The influence of object properties on haptic memory
by Latona D Murdoch

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Applied Psychology
Montana State University

Abstract:
A viable model of haptic perception and memory has not been constructed due to the lack of research which would help define it. Research on haptic memory is especially scarce. The current study attempts to add to the body of knowledge about haptics in general and the nature of haptic memory specifically.

Haptic sensation receives information from three sub-systems: cutaneous, afferent kinesthetic and efferent kinesthetic senses. Because haptic perception involves information from several sources, it must be determined which source, and thus which type of perception, is most important for recall in haptic memory. Some researchers propose that haptic memory is based on kinesthetic or spatial information. However, the present study proposes that haptic memory is based on cutaneous or textural information.

Twenty volunteers from upper- division psychology classes participated. A procedure to control for both kinesthetic and cutaneous information was designed by holding each type of information constant. Thus, the texture set controlled kinesthetic information by using identically shaped blocks covered with ten different textures. The shape set controlled cutaneous information by using identical textures covering ten different shapes. Participants were blindfolded and required to learn a CVC trigram label for each object in each set using an over-learning procedure to insure that memory retrieval was tested. Recall tests were administered at intervals of 5 minutes, 1 hour, 24 hours, 1 week and 2 weeks. A 2 (texture vs. shape) x 5 (recall times) repeated-measures ANOVA was significant for the number of correct responses for each stimulus set ($F(1, 19) = 6.22$, $p = .02$) and for each recall time ($F(1, 19) = 16.30$, $p = .00$) as well as a significant interaction ($F(1, 19) = 3.02$, $p = .02$). Follow-up t-tests indicated a significant difference between stimuli types at one week and two weeks.

Results suggest that haptic memory is based primarily on cutaneous, rather than kinesthetic, information. The salience of textural, or cutaneous, information appears to persist in the transition from haptic perception to haptic memory.

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ABSTRACT

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INTRODUCTION

The skin is the first sensory organ of the human body to develop and the largest (Montagu, 1986). It is highly responsive. The skin protects us from our environment, while allowing us to interact with it, primarily through the sense of touch. Similar to other senses, touch gathers information which is carried to the brain to be organized, classified, sorted, stored and retrieved. Touch can provide information which is as meaningful as that sensed by the eyes or ears. Although touch predates vision or hearing in human physical development, it has been largely overlooked in the psychology of sensation, perception and memory. When mentioned, it is usually described in physiological terms and is often associated with unpleasant events such as pain. The day-to-day function of touch is a neglected area of research. A model of touch perception is only now being considered as researchers acknowledge the importance and contribution of touch. The present research study is an effort to contribute to the construction of a model of touch perception and memory. An additional aim is to further the study of practical applications of haptic information in memory.

Haptic Perception

Haptic perception, or the sense of touch, begins with two types of physiological sensations: cutaneous and kinesthetic. Cutaneous sensation, also known as tactile, has been defined as the "stimulation of the outer surface of the body by means of receptors within the skin and the associated nervous system" (Loomis & Lederman, 1986, p. 31-1). Kinesthetic sensation can be further divided into afferent and efferent information. Afferent kinesthetic sensation is the information relayed to the brain from the muscles, joints and skin regarding body position and movement (Loomis & Lederman). It is considered passive because it does not initiate movement. Efferent kinesthetic sensation occurs when information travels outward from the brain to the receptors in the joints, muscles and skin. When the observer exerts control or purposeful movement through efferent information, the haptic mode becomes active (Loomis & Lederman). Haptic sensation results from the interaction of tactile and both types of kinesthetic input.

Information from cutaneous, afferent kinesthetic and efferent kinesthetic sensors in the haptic system is independent. This means information can be gathered through a single type of sensation (e.g. cutaneous only). A more complete representation is perceived when information from two or three receptor types are combined (e.g. cutaneous and kinesthetic). Thus, it is logical to assume that the combination of sensations which yields the most information (e.g. cutaneous, afferent and efferent kinesthetic) gives the most complete sensory experience to the observer. Yet not all psychologists use this gestalt-type model. Many focus totally on tactile sensations. Geldard (1957) described only the <u>skin</u> as a sensory organ. He even suggested a way to produce the sensation of motion without actual movement by the subject. Nafe and Wagoner (1941) examined only the displacement of skin layers by metal weights and Stevens (1959) tested only vibro-tactile stimulation of the finger and the arm. Contemporary research continues to apply this limited perspective to the experimental investigation of touch. In an overview of his research, Verillo (1993) describes his examinations of developmental deficiencies in vibro-tactile sensitivity. Specifically, he investigated the decline in performance of tactile receptors as we age and found considerable differences between younger and older adults.

More recent work by Woodward (1993) centered on tactile discrimination deficits linked to aging. Both of these later studies involved passive tactile stimulation of the skin of the hand.

Another approach uses the gestalt perspective to investigate haptic sensation and perception. This strategy assumes that haptic perception has a phenomenological quality. In other words, total perception does not occur unless the observer/toucher <u>actively</u> perceives the object being touched. Focusing only on the tactile part of haptic sensation ignores important information that provides a more complete representation of the touched object. The interaction between the three sub-systems is considered as important as the individual sensations of each. Gibson (1962) supported this gestalt approach and claimed active haptic touch did "not fulfill the supposed criteria for a *single sense* modality [italics added]" (p. 479). He proposed the haptic system is an integrated one, using as an example ten separate sensations from ten separate fingers yielding a unified experience of an object. Even earlier, the exploration of how sensations influence behavior and how "motor responses influence sensory discrimination" (Hayek, 1952) was suggested as a topic for research (p. 81). Building on the gestalt approach, contemporary researchers such as Fagot, Lacreuse and Vauclair (1994), Klatzky, Lederman and Metzger (1985) and Klatzky, Loomis, Lederman, Wake and Fujita (1993) used real or abstract three-dimensional objects. Three-dimensional objects allow active haptic perception to occur, which means all types of sensations produced by the haptic system can be utilized by the subject.

Investigation into the movements made during object exploration further supports the gestalt approach to touch perception. Research has documented that stereotyped movement patterns are used by persons during the haptic exploration of three-dimensional objects (see Fagot, et al., 1994; Klatzky & Lederman, 1992; Lederman & Klatzky, 1987). These movement patterns are referred to as exploratory procedures or EPs. Each EP is associated with the particular tactile property it is used most often to elicit (Lederman & Klatzky). For example, people often use lateral motion (small side-to-side movements of the finger pads) to sense textural information such as roughness. Weight is sensed by lifting an object, usually in the palm of the hand. EPs illustrate the separate but integral nature of the haptic sub-systems by combining afferent and efferent kinesthetics with tactile sensations. Lederman and Klatzky propose that "the hand may achieve higher levels of perception and cognitive performance than otherwise possible" because of the interdependence of kinesthetics and tactile sensations (p. 343).

Haptic Memory

Once sensed, the haptic information must be encoded for processing and retrieval. It is here that information (or input) moves from the sensory domain to the cognitive. A standard approach to the study of encoding is to measure how much information can be retrieved from short-term memory, long-term memory, or both. Measuring memory is a valid tool for exploring the abilities and deficiencies of encoding and retrieval of information. Investigation of other senses, such as the visual and auditory systems, has naturally led to work on memory for the types of information perceived by those systems. However, little research has explored haptic memory. Most research on touch still focuses solely on sensation and perception. As with the other senses, knowledge of haptic perception gives us clues to the mechanisms involved in haptic memory. But the interaction of the three systems of active haptic perception (i.e. cutaneous, afferent and efferent kinesthetics) raises questions about the source of haptic memory. One hypothesis would suggest that haptic memory uses integrated input from all three sub-systems, giving each equal weight. While this idea seems logical, it is not in keeping with what we know about other perceptual systems. For instance, the "figure-ground relationship is the most fundamental principle of perceptual organization" (Wood & Wood, 1996, p. 108). Figure-ground perception occurs when some of the information we sense stands out from the rest. It occurs in vision and audition, as well as tactile perception. It is considered by many scientists to be innate. For example, we can pick out conversation from all the background noise around us or the face of a friend in a crowd. Similarly, we ignore the pressure of clothing on our skin but not someone's hand on our arm. While these senses are detecting all stimuli which are present, the brain is selective of the stimuli to which it attends. If figure-ground applies to other senses, it should apply to haptic perception as well.

If all haptic sensations are not equally weighted, then which information is the most salient? There are two possibilities. Much of what is perceived through touch is spatial or kinesthetic in nature, such as overall shape, volume, and position relative to the body. This type of information suggests that perception, and thus memory, is based on spatial or kinesthetic information. Equally reasonable is the assumption that cutaneous input, such as temperature, weight, texture and hardness, might be more heavily weighted.

There is evidence to support this idea. Klatzky, et al. (1987) designed several experiments to determine the most salient properties of objects under touch only and touch + vision conditions. A free sorting task was used to allow subjects to categorize objects according to any of the available object attributes (shape, hardness, size, texture, weight, volume, and temperature). Klatzky, et al. (1987) theorized that each perceptual system may have a different combination of properties which are the most salient. Furthermore, these researchers proposed that haptic perception would employ a different set of object properties during classification than would vision and touch together. The results of the sorting task showed texture and hardness to be the most salient properties of tactile perception while size and shape were most salient in the vision + touch condition.

There is one other possible explanation of haptic memory. Humans are verbal beings, with many cognitive processes using language to carry out tasks. Thus, it would be reasonable to argue for a linguistic component to haptic memory. Perhaps what is being remembered is a verbal label or description of the object, rather than the actual haptic information. Instead of a memory of how a pencil feels in your hand (e.g. long, nearly round, slender, hard) you merely remember the word "pencil". This explanation of haptic memory has been tested. Subjects were presented with a list of concrete nouns under a vision-only condition, and groups of real objects under vision-only, vision + touch and touch-only conditions (Stadtlander, Murdoch & Heiser, 1997). Subjects were able to recall significantly fewer concrete nouns than real objects in any of the other conditions. If haptic memory was based on recall of an object's label, rather than on haptic properties, it would be expected that labels (nouns) alone would be remembered as well as object/label pairs. Stadtlander, et al. used real objects, so it could be argued that the haptic information served as a cue for the object's label. However, a surprise written recall task demonstrated the same superiority of objects over nouns. Thus, there is evidence suggesting that haptic memory is not simply a variation of memory for labels but rather memory for the physical properties of an object.

The interactivity of the haptic sub-systems raises the same questions about the nature of haptic memory as it does about haptic encoding processes. It is most likely that the encoding process assigns different weights to the information coming from the various haptic sub-systems. It remains to be tested whether the most heavily weighted information become the most easily recalled. In addition to theoretical problems, the sub-systems of touch pose unique methodological problems as well. Recent research suggests a possible solution. Klatzky & Lederman (1992) propose that the exploratory movements (EPs) mentioned earlier may be specific to the nature of the object being explored. When a certain property was to be used as the basis for discrimination between objects (such as size or shape), hand movements associated with that property were used intuitively. These movements are distinctive enough that they can be reliably identified and classified by naive observers (Lederman & Klatzky, 1987). The use of distinctive exploratory hand movements connected with specific object properties suggests that similarly shaped objects will be explored with similar movements. If this is true, then it should be possible to control for the variable of kinesthetic information by holding the shape of objects constant (using identically shaped objects) and varying one or more of the cutaneous types of information. Conversely, holding the selected cutaneous information constant but varying the shapes of objects should test for spatial or movement cues in memory. The next step is to decide on which tactile input to use. Study of the salience of various object properties strongly suggests that of all the tactile sensations, texture is the most salient (Klatzky, et al., 1987).

The present experiment attempted to differentiate between the two possible foundations of haptic memory. Two types of stimuli were used: 1) all shapes, and thus presumably the movements were the same but the textures varied (hereafter referred to as the texture set) and 2) all textures were the same but the shapes and movements varied (referred to as the shape set). The effects of each of these stimulus dimensions on immediate and delayed recall were examined.

As noted previously, there are three possible sources of haptic memory, hence three hypotheses are needed. Hypothesis 1: proposes there will be no significant difference in the number of items recalled between sets. Since other perceptual systems use differential weighting of sensations, haptic perception most likely does as well. Thus, results of no difference will suggest that tactile sensations and movement interact strongly enough that they can not be separated using the current procedure. Hypothesis 2: a greater number of items of the texture set will be remembered, suggesting tactile sensations provide the basis of touch memory. Hypothesis 3: a greater number of items of the shape set will be remembered. This result would support the view that memory for touch is based primarily on patterns of movement or spatial information.

The use of delayed recall tests at periods of 1 hour, 24 hours, 1 week, and 2 weeks necessitate additional hypotheses. Hypothesis 4: states that both the texture and shape sets will be equally well-remembered as a function of time. Hypothesis 5: proposes that there will be a difference in the number of objects recalled between stimulus sets at different recall times.

METHODS

Participants

Twenty-four students from upper-division courses in psychology at Montana State University-Bozeman volunteered as participants. The participants were entered into a prize drawing for a $50 gift certificate as a reward for completing the initial learning trial and again for each subsequent recall test completed. Four participants were not included due to failure to keep follow-up appointments. Twenty participants, 10 women and 10 men, completed the entire experiment. Participants completed a questionnaire regarding injury (e.g. broken bones, deep cuts) and diseases (e.g. carpal tunnel syndrome) of their dominant hand. No participant had sustained serious damage to their dominant hand. The amount of callous on the palm and fingerpads was also ranked on a scale of 1 (slight) to 5 (heavy). The mean callous ranking for all participants was 1.65 (SD = 1.27). Callousness was uncorrelated with recall test scores for either stimulus set.

Stimuli

Stimuli consisted of 100 wooden blocks in 10 different shapes. Each block within a shape group was covered with a different material to provide a unique textured surface. This produced an array of 100 objects which varied along two dimensions: shape and texture (see Appendix for a list of shapes, textures). A texture set was constructed by collecting all the objects of a specific shape; each with a different texture. A shape set contained all the objects covered with a specific texture, each with a different shape. Each possible set of objects (10 texture and 10 shape) was assigned a number and a random number table was used to assign a set of each type to a participant. Each object in the chosen set was given a pronounceable CVC trigram label to use as the information to be recalled. For example, the disk shape was called BAF for each subject, regardless of its texture; the foil texture was always YIM, regardless of its shape. Because sets were chosen from an array, one object appeared in both sets but had a different label in each set.

Learning Trial Procedures

Each participant was given two sets of learning trials using a touch-only (blindfolded) condition. A learning trial consisted of the repetitions needed by the participant to correctly name all 10 objects twice in succession while handling each object. The two set types were counter-balanced between learning trials. Participants were instructed to use one hand to inspect each object, one at a time for five seconds. During the first two repetitions the experimenter announced the item's label (tri-gram) as the object was placed in the participant's hand. During subsequent repetitions, the experimenter named the object only after the participant indicated he or she was unable to do so. Objects were presented in randomized order during each repetition. Once the criterion of two perfect repetitions was achieved, the participant performed a movement-related distracter task by sorting poker cards into suits. The distracter task was performed for five minutes then the participant was tested. In the recall test, the participant was asked to recall each object's label when handling the object. The participant read aloud for five minutes before beginning the second learning trial with the other set of objects.

Delayed Recall Procedures

Delayed recall tests were conducted with each participant at intervals of 1 hour, 24 hours, 1 week and 2 weeks after the initial learning trials. Participants were aware of the planned delayed recall tests and were instructed to avoid any type of rehearsal and/or writing down the names of objects. Objects were presented in random order and sets were counterbalanced during each delayed recall test. Participants were blindfolded and asked to give the label of each object as it was handled. The two sets of stimuli were presented one after the other.

RESULTS AND DISCUSSION

A 2 (texture vs. shape) x 5 (recall times) repeated-measures ANOVA performed on the number of correct responses for each stimulus set and for each recall test showed significant results as well as a significant interaction. The data support both hypothesis 2 (higher texture scores overall) and hypothesis 5 (higher texture scores at all recall times).

Table 1. ANOVA for Stimulus Set Type by Recall Time

		SS	DF	MS	F	Sig of F
Stimuli	Within	39.69	19	2.09		
	Between	13.00	1	13.00	6.22	.022*
Time	Within	160.73	76	2.11		
	Between	137.87	4	34.47	16.30	.000***
Stimuli by Time	Within	53.33	76	.70		
	Between	8.47	4	2.12	3.02	.023*

* $\underline{p} < .05$, *** $\underline{p} < .001$

The interaction between stimulus types as a function of time is illustrated in Figure 1. Recall times are stated in hours on the X axis in order to more accurately depict the amount of time between the immediate recall test (at 5 minutes) and subsequent recall test times. The texture set was significantly higher at immediate recall (see Table 2). Scores for both stimulus types remained fairly stable through the twenty-four hour recall test, then dropped. According to within-subject $\underline{t}$-tests, the mean number of correct responses was not significant ($\underline{p} < .01$) at 1 hour or 24 hour recall tests due, presumably, to the over-learning procedure used during the learning trials (see Table 2).

Figure 1

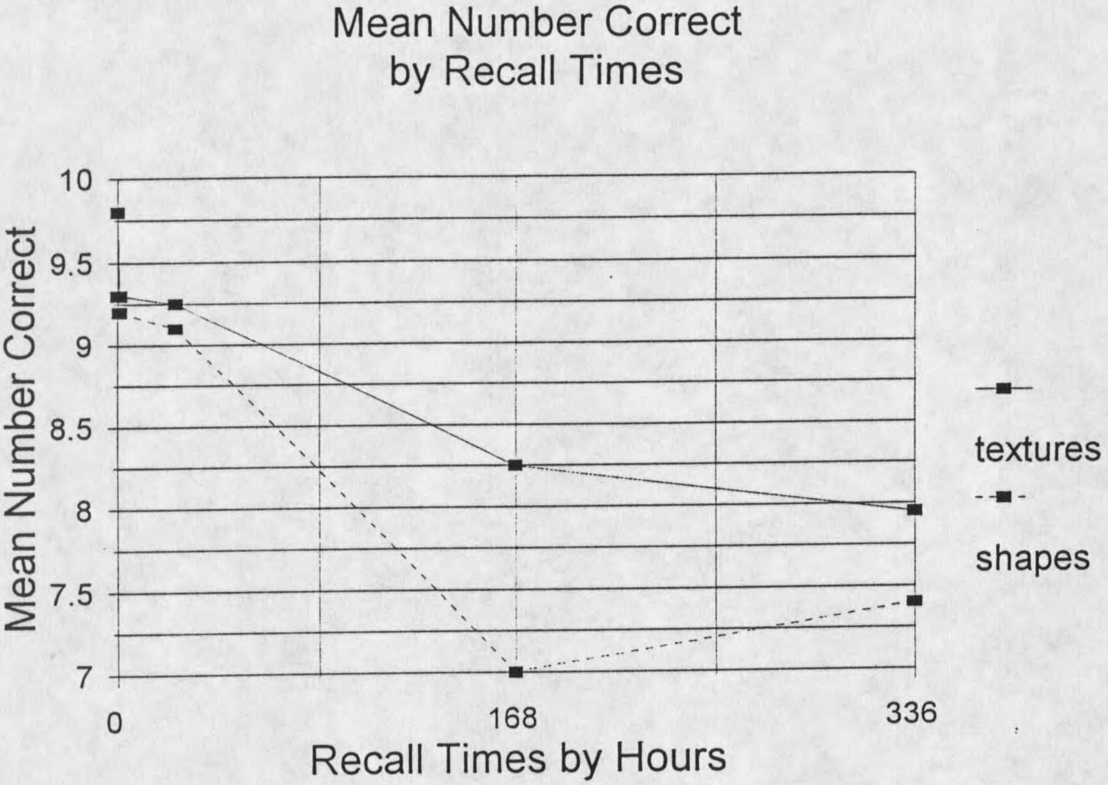

Table 2. Results of t-tests Between Stimulus Sets at Recall Times

	t statistic	df	Sig.
Immediate	-2.236	19	.038*
1 Hour	- .326	19	.748
24 Hour	- .484	19	.634
1 Week	-3.324	19	.004**
2 Weeks	1.675	19	.110

* $p < .05$, ** $p < .01$

Between the twenty-four hour recall and the two week recall tests, scores decreased by an average of 1.0 items in the texture set and 2.1 items in the shape set. Means are listed in Table 3. A t-test of the means of correct answers between stimulus types was significant at the one week recall test (see Table 2 above). The difference in mean number correct between 24 hours and 1 week for both stimulus types was significant, (t (19) = 2.431, p < .025).

Table 3. Mean Correct Scores of Stimulus Set by Recall Times

		Recall Times				
Stimulus Type		5 Minutes	1 Hour	24 Hours	1 Week	2 Weeks
Texture	Mean	9.80	9.30	9.25	8.25	7.95
	SD	.52	1.17	.91	1.52	2.14
Shape	Mean	9.30	9.20	9.10	7.00	7.40
	SD	.92	1.06	1.12	2.13	2.50

A duplicate object appeared in each set because sets were chosen from an array of objects. For example, a participant was assigned the felt (texture) set and the cube (shape) set. Thus a felt-covered cube appeared in both sets. The duplicate object could potentially affect both the learning trials and the recall tests. During the learning trials it was possible that interference from the duplicate in the first set would cause the duplicate in the second set to be learned either more or less quickly. A t-test showed there was no significant difference between the number of trials needed to learn the duplicate object in either set (t (19) = -1.098, p = .286). The number of errors of each duplicate during recall tests was low. For the texture set duplicate, the mean number of errors was .95 (SD =

1.47). For the shape set duplicate, the mean number of errors was 1.0 (SD = 1.26). The t-test was not significant (t (19) = .114, p = .910).

The support of hypothesis 2 is especially interesting because many participants indicated they felt the texture set was both harder to learn and to remember. While the number of learning trials for the texture set (M = 8.6, SD = 4.3) was greater than the shape set (M = 6.85, SD = 3.79), the result of a paired t-test was not significant, t (19) = -1.809, p = .086. A chi-square test conducted on the total number of correct scores of each set indicated that no object was significantly different from the overall mean number correct for that set. For the texture set, χ^2 (9) = 3.558, $p > .05$; for the shape set, χ^2 (9) = 9.034, $p > .05$. In other words, each object (including the duplicate object) was no more or less memorable than any other object.

GENERAL DISCUSSION

The main effects of the analysis of variance support the hypothesis that items of the texture set would be better recalled than the shape set. Although significant differences do not show up until later recall tests, scores for the texture set were higher at all recall times. These results support and extend the work of Klatzky, et al. (1987) on the salient features of objects under a touch-only condition. These researchers maintain "the haptic system has its own encoding processes and pathways" and that "even when representations achieved hapticly and visually are held in common, the two domains are likely to give different weights to such codes" (Klatzky, et al., 1987, p. 357). The approach used in the present experiment demonstrates that cutaneous information, and specifically texture, is more heavily weighted in haptic perception and memory. The superiority of texture over shape as a function of time also suggests that textural information is more stable over time. This stability helps to explain the use of texture as a retrieval strategy for abstract objects in a previous study (Stadtlander & Murdoch, 1997). Even when it seems that both texture and shape information were encoded to a similar degree, more textural information is recalled, particularly during later recall times. These results suggest a haptic model of perception and memory based on textural cutaneous information, rather than primarily kinesthetic model. Results also indicate a equally-weighted cutaneous/kinesthetic model is unlikely.

The present experiment also provides additional evidence against the verbal explanation for haptic memory. Abstract objects and CVC trigrams were used to avoid as much as possible the "labeling" problem. But stimulus objects could be classified by a label such as triangle, cube, rough, or fuzzy. Concrete labels such as these would have required making associations between new perceptions and old labels. Abstract CVC trigrams were used to hinder participants from using these more concrete labels as well as to provide information to be recalled. Since these trigrams are unique, non-descriptive and lack meaning, new associations had to be made between the haptic perceptions and the unique labels.

The lack of interference of the duplicate object was surprising, both in the learning trials and the recall tests. The lack of significance for both the number of learning trials and recall test scores suggests that participants experienced the object according to the property of the set it was in. To use the previously cited example of the felt-covered cube, the object was fuzzy in the texture set and cube-shaped in the shape group.

It was informally noted that subjects often handled certain shapes in similar ways. The spool was usually rolled between the thumb and fore finger, traveling from finger tip to the first joint and back. The ball or sphere was enclosed tightly in the palm while the pads of the thumb and fingers moved slightly from side-to-side. Both round dowels differed only in length (see Appendix) and were enclosed in the palm with the pads of the little finger and thumb placed on the ends, presumably to gauge the length of the object. The observations of the use of similar movements agree with the formal observations made by of Klatzky and Lederman (1992). Object shape is easily manipulated and use of identically shaped objects to control for kinesthetic sensation would be an viable method in the study of haptic perception and memory. Some support for this method can be inferred from the lack of interference between the duplicate object. If both haptic properties were encoded equally during both sets of learning trials, a greater number of errors would have occurred. Replicating the current study is suggested so formal observation of movements used to explore identically shaped objects can be evaluated as a research tool.

Texture was better remembered than shape at later recall times. This outcome has interesting implications with regard to industrial design, human factors, ergonomics and consumer product applications. Casual observation notes many manufacturers design products with haptic features, such as push buttons, which use object attributes more salient to the visual perception system rather than the haptic perception system. Shape and size are the most often manipulated attributes in manufacturing, although recent research shows that these properties are not the most salient. If texture is both the most salient and memorable property of many physical objects, then it is suggested that textural information will increase the usability and memorability of product features. It is not proposed that texture alone will suffice to make objects easier to learn or to remember, but the inclusion of textural information in combination with other information such as shape or color could greatly help increase a product's usability. In addition, the combination of texture with other haptic information will give product design engineers and manufacturers a wider variety of attribute combinations to choose from when designing new products.

A greater understanding of haptic memory is now possible due to the results of the present experiment. This understanding can lead to applications utilizing more of the sensory input, perceptual organization, and memory capacities of which human beings are capable. Reliance on a single perceptual or encoding system taxes cognitive resources and can lead to encoding and retrieval failures. Use of additional resources, such as touch, may alleviate some cognitive overload. Improvement strategies for informational encoding and retrieval based on haptic perception need to be developed and tested.

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APPENDIX

Textures	Tri-Gram	Shapes	Tri-Gram
Wood	TOF	3" x 3" Square	LAT
Wax	BAL	3" x 3" Right Triangle	GUK
Foil	YIM	2" x 2" x 4" Rectangle	PIB
Felt	DAL	1.5" Ball	VOX
Coarse Glitter	JIT	1" Cube	MAZ
Lines of hot glue	FUM	1.5" Disk	BAF
Batting	WOM	6" x .75" Tongue depressor	WEK
Rubber shelf liner	TEB	1" x 4" round dowel	ZAN
Fine sand	RIV	1" x 2" round dowel	FOD
Bubble wrap	HAX	1.25" Spool	SIG