The development of haptic (active touch) perception has long been an area of interest in occupational therapy (Cermack, 2006; Hoop, 1971). Haptic perception is commonly tested (e.g., Manual Form Perception Test, Ayres, 1989) and haptic activities may be used to augment visual activities (Schneck, 2010). Studies have found that haptic activities can enhance recognition of geometric shapes (Kalenine, Pinet, & Gentaz, 2013) and improve phonemic awareness (Bara, Gentaz, Colé, & Sprenger-Charolles, 2004) in kindergarteners. Among elementary school age children with learning disabilities, improving haptic exploration strategies has been found to improve general perceptual skill development (Locher, 1985); however, no known recent studies have confirmed this finding. Yet research regarding the use of touch as an active information gathering tool receives little attention, particularly with children older than preschool age. Before we can consider the use of haptic activities as a means to a therapeutic goal, a better understanding of this type of perception is needed. This study investigates haptic exploration in children and adults to determine the characteristics of touch and movement that are associated with accuracy and efficiency as they use their hands in cross-modal (vision and haptic) and unimodal (haptic only) shape matching tasks.

Characteristics of Haptic Scanning

In ways comparable to visual scanning, in which the point of focus is moved rapidly from feature to feature to encode an image (Henderson, 2007), hands can be used to explore and identify an object through haptic scanning by moving the point(s) of contact along the edges of a shape to perceive its image and encode it into short-term memory. Haptic perception of an object requires movement: the fingertips moving across the object stimulate cutaneous sen-
sory receptors giving information about surface features, whereas the movement provides information about its spatial characteristics (Klatzky & Lederman, 2003). Multiple sources of sensory input (from skin, muscles, and joints) are integrated to create this perception (Schaaf & Lane, 2009). The possible combinations of sensations arising from one to ten fingers, one or two hands, and the numerous muscles and joints in the hands and upper extremities, all moving over time, are considerable (Gibson, 1962). Haptic scanning strategies must be employed for optimizing input sources and organizing the search. Skill in this area would be expected to improve with age because strategies are learned through experience (Millar, 1999).

Although research on haptic scanning, particularly with children, is sparse, some characteristics of haptic behavior that have been reported may be important to consider in investigating scanning strategies. One characteristic is the use of one versus two hands. Klatzky, Lederman, and Balakrishnan (1991) provided a detailed account of the patterns of movement used by adults as they explored novel shapes with the purpose of making specific comparisons. Two-hand use was nearly universal, and the use of two hands moving together was noted as having high persistence during the tasks. Two-hand exploration has been seen as a positive development associated with successful matching in children (Bushnell & Baxt, 1999; Kalagher & Jones, 2011a), and with adults the use of two hands (on instruction of one or two hand use) leads to increased salience of shape (Klatzky, Lederman, & Reed, 1989). Also, in a different type of tactile activity, two-handed (or -fingered) Braille readers tend to be faster than one-handed readers (Millar, 1987). Millar (1999) described the use of two hands as providing a frame of reference, each hand a reference for the other.

The hand and finger movements used in haptic scanning of an object have also been investigated. In adults, Lederman and Klatzky (1987) identified contour following as the type of hand movement used to identify the exact shape of an object, “a dynamic (exploratory procedure) in which the hand maintains contact with the contour of the object” (p. 347). In Klatzky et al. (1991), the most common patterns observed were those using multiple points of contact with the object and molding fingers around a shape or part of the shape (enclosure). Single-handed simple contour following was only occasionally observed. Combinations of enclosure and movement, such as the thumb and index following along a convex feature ending in a pinch, were also frequently seen.

Preschool age children exploring objects haptically have been observed using contour following patterns similar to those used by adults (Kalagher & Jones, 2011b; Schwarzer, Kufer, & Wilkening, 1999). Kalagher and Jones (2011a) noted that although the mature movement patterns may be seen, they are not used in all circumstances and some “non-informative” (e.g., “static finger”) hand patterns have been observed. These observations are consistent with those noted by Piaget and Inhelder (1967), who described changes in haptic exploration in terms of ability to coordinate exploratory movements. Early in development, approximately 2 to 3 years of age, children can recognize objects, but only familiar ones, by using global single touches (or centrations, in Piaget’s terminology) such as whole hand patting. Later, children begin to coordinate successive haptic perceptions and can recognize abstract objects. By approximately 6 to 7 years of age, children use a fixed point of reference to organize perceptions and are considered at the highest level of haptic perceptual activity. Based on Piaget’s work, Hoop (1971) recorded the haptic explorations of preschoolers using a point system for the types of exploration and the levels of organization demonstrated. The highest points were given for using a constant point of reference (holding in a constant place with one hand while the other explores). The oldest children, 5½ year olds, obtained the highest scores reflecting the most systematic exploration.

No recent research was found on the Piagetian view of the development of points of reference in haptic exploration, and little (recent or old) addresses the haptic skills of children older than preschool from any theoretical base. Yet general perception continues to develop through childhood, as noted by Piaget and Inhelder (1967) and as evidenced in many standardized visual perception tests (e.g., TVPS-R, Gardner, 1996). The early elementary school years are also a time when concerns about visual perception and visual motor skills arise and may be addressed by occupational therapists. Therefore, an investigation of the haptic perceptual abilities of early elementary school children could provide useful information for therapists.

Cross-Modal Transfer

Studies that investigate haptic perception often use tasks of matching an object by feel to a visual choice, known as a cross-modal transfer. Therefore, an important component of many haptic perception tasks is the connection with visual processes. Cross-modal transfer is an ability that has a devel-
developmental trajectory that begins very early in life (for a review of early development, see Cermak, 2006). Preschoolers have been noted to be able to recognize both familiar and unfamiliar objects in haptic-to-visual matching tasks, but are less proficient at this than mature participants (Bushnell & Baxt, 1999; Kalagher & Jones, 2011a). By age 6 years, children have been found to be equal to adults on cross-modal categorization tasks (Garbin, 1990), although on a difficult task (precise size discrimination task with conflicting visual and haptic information) optimal integration may not occur until approximately age 10 years (Gori, Del Viva, Sandini, & Burr, 2008).

Even in the absence of an actual visual referent, haptic recognition is believed to share some of the same perceptual phenomena as visual images, generating a mental representation of the percepts arising from touch and movement (Gibson, 1962; Piaget & Inhelder, 1967). The nature of cross-modal perception, whether it is a single multisensory representation or an integration of two separate representations, is a current topic of debate in cognitive psychology. (For a summary of current research in this area, see Lacey, Campbell, & Sathian, 2007.) Additionally, neurological evidence supports the integration of the two modalities. For example, functional magnetic resonance imaging studies of the brain show that parts of the visual system are activated during haptic exploration (James et al., 2002) and transcranial magnetic stimulation used to interfere with the visual cortex results in impaired tactile perception (Sathian & Zangaldze, 2002). The current study was designed to observe patterns of exploration in both cross-modal and single modality conditions.

Haptic shape perception is a highly cognitive, multimodal ability requiring short-term memory of sensations over time, perceptual abilities, and a strategy for gathering information. The characteristics of haptic perception that have been found to be associated with skill development are the use of two hands (rather than one), the coordination of multiple touches (rather than single or static touching), and the use of a constant reference point. Because nearly all previous research has investigated the haptic exploration of children up to preschool age and adults, information about how elementary school age children explore by touch is needed to more fully understand perceptual development at this age.

Current Study

It has been shown that by preschool age children generally use adult-like exploration patterns for single object exploration (Kalagher & Jones, 2011b; Schwarzer et al., 1999); therefore, a more complex haptic task is needed to observe differences between school age and full maturity. The assumed connection between visual and haptic perception provides the inspiration for the study tasks: a typical visual perception test, similar to those used in standardized visual-perception tests, has been transformed into a haptic perception test by making either the target or choices, or both, out of wood. Because the study tasks involve several shapes presented at once, a strategy for exploration and maintaining information must be employed to satisfy the goal of identifying an exact match. The study tasks proceed from an all-visual matching task to a mix of haptic and visual and finally to an all-haptic matching task. This order allows participants to become familiar with the demands of the haptic matching tasks and provides an opportunity to observe strategy differences in haptic-visual compared to haptic only tasks.

The target group of this study was elementary school age children. A group of college undergraduates was also included to provide a measure of mature skill development. This is an exploratory descriptive study conducted to discover the haptic scanning patterns and strategies for organizing actions that may be related to efficiency and accuracy in a shape matching task.

Methods

Participants

Participants included a convenience sample of 25 early elementary school age children 6 years, 6 months to 9 years, 6 months (mean age: 8-2 years); 10 were male. Children were from local families known to university employees. They had no known learning or sensory disabilities according to parent report. Each child received a stipend of $10 and the parent received $25. The adult group included 25 undergraduate university students; eight were male. The adults participated either voluntarily or in fulfillment of a course requirement. The Institutional Review Board of the University of Scranton approved this study. For children, parental consent and participant assent was obtained; adults provided informed, signed consent.

Set-up

Participants sat at a table in an appropriately sized chair. Directly in front of the participant was a 12 × 24 inch platform raised 8 inches off the table. The haptic task items were presented under this platform by an investigator from the other side of the table. A cloth draped over the front of the platform prevented the participant from seeing the items. The matching choices for the haptic-visual tasks were shown on
a 20-inch computer monitor positioned beyond the platform at eye level to the participant. A small web-cam with auditory recording was directed to the area under the platform, where it recorded participants’ hand movements and their vocalizations.

**Study Tasks**

The following tasks were used in this study. The aim was to make the type of shapes used in both visual and haptic conditions similar, solid forms varying in contour of the edges. The wood cut-out shapes used in the haptic tasks were affixed to a board to maintain the orientation and order of choices.

**Vision Only.** Items were shown on the computer screen. Each task item had a target shape positioned top and center, and four match choices aligned horizontally below target. Six items were given.

**HV/1 (Haptic-Visual Matching/One Form).** This task was intended to serve as an introduction to the multi-form haptic tasks. A single wood shape measuring approximately 3 × 3 inches and ¼-inch thick was affixed to a larger board that could be moved in and out of the space below the platform. Four choices for matching were presented on the monitor. One practice item, then two test items were given.

**HV/4 (Haptic-Visual Matching/Four Forms).** Four wood shapes of similar design measuring approximately 2 × 2 inches were affixed to a board. A visual target that matched one of the wood shapes was shown on the monitor. One practice item and then three test items were given.

**H/5 (Haptic-Only Matching/Five Forms).** Five 2 × 2 inch wood shapes were affixed to a board. One shape was the target, placed top and center, and four matching choices were aligned horizontally below the target. One practice item and then three test items were given. Samples of each task are shown in Figure 1.

**Procedure**

Participants were shown the first Visual Only task item and were instructed, “See the shape on the top?” with the examiner pointing, “Find which shape down here matches that top shape exactly. You can say one, two, three, or four.” The test items were then presented. Next, the HV/1 activity was introduced with a sample of a wood shape affixed to a board and presented on top of the platform in full view. Participants were encouraged to feel the shape and were told that their job will be to feel a shape behind the curtain and match it to one shown on the computer screen. The examiner then lifted the curtain that covered the space below the platform, showing the participant the area to be used for feeling the wood shapes. The board for each task item was placed in the space behind the curtain. When the participant was instructed to “go ahead,” the visual matching choices appeared on the computer screen. Participants voiced their choice (e.g., “the third one”).

The two multi-shape tasks, HV/4 and H/5, were then presented, each with a sample board provided in full view to the participant prior to the test items. Instructions were given to find the match to the single visual shape on the screen for HV/4 and to find the match to the top shape on the board for H/5. Participants were encouraged to tap on their choice rather than name it by number to avoid confusion as to the shape’s serial position.

**Data**

The main focus of this study was on the patterns of exploration used by participants in the HV/4 and H/5 tasks, the tasks that involved multiple shapes to feel. The Visual Only task served as an introduction and it was intended that errors would be used to assess efficacy of visual scanning; however, few errors were made and thus it is not analyzed further. HV/1 task, although also used as an introduction, was analyzed for strategies, particularly to compare to earlier research findings on single form haptic exploration (e.g., Klatzky, Lederman, & Balakrishnan 1991). Because only one haptic form was involved in this task, it is not included in the analyses of multi-shape items.

Determining the patterns of hand movements used by the participants during haptic exploration...
involved several steps. First, the author repeatedly reviewed the HV/4 and H/5 videos and identified three potential general categories of strategies (one hand, two hands used symmetrically on one shape at a time, and two hands on separate shapes). Next, three student research assistants were given the descriptions of those strategies and together they reviewed the videos and assigned one strategy to each task item. They were encouraged to critique the categories. They were blind to the age of the participant (it was generally not possible to determine age by video of hands alone). During this process we decided that the final category should be divided into two: two hands alternating and two hands simultaneous (fully described below). In some cases more than one strategy was employed during a single task item; then the strategy used for determining the match was counted. Thus, a participant may have used one strategy to explore the shapes but a different strategy to recheck the final answer; this would be coded as using the first strategy.

After the group assigned one of the four strategies to each task item for each participant, a different student assistant, naive to the purpose of the study, was given a description of the four strategies and was instructed to code each observation according to which was used predominantly to arrive at the choice (and not initial orientation or re-checking choice). This reviewer agreed with the original coding on 82% of items. The disparity came mostly from whether two hands were used alternately or simultaneously.

To provide an objective measure of the question-able videos, the group of student research assistants reviewed them again slowly, by 1-second intervals, and tallied whether one or two hands were moving during each second. A few item recordings remained difficult to determine which strategy was used because more than one was observed. Because these items were mostly from children, and because it was apparent from our observations that there was a progression in skill level associated with these strategies (later confirmed in data analysis), a liberal standard was adopted to ensure the participant received credit for the highest level strategy. A threshold of one-third (not the majority) of seconds showing highest level strategy resulted in categorizing the item at that level because it showed that the participant was able to employ that strategy.

Each participant was coded for one strategy (the highest level observed) for each task item. This resulted in 100 observations for HV/1 (50 participants × 2 items) and 300 observations for HV/4 and H/5 (50 participants × 6 items). Correctness of choice and time to respond for each item were also recorded. Because time was not controlled (i.e., no instructions to “answer as fast as you can”), and because of great variability, time to respond was not further analyzed. SPSS package 17.0 (SPSS, Inc., Chicago, IL) was used for data analysis.

Results

Inspection of the video recordings of participants’ hand movements revealed the following strategies for haptic exploration of the single- and multi-shape tasks.

HV/1 Strategies

The common strategy used by participants to determine the match of a single shape to visual choices was to feel the contours that differentiated the choices; in the example in Figure 1, that would be top bump and bottom contours of the shape. Nearly all participants used a combination of enclosure and movement, or dynamic enclosure. Enclosure was indicated by multiple contact points, either with two hands and/or with two or more fingers on one hand (usually thumb and another finger). Two children, both 7-year-old boys, used a simple contour following procedure (one finger) in which the edges of the shape were felt in the absence of a reference finger, similar to tracing the shape, and each made one of the only eight errors seen in this activity. The major strategy difference found between the two age groups was the use of one hand versus two hands; 44% of the children used one hand for feeling the shape, compared to 16% of adults.

HV/4 Strategies

In this task that included four shape choices to feel, four strategies were observed. Two strategies observed were similar to those seen in HV/1: one hand feeling the shapes (1H) and two hands simultaneously feeling the contours of one shape at a time, often using symmetrical movements (2H-sym). Two new strategies unique to multi-shape exploration were observed: two hands used with one feeling a shape and the other keeping place elsewhere on the array, hands may switch roles mid-task but were used alternately (2H-alt), and two hands simultaneously feeling two different shapes (2H-sim). Using a 2 × 4 (age group × strategy) Pearson chi-square test, adults differed significantly from children in strategy use (chi-square [3] = 11.56, p = .009). Adults were more likely to use two hands on different shapes (2H-alt and 2H-sim) and children were more likely to use 1H. Figure 2 shows the proportion of each strategy by age group.
H/5 Strategies

With both the target and choices explored haptically, nearly all participants explored the target shape first. Then four strategies for finding choices were observed that were similar to those seen in the HV/4 tasks: one hand feeling all shapes occasionally returning to the target for recheck (1H); two hands simultaneously feeling the contours of each shape and target one at a time (2H-sym); two hands used with one hand remaining on target while the other explores the choices, hands working alternately (2H-alt); and two hands with one hand remaining on target while the other explores, both hands simultaneously active (2H-sim). Occasionally participants felt two choices, rather than the target and a choice, during part of the exploration. Adults again differed significantly from children in strategy use (chi-square [3] = 28.92, p < .001). Adults were more likely to use two hands on different shapes; however, 2H-sim was now their most common strategy. Children again were more likely to use 1H or 2H-sym. Figure 2 shows the frequency of each strategy by group.

Assignment of Strategy Levels

The four strategies were ranked in order of apparent effectiveness and maturity, with 1H the lowest level and 2H-sim the highest. Effectiveness of a strategy was judged by the proportion of errors associated with each strategy (Figure 3). Children made the large majority of errors (85%) and errors were more likely found in the lower level strategies (chi-square [3] = 15.05, p = .002). Maturity was judged by each strategy’s association with the two age groups and this ordering was consistent with the ordering by errors.

Age-Related Differences in Children

Spearman correlation showed no significant relationship between the age of the child and the strategy (ordered 1 to 4 by level) used on any of the six multi-shape tasks, although a positive trend toward the higher level with age was noted. Correlations ranged from r = .098 to .390.

Discussion

Using touch to find an exact match of a shape from an array of choices requires a strategy for coordinating multiple sources of input (tactile and proprioceptive) to create a percept of the shape and maintaining that percept over time as options are explored. This study sought to discover the strategies used by two different age groups, elementary school age children...
and adults, during haptic exploration. Four categories of strategies emerged: one hand exploring, two hands symmetrically exploring one shape at a time, two hands alternating between one shape and another, and two hands simultaneously exploring different shapes. With only one shape to explore, patterns similar to those noted by Klatzky et al. (1991) and Kalagher and Jones (2011a; 2011b) were observed. Nearly all participants used multiple points of contact moving around the edges, or dynamic enclosure. The main difference between the groups was that children were less likely than adults to use two hands, a finding that is consistent with Bushnell and Baxt (1999) and Kalagher and Jones (2011a).

The unique aspect of this study was the use of multi-shape haptic tasks. In these tasks, new characteristics of exploration were identified. The use of two hands in two different places on an array was associated with adult performance and with relatively few errors. Participants were not given specific instructions to use two hands, and it is possible that children simply did not think to use a second hand. However, it was observed that several children had the second hand inside the feeling area; one was even coached to use the second hand (erroneously, by a parent) but still did not use it. When given multiple shapes to explore, most adults and only some children used two hands separately to gather information from two shapes at the same time. This progression may reflect an ability to process more information at one time, perhaps a haptic instance of a theory of limited attentional capacity (e.g., Cowan et al., 2005) or M-capacity (e.g., Morra, 1994). The use of only one hand or two hands on one shape may have a low demand on attentional capacity, whereas two hands on different places on the array may require greater capacity, particularly if the two hands were simultaneously gathering information.

In the HV/4 tasks, it was rare for even adult participants to use the 2H-sim strategy. This task had a visual target and thus the vision modality was used to actively explore the target while the haptic modality was used to explore the choices at the same time. It has been reported that cross-modal perception exacts a cost to attention for each modality; attention is not additive with two sources of information, rather it appears to be at least partly shared (Hatwell, 2003). In the H/5 task, both the target and the choices were presented haptically and more participants, almost exclusively adults, used one hand for active exploration of the target while the other explored the choices, thus two separate sources of simultaneous information within one modality. This suggests that greater attentional resources were available for haptic perception in the haptic-only tasks than for cross-modal tasks, particularly for adults.

The findings are consistent with Piaget and Inhelder (1967), Hoop (1971), and Millar (1999): when two hands are used they can act as a spatial anchor or reference point for each other. The ability to make use of frames of reference is a central tenet in Piagetian theory of general perceptual development and not limited to haptic perception. Here, the use of one hand as a reference was associated with more effective strategies, in terms of accuracy, for exploration. Evidence was found for a developmental trend in strategy use. Although the trend was not significant within this small sample of children, the differences between the children as a group compared to adults were significant. It should be noted that there was considerable individual variation in both age groups; some of the youngest children used the highest level, whereas some adults used the lowest level strategy, indicating that development of strategy use is not absolutely related to age.

There were several limitations with this study. The coding of strategies was created for this study; therefore, further studies are needed to confirm they represent developmental levels. Also, haptic matching was a new experience for the participants for which they may not have had a ready strategy. Perhaps with more exposure some participants might have discovered a more effective strategy for the task.

Implications for Occupational Therapy Practice and Future Research

Evidence supports the incorporation of a haptic component into some areas of early elementary learning (Bara et al., 2004; Kalenine et al., 2013). Because occupational therapy practitioners often engage children in multi-sensory experiences as part of treatment, practice would benefit from a greater understanding of the development of haptic exploration. In this study, it was found that the use of two hands rather than one was related to mature and accurate performance, and the coordinated use of the two hands, with one maintaining contact with the target as a reference, was optimal. Therapists using haptic activities as part of a multi-sensory learning experience (e.g., learning letters and shapes) might encourage the child’s use of two hands, one as a reference and the other exploring, during these activities.

An important area of research for occupational therapy would be to determine whether haptic exploration can improve with practice and to confirm the Locher (1985) findings that improvement in haptic exploration could lead to general improvement in perceptual skills such as the spatial relations and part-
whole perception that underlie pencil-and-paper and construction activities. An unexpected finding was how attention allocation differs in a cross-modal task; there were few instances of simultaneous two-hand exploration when the task involved two modalities. It may be that in activities requiring both touch and vision (e.g., shoe tying or craft activities), the available attentional capacity for each modality is reduced compared to each modality used alone. Additional research could clarify that finding. Finally, further research could investigate the differences in haptic exploration in both cross-modal and unimodal tasks among children who have known difficulties with attention or visual perception.

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References