligent robotic systems that use tactile sensing (Harmon, 1982). By understanding the mediators between haptic exploration and identification, we may discern levels of information representation that are appropriate for robots to simulate human behavior, thus rendering them capable of highly accurate identification performance.

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APPENDIX
Stimulus Objects

Category	Articles
Personal	comb, emery board, glasses, hair dryer, ring, swab, toothbrush, wallet, watch
Entertainment	balloon, baseball bat, baseball glove, birdie, crayons, golf ball, playing cards, record, tennis racket, whistle
Clothing	belt, boot, mitten, scarf, shoelace, sock, sweater, T-shirt, tie
Foods	carrot, cracker, egg, onion, potato, pumpkin, rice, tea bag
Office Supplies	binder, book, bow, calculator, clipboard, envelope, eraser, notebook, paper clip, paper pad, pen, pencil, pencil sharpener, ruler, stapler, tape
Tools	clamp, hammer, paintbrush, sandpaper, scissors, screw, screwdriver, twine, wrench
Household	ash tray, bandage, button, candle, clothespin, dust pan, electric cord, flashlight, flower pot, hook, key, light bulb, match book, padlock, rubber band, safety pin, scrub brush, sponge, thread, toilet paper, toothpicks, umbrella, watering can
Kitchen Supplies	baby bottle, bottle opener, bowl, fork, funnel, glass, kettle, knife, ladle, muffin pan, mug, plate, pot, spatula, strainer, wooden spoon

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