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Young Children's Haptic Exploratory Procedures

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Abstract

Adults vary their haptic exploratory behavior reliably with variation both in the sensory input and in the task goals. Little is known about the development of these connections between perceptual goals and exploratory behaviors. Thirty-six children 3, 4, and 5 years of age and 20 adults completed a haptic intra-modal match-to-sample task. Participants were instructed to feel the shape, texture, rigidity, or weight of a sample object, and then asked to find which of three test objects matched the sample on that specific property. Hand movements were examined to determine whether children produced the same exploratory procedures while gathering perceptual information about each property as adults who searched for the same kind of information. Children demonstrated that they had good haptic abilities in two ways: they matched the sample objects on the specified perceptual dimension at near ceiling levels, and they produced the same hand movement patterns to find the same properties as adults.

The human hand is a powerful tool. The sensory and motor subsystems that serve the hand allow for quick and efficient interactions with the world. The hand's sensory system is designed to learn about the perceptual features of objects and is made up of cutaneous, thermal, and kinesthetic sensors. The hand's motor system is designed to interact with and manipulate objects (Klatzky & Lederman, 2002; Lederman & Klatzky, 2009). The sensory and motor systems are not independent. How the hands are moved determines what sensory information is obtained. The sensory input obtained guides further hand movements and importantly, constrains what can be perceived.

When adults search for perceptual information, their hand movement patterns (i.e., the haptic exploratory behaviors) are efficient, rapid, and systematic (e.g., Klatzky, Lederman, & Metzger, 1985). Lederman, Klatzky, and their colleagues have extensively studied the haptic exploratory abilities of adults. Lederman and Klatzky (1987) recorded the hand and finger movements of adults attempting to extract perceptual information about specific object properties – shape, texture, hardness, weight, temperature, volume, part motion, and specific function – using haptics alone. Subjects were instructed to find which of three test objects was the best match for a standard object on one of these eight specific dimensions. None of the test objects was identical to the standard and participants were told to ignore all other properties of the objects. The participants' object matching choices and the hand movements that preceded them were recorded. The researchers identified eight stereotyped hand movement patterns or “exploratory procedures,” each associated with a specific task goal. For example, adults asked to match objects by texture generally produced “lateral

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motion” – movements of the fingers lateral to the object’s surface. In contrast, adults asked to match objects by shape produced “contour following” – tracing the object’s contours with their fingertips. Hand movements during haptic exploration varied reliably both with the sensory input and with the kind of information participants had been asked to seek. The consistent relations between particular hand movements and particular goals suggested that observing how participants moved their hands during haptic tasks could reveal the goals behind their exploratory behavior (Lederman & Klatzky, 1987).

Little is known about the development of the connections between particular perceptual goals and particular exploratory manual behaviors observed in adults. In the present study, we ask whether young children perform the same hand movements as adults perform to achieve the same perceptual goals. There are very few previous studies on this question. Bushnell and Boudreau (1991, 1993, 1998) developed (but did not test) a set of hypotheses about when in development the exploratory procedures in Lederman and Klatzky’s (1987) taxonomy might become available to infants and young children due to age-typical advances in motor behavior and attention. For example, these authors suggested that infants should not be able to produce the contour-following exploratory procedure associated with haptic perception of shape until 9 or 10 months of age, because it is not until this age that infants acquire the ability to move their two hands independently. Bushnell and Boudreau (1991, 1993, 1998) suggested that children might have the capacity to display mature haptic exploratory movements when they reached the preschool period.

However, there are few data on whether preschool-aged children do employ adult-like exploratory procedures. In fact, there are few data on children’s hand movements of any kind during haptic object exploration. Instead, research on the development of haptic perception has largely focused on children’s ability to use haptic information for object recognition either in haptics or in vision. A number of studies have concluded that young children have poor haptic perception. However, this conclusion has been based on findings of deficits in young children’s ability to transfer information between haptics and vision in inter-modal object recognition tasks. These studies have not reported how children moved their hands during haptic exploration (e.g., Milner & Bryant, 1970; Rose, Blank, & Bridger, 1972).

In contrast, a number of studies have looked at what children do with their hands during visual object exploration. Ruff (1982, 1984, 1986, 1989; Ruff & Kohler, 1978) carried out a number of studies documenting how infants handle objects during visual exploration, but there is no evidence that the set of hand movements produced by infants in the service of visual exploration overlaps with the set of hand movements that serve haptic perception. Klatzky, Lederman, and Mankinen (2005) asked preschool-aged children to make decisions about the appropriateness of a tool to perform a certain task –for example, could a spoon be used to carry a piece of candy. Children were visually presented with the tools and also allowed to handle them. The children were more likely to haptically explore objects when the important object property was rigidity than when it was shape. Moreover, when the children chose to explore haptically, they tested the objects for rigidity using the same exploratory procedure as adults use for assessing rigidity (i.e., pressure; Lederman & Klatzky, 1987).

Only three previous studies have documented what children do with their hands during haptic exploration. Schwarzer, Kufer, and Wilkening (1999) reported that children aged 3 to 9 years produced adult-like exploratory procedures. Following haptic exploration, children in this study haptically grouped novel objects that simultaneously varied in shape, texture, weight, and size. Almost all participants categorized the objects analytically - that is, on a single perceptual dimension – as opposed to holistically. In at least 60% of their trials, 3- to

5-year-old children produced enclosure, lateral motion, and contour following – three adult-like exploratory procedures. However, whereas adults used enclosure and contour following to find shape information, the children in this study produced these two movements at high frequencies before categorizing objects by texture. It is possible that the children in Schwarzer et al. (1999) produced something similar to enclosure and contour following but that these movements were not really the same as those produced by adults; or that children obtained shape information from these two procedures but failed to use it during categorization. It is also possible that exploratory procedures and perceptual goals are not as strongly and distinctively linked in children as they are in adults. In any case, Schwarzer et al.'s (1999) report of exploratory procedure use by children indicates that at least three of the movement patterns reliably found in adult haptic exploration were in the children's repertoires.

More recently, Scofield, Hernandez-Reif, and Keith (2009) noted the hand and finger movements of children in a word-learning study. Children aged 2, 3, 4, and 5 were taught the names of novel objects experienced haptically. While still holding each novel object out of sight, the children were asked to indicate which of two objects was a visual match for the object that they were holding. Video recordings were coded for how children manipulated the exemplar object while it was being labeled. The taxonomy of exploratory procedures developed by Lederman and Klatzky (1987) was not used. Instead, hand movements were examined for instances of the following three categories: "touching" (using two hands to explore the object); "enclosing" (using one or two hands to surround the object); and "exploring" (active handling of the object). Children received one point for each category of behavior observed in each of two test trials (maximum score = 6). Scofield et al. (2009) were interested in whether higher manipulation scores would be associated with better word-learning performance. Their results indicated that manipulation scores both increased with age and were significantly and positively correlated with better object name learning.

Kalagher and Jones (2011) compared visual object recognition following visual or haptic exploration in children 2 ½ to 5 years of age and in adults. The hand movements produced by participants at each age level during exploration in the two modalities were also compared. A novel name extension paradigm was used. On each trial, participants explored an exemplar object either haptically or visually and were told its novel name (e.g., "That's a dax"). After the exemplar object was removed, participants were visually presented with three test objects and asked to indicate the object with the same name as the exemplar (e.g., "Show me the dax"). Test objects were 3-dimensional and each matched the exemplar and differed from the other two test objects on one perceptual dimension – color, texture, or shape – and differed from both the exemplar and the other two test objects on the other two perceptual dimensions. All age groups in that experiment chose a preponderance of same-shape matches after visual exemplar exploration. However, only 5-year-olds and adults made shape-based matches after haptic exploration. Children younger than five were equally likely to choose any of the three test objects, including the color match, which in haptics bore no resemblance to the exemplar.

Digital recordings were coded for children's hand movement patterns during exploration in both modalities. Hand movements during visual exploration were minimal and consisted largely of holding and turning the objects in the service of vision. Analysis of children's hand movements during haptic exploration found no instances of the hand actions in Lederman and Klatzky's (1987) taxonomy of adult exploratory procedures, but did find that certain other hand movements produced by children were reliably associated with subsequent object matches based on either shape or texture similarity. However, children younger than five produced these hand movements at very low frequencies.

Kalagher and Jones (2011) speculated that performance in children younger than five might improve if their behavior was organized by specific perceptual goals like those given to Lederman and Klatzky's (1987) adult subjects. We address this possibility in the present experiment. We provide children with specific perceptual goals - that is, we ask children to find information about different, specific object properties by feeling objects that are out of sight - and then we both measure their success in finding the different kinds of information, and also examine the kinds of hand movements that are associated with that success.

We use a modified version of the match-to-sample paradigm employed by Lederman and Klatzky (1987). Children 3, 4, and 5 years of age and adults are asked to feel the shape, texture, rigidity ("feel how hard/squishy...") or weight ("feel how heavy/light...") of a sample object, and then asked to find which of three test objects - also apprehended only in haptics - matches the sample on that specific dimension. We examine the participants' hand movements to determine whether they are the same property-specific actions observed in Lederman and Klatzky's (1987) participants. We also measure participants' accuracy in matching on the different dimensions, and the exploratory procedures associated with participants' successful matching on each dimension. In this way, we attempt to determine whether children at each age level can produce adult-like exploratory procedures when given specific perceptual goals, and whether those movements are systematically associated with successful haptic perception of the specified object properties.

Method

Participants

Thirty-six children and 20 adults participated. The children spanned three age groups: 3-year-olds (range: 36 to 46.9 months, $M = 42$ months); 4-year-olds (range: 48 to 59 months, $M = 54.3$ months); and 5-year-olds (range: 60.4 to 66.4 months, $M = 62.48$), with 12 children (5–7 males) in each group. Participants reflected the local community in social class, ethnicity and racial identity: almost all participants were from white, middle class families. Adults were university students participating for partial fulfillment of a course requirement.

Stimuli

There were three object sets used for warm-up trials and eight object sets used for experimental trials. Three dimensions - color, shape, and size - were tested in the warm-up trials. Shape, texture, rigidity, and weight were the four perceptual dimensions tested in the experimental trials. Each of the four dimensions used in the experimental trials was tested twice, with a different object set for each trial.

Each of the 11 object sets consisted of one sample object and three test objects. One test object in each set was identical to the sample object. Each of the other two test objects differed from the sample object only on the perceptual dimension being tested - its weight, shape, texture, rigidity, color, or size - and differed from the other two test items on that same dimension. Thus, within any given stimulus set, there were two identical objects (the sample and one test object) and two other test objects that differed from the two identical objects on the sample perceptual dimension. Sample and test objects were 3-dimensional, novel objects constructed from a variety of materials including wood, clay, and cloth. Sizes ranged from $7 \times 4 \times 4 \text{ cm}^3$ to $13 \times 9 \times 4 \text{ cm}^3$. Textures, shapes, weights and rigidity were widely varied and easily discriminated in haptics by adults (see Figure 1A for an example of a shape-match stimulus set used in the experimental trials and Figure 1B for an example of a rigidity-match stimulus set).

Procedure

All participants completed four warm-up trials in the same order, and eight test trials in one of two random orders. Each child was seated next to his or her parent and across a table from the experimenter, who explained that they were going to play a “matching game.” Adult participants also sat across a table from the experimenter. The procedure began with the four warm-up trials designed to ensure that participants understood the task. In the first three warm-up trials, participants were simply handed an object and told to look at a particular feature of the object (e.g., “Look, see what color this is? In a moment, I’m going to ask you to find an object that’s the same color as this.”). After five seconds, participants were presented with three test objects. The test objects differed from the sample object on only one perceptual dimension (in this example, color). The participant was then asked to indicate the test object that was identical to the sample object on the specified perceptual dimension (e.g., “Can you show me the one that is the same color as the first one?”). The instructions on the second and third warm-up trials asked the participant to match on shape and size, respectively.

The last of the four warm-up trials introduced the haptic portion of the experiment. Here, participants placed their hands and forearms through two large rectangular openings cut into a large piece of cardboard folded vertically at the midpoint so as to stand on the table. A piece of cloth was then pulled over the cardboard and the participants’ arms to prevent participants from seeing through the holes (see Figure 2). The experimenter put the sample object from the second warm-up trial into the participant’s hands from behind the cardboard and asked the participant whether he or she could feel it (e.g., “Can you feel the shape? In a moment I’m going to ask you to find another object that has the same shape.”). After five seconds, the experimenter retrieved the sample object and put all three test objects behind the cardboard, helping the participant find each of them by touch if necessary. The experimenter then asked the child to indicate (by pulling the object out from behind the cardboard) the test object that was identical to the sample object on the specified perceptual dimension (e.g., “Can you find the one that is the same shape as the one you just felt?”). Test objects were presented simultaneously and it was left up to the participant to choose the one to explore first. There was no time constraint on test object exploration.

Test trials followed immediately and were structured just like the last warm-up trial: participants were handed the sample from one object set out of sight behind the cardboard, and told to pay attention to a particular perceptual dimension (e.g., “Can you feel how hard this is? I’m going to want you to find one that is just as hard.”). The same adjective attributed to the sample object was used when children were asked to find a match for the sample (e.g., “Can you find the one that is just as hard as the one you just felt?”). Table 1 provides a list of the adjectives used and the associated perceptual dimension. Participants usually pulled their choice of matching test object out from the behind the cardboard. Children were given a sticker after each trial regardless of which choice they made. Participants were not given feedback on performance: the experimenter simply said an enthusiastic “Okay!” when a choice was made.

The experiment was digitally recorded, and the records were later scored for the test object chosen (correct or incorrect). The digital recordings were also coded for particular hand movements produced while participants explored sample objects and while they explored test objects. Specifically, coders blind to the hypotheses of the experiment looked for instances of six of the eight exploratory procedures identified by Lederman and Klatzky’s (1987) in their adult sample: (1) contour following, associated with adults’ search for shape information; (2) lateral motion, associated with adults’ search for texture information; (3) pressure, associated with adults’ search for information about rigidity; (4) unsupported holding, associated with adults’ search for information about weight, (5) enclosure,

associated with adults' search for global shape and volume, and (6) static contact, associated with adults' search for temperature. The other two adult exploratory procedures were associated with object part motion and function, and thus were not appropriate for our stimulus objects. Coders also looked for movements that were not in Lederman and Klatzky's (1987) original taxonomy. This resulted in the identification of one more movement pattern, "pinching," observed in a number of the participants.

Results

Match-to-sample performance

The first question was whether preschool-aged children could indeed match the sample objects correctly on the specified perceptual dimensions. The mean proportions of correct object matches for 3-year-olds ($M = .84$, $SD = .15$: $t(11) = 11.65$, $p < .001$), 4-year-olds ($M = .84$, $SD = .19$: $t(11) = 9.16$, $p < .001$), 5-year-olds ($M = .86$, $SD = .17$: $t(11) = 10.66$, $p < .001$), and adults ($M = .97$, $SD = .06$: $t(19) = 51.2$, $p < .0001$) were all at levels far exceeding chance (.33), as confirmed by one-sample t -tests. Next, the participants' proportions of correct matching scores were entered into a 4 (Age Group: 3, 4, 5 year olds, and adults) X 2 (Gender) analysis of variance. There was no main effect of Gender, $F(1, 48) = .03$, ns . However, there was a main effect of Age Group, $F(3, 48) = 2.8$, $p = .04$, $h_p^2 = .15$, and an Age Group by Gender interaction, $F(3, 48) = 3.67$, $p < .05$, $h_p^2 = .16$. Table 2 displays the mean proportions involved in this interaction. The significant interaction reflects the fact that 4-year-old females and 5-year-old males, although close to 80% correct in their matching, were nevertheless significantly less often correct than the other same-aged and adult participants (Tukey's HSD (.05) = 0.15). These findings have no clear meaning. Overall, what is clear from these results is that children in all age groups were well able to use haptic perceptual information to match the objects in our sets on the specific perceptual dimensions tested. (Insert Table 2 about here)

Exploratory procedures during goal-directed haptic exploration

We next examined participants' hand movements during haptic exploration to determine whether the exploratory procedures reported by Lederman and Klatzky (1987) were produced by our subjects; whether specific exploratory procedures were associated by our subjects with the particular perceptual dimensions on which they were instructed to match; and whether these associations matched those reported by Lederman and Klatzky (1987). Hand movements were clearly visible on 276 (96%) of the children's 288 trials. The remaining 12 trials could not be coded because children removed object(s) from behind the cardboard before they made their test object choices. Hand movements were clearly visible on all (160) of the adults' trials. Therefore, there were a total of 436 trials of hand movement data to analyze. Of the total 436 trials, 88 (20%; 22 trials from each age group) were randomly selected and analyzed for inter-coder agreement (Cohen's kappa). Cohen's kappa on whether or not a specific exploratory procedure was present on each trial for both sample object exploration and test object exploration was .68.

The hand movement coding yielded the frequencies with which each of the seven exploratory procedures was produced by each participant while exploring the sample object, and separately, while exploring the test objects from each of the sample sets. There were two hand movement patterns that were very different from the others – Enclosure and Pinching. "Enclosure" was coded whenever a participant wrapped a hand around any part of the object except the base (holding the object with the base in the palm of the hand was coded as "Unsupported Holding"). Participants produced Enclosure at comparatively high frequencies across all Exploration Phase (i.e., exploration of sample or of test objects) and Property (i.e., Shape, Texture, Rigidity, or Weight) conditions (mean instances ranged from 1.911 to 2.893

during sample object exploration and from 3.304 to 6.232 during test object exploration). Enclosure could conceivably have been used by our subjects to obtain haptic information about shape, texture, rigidity, or weight. However, because Enclosure could not be distinguished from just holding the object, we could not determine the frequencies with which participants used this action for haptic exploratory purposes. Thus, Enclosure will not be analyzed further. Pinching occurred at very low frequencies in each of the eight Exploration Phase and Property conditions (mean instances ranged from .018 to .339 during sample object exploration and from .018 to .375 during test object exploration), and so this behavior too will not be analyzed further.

The frequencies with which participants produced the remaining five exploratory procedures (see Table 3 for means) were analyzed for comparison with Lederman and Klatzky's (1987) results. We first looked to see if the frequencies with which participants produced specific exploratory procedures differed from each other within each Property condition. If a difference was found, we then asked whether the most frequent exploratory procedure was the one predicted by Lederman and Klatzky (1987).

Eight separate analyses of variance were performed, one for the data in each of the columns of Table 3. All eight ANOVAs took the same form – a 5 (Hand Movements: Lateral Motion, Pressure, Unsupported Holding, Static Contact and Contour Following) X 2 (Gender) X 4 (Age Group: 3-, 4-, 5- year olds, and adults) mixed design. All eight ANOVAs yielded main effects of hand movements. The statistics for these main effects are presented in Table 3.

We looked for the sources of the main effects of Hand Movement to determine whether different specific hand movements were associated with participants' attempts to assess the four different object properties. In each Exploration Phase and Property condition there was one kind of hand movement that was produced far more frequently than any of the others. We used paired-sample *t*-tests with Bonferroni corrections to compare the mean frequency of the most frequent hand movement in each condition to the mean frequencies of each of the other four hand movements. Because there were four pair-wise comparisons, the alpha level was corrected to $0.05/4 = .0125$.

The pair-wise comparisons confirmed that Pressure was by far the most common hand movement produced by all participants assessing the property of Rigidity in both the sample object and the test objects, *t* (55) values range from 11.99 to 18.14, all *p* values <.001. Contour Following was associated with assessments of Shape in both sample and test objects, *t* (55) values range from 4.01 to 11.87, all *p* values <.001; Lateral Motion was associated with assessments of Texture, again in both the sample and test objects, *t* (55) values range from 2.78 to 10.45, all *p* values <.01; and Unsupported Holding was associated with assessments of Weight in both sample and test objects, *t* (55) values range from 11.88 to 20.27, all *p* values <.001. These are the same associations reported by Lederman and Klatzky (1987).

The eight ANOVAs produced five additional findings. For the property Shape, there was a significant Hand Movement by Age Group interaction for both sample object, $F(12, 192) = 2.08, p < .01, h_p^2 = .15$, and test object, $F(12, 192) = 8.07, p < .001, h_p^2 = .34$, exploration. During exploration of the Shape of the sample objects, adults ($M = .15$) produced significantly less Unsupported Holding than 3-year-olds ($M = 1.33$) and both adults and 4-year-olds ($M = .833$) produced significantly less Unsupported Holding than 5-year-olds ($M = 1.75$). During exploration of the Shapes of the test objects, 3- and 4-year-olds ($M = 1.92$ and $M = 1.5$, respectively) produced significantly less Contour Following than adults ($M = 5$).

The analysis of hand movements during exploration of the Textures of the sample objects, yielded a main effect of Age Group, $F(3, 48) = 4.98, p < .01, h_p^2 = .23$, subsumed by a Hand Movement by Age Group interaction, $F(12, 192) = 4.15, p < .001, h_p^2 = .21$, due to a difference between 3-year-olds ($M = .08$) and 5-year-olds ($M = 1.17$) in Contour Following. There was a similar interaction during exploration of the Textures of test objects, $F(12, 192) = 3.76, p < .001, h_p^2 = .19$, because 4-year-olds ($M = 0$) produced less Contour Following than 5-year-olds ($M = 1.5$), adults ($M = .45$) produced less Unsupported Holding than 3-, 4-, and 5-year-olds ($M = 2.25, M = 2.25$, and $M = 3.75$, respectively), and 3- and 4-year olds produced less Unsupported Holding than 5-year-olds.

Despite these scattered age differences, it remained true of all age groups that the significant associations between specific hand movements and the haptic assessment of specific object properties replicated the findings reported in Lederman and Klatzky (1987). Thus, the data replicate Lederman and Klatzky's (1987) results with adults in this task and show in addition that preschool-aged children can and will use the same specific hand movements as adults use to haptically assess the same specific object properties.

Discussion

Adults exploring objects by touch tend to produce hand movements that differ systematically with different task goals (e.g., the movements used to identify an object by shape differ from the movements used to identify the same object by texture). At the same time, the relations between specific perceptual goals and specific kinds of hand movements are markedly similar across individuals, at least in American samples (Lederman & Klatzky, 1987). Moreover, it has been reported that at least one nonhuman primate species – capuchin monkeys – produced the same exploratory hand movements as humans when both species explored the same objects (Lacreuse & Frigaszy, 1997).¹ However, it is not clear how adult humans or capuchin monkeys come to produce the specific hand movements they do. Very little is known about when and how these hand movement patterns emerge in development, and how different movements come to be linked to the search for haptic information about specific perceptual properties.

In the present study, we asked whether the same links between perceptual goals and specific hand movement patterns observed in human adults (Lederman & Klatzky, 1987) would also be found in preschool-aged children. The question is relevant both to understanding the origins of haptic behavior in adults, and also to understanding previous reports that children younger than 5 have poor haptic perceptual abilities. Previous studies have found that children younger than 5 perform poorly when they must use information obtained through touch to succeed in a visual object recognition task (e.g., Bushnell & Baxt, 1999; Milner & Bryant, 1970; Rose, et al., 1972). Such poor performance does not appear to reflect a general problem with inter-modal transfer of perceptual information, because the same children successfully transfer information from vision to haptics. Researchers long ago suggested

¹Interestingly, nonhuman primates have been shown to execute exploratory procedures similar to those found in adult humans. Lacreuse and Fragaszy (1997) recorded the hand movements of 21 capuchins (*Cebus apella*) and four adult humans while each haptically explored objects covered in sunflower seeds. The sunflower seeds were strategically placed on the objects so as to promote the use of particular exploratory procedures: for example, seeds were placed on the side surfaces of planar geometric shapes to elicit the contour following exploratory procedure. In comparing the haptic exploration patterns of the capuchins and humans, Lacreuse and Fragaszy found that adult humans outperformed the capuchins in both the frequency with which exploratory procedures were produced and the exhaustiveness of the search (measured in total time spent exploring). However, differences were not found in the repertoires: both humans and capuchins used the same movements. The similarities found in this study could reflect some “hard-wired” link between perceptual goals and exploration patterns – the legacy of an ancestor common to humans and capuchins. It seems more likely, however, to be a product of the mechanical similarities between the hands of the two species and their consequent movement potentials interacting with the sensory characteristics of the stimuli. A full account of the development of human haptic exploratory movements might distinguish between these two possibilities.

instead that young children may form poor haptic representations because they fail to obtain the necessary sensory input due to inadequate exploration with the hands (e.g., Milner & Bryant, 1970; Rose, Blank, & Bridger, 1972). However, these suggestions were not tested empirically until the present study.

The question we address is whether preschool-aged children lack the requisite manual exploratory competency for haptic perception, or have that competency but sometimes fail to use it. To our knowledge, only three previous studies of children's manual exploration of objects have examined children's hand movements, not in the service of vision, but for strictly haptic perceptual purposes. One of these (Scofield et al, 2009) used a simple coding scheme of three broad categories that does not allow comparison with adult exploratory hand movements. Of the remaining two previous studies, one (Schwarzer, et al., 1999) reported that children did produce three adult-like exploratory procedures (Lederman & Klatzky, 1987). However, these exploratory procedures were not linked differentially to specific object properties as they are in adult haptic exploratory behavior. In the third previous study of children's exploratory hand movements (Kalagher & Jones, 2011), preschoolers did not produce adult-like exploratory procedures when exploring novel objects, and gave only faint evidence of linking any specific hand movements to the search for specific kinds of object information. Kalagher and Jones (2011) concluded that children's unsystematic inter-modal object matching performance was a result of inconsistent haptic exploration.

In the present study, in contrast, children at all age levels showed adult-like competency in the haptic exploration and perception of objects. The children produced adult-like exploratory procedures while correctly matching the sample objects to test objects on the specified perceptual dimensions – all within the haptic mode. Specifically, children selectively produced Pressure when matching on rigidity, Contour Following when matching on shape, Lateral Motion when matching on texture, and Unsupported Holding when matching on weight. The results indicate that even 3-year-old children have these exploratory procedures in their repertoires, and know just as well as adults do which exploratory procedure to use to gather which kind of perceptual information.

This adult-like performance stands in sharp contrast to the minimal haptic exploratory behavior produced by children in Kalagher and Jones (2011) and to the failures of children in past studies to use information obtained through haptic exploration for visual object matching. Children's performance in the present object-matching task may have been bolstered by the fact that both exploration and matching were carried out in the haptic modality, so that no inter-modal information transfer was required. Children might also have been helped by the fact that the objects in each of our stimulus sets differed on only one perceptual dimension, so that the relevant dimension was easy to identify. However, neither of these factors explains why children in the present study produced adult-like hand movements specific to the search for specific kinds of perceptual information.

In our view, the most likely reason for the appearance and systematic use of these hand movements is that children's haptic exploratory behavior in the present study was directed by the top-down perceptual goals provided by the experimenter. Conversely, it seems likely that young children in previous studies may have failed to transfer haptic information for use in visual object matching tasks because they did not first conceive for themselves the task goal of obtaining specific kinds of perceptual information about the objects from their hand movements, with the result that they did not have haptic information to transfer.

Lederman and Klatzky (1987) suggested that adults' choices of specific exploratory procedures are driven by top-down influences including task goals. The present results

indicate that the same is true of children's deployment of specific exploratory procedures. The results show that children in the preschool period have already developed at least four of the manual exploratory movement patterns that adults display, and that they are able to use those movements selectively and strategically to gather information about specific object properties. What has yet to develop are the kinds of executive functions and situational understanding that will provide adult-like self-direction in the deployment of these abilities in laboratory tasks like ours, and in a wide range of perceptual tasks in their everyday lives.

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Preschool-aged children and adults completed a haptic intra-modal matching task.

Do children produce the same haptic exploratory procedures as adults?

Children demonstrated good haptic abilities.

They matched objects at near ceiling levels.

They produced the same hand movement patterns to find the same properties as adults.

Figure 1.

A. Sample stimulus set for shape trials. B. Sample stimulus set for rigidity trials.

Figure 2.
Picture of experimental set-up.

Table 1

For each property, instructions given to the children while haptically exploring sample objects.

Property	Instruction
Rigidity	Feel how hard this is. Can you find me another one that feels just as hard? Feel how squishy this is. Can you find me another one that feels just as squishy?
Shape	Feel the shape of this. Can you find another one that feels like the same shape?
Weight	Feel how heavy this is. Can you find me another one that feels just as heavy? Feel how light this is. Can you find another one that feels just as light?
Texture	Feel how rough/scratchy this is. Can you find me another one that feels just as rough/scratchy? Feel how soft this is. Can you find me another one that feels just as soft?

Table 2

Mean proportions of correct matches for each gender at every age level.

Gender	Age (years)			
	3	4	5	Adult
male	0.829	0.969	0.786	0.966
female	0.85	0.781	0.971	0.972

Sources of the main effects of Hand Movement. Mean number of times participants produced each of the five kinds of hand movements are given separately for sample and test object exploration in search of information about each of the four tested object properties. Effect sizes are partial eta squared.

Table 3

	Exploration Phase							
	sample				test			
	Rigidity	Shape	Texture	Weight	Rigidity	Shape	Texture	Weight
Pressure	4.929	0.089	0.071	0.036	7.518	0.036	0.125	0.018
Contour Following	0.071	2.036	0.429	0.357	0.018	3.286	0.482	0.357
Lateral Motion	0.321	0.375	1.643	0.214	0.268	0.893	3.000	0.143
Unsupported Holding	1.589	0.893	0.786	2.464	2.429	1.732	1.929	5.857
Static Contact	1.000	0.411	2.893	0.214	1.893	0.964	0.589	0.732
<i>F</i> (4, 192)	139.02	43.59	105.35	111.03	122.84	41.42	41.38	204.25
<i>p</i> -value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Effect size	0.74	0.48	0.69	0.70	0.98	0.46	0.46	0.81