Why do four- year- olds show poor cross-modal transfer between haptic and vision?

Hilary Kalagher (hkalaghe@indiana.edu)
Department of Psychological and Brain Sciences, 1101 E 10th Street
Bloomington, IN 47405 USA

Susan S. Jones (jones1@indiana.edu)
Department of Psychological and Brain Sciences, 1101 E 10th Street
Bloomington, IN 47405 USA

Abstract

Four year olds have difficulty transferring information from the haptic to the visual modality. This difficulty may reflect qualitative differences in haptic and visual object representations or children's inability to obtain the same kinds of perceptual information in the two modalities. Twenty 4-year-olds explored novel objects either haptically or visually, then haptically chose a match from among three test objects that each matched the exemplar on one perceptual dimension. Children chose shape-based matches after visually exploring category exemplars. However, after haptic exemplar exploration, children were equally likely to pick a shape- or texture-based match. Analysis of children's hand movements during haptic exploration showed that certain movements reliably predicted shape-based matches. This finding suggests that children have difficulties in cross-modal transfer because their haptic exploration is not driven by a top-down perceptual focus as it is in adults.

Keywords: Haptic Perception; Cross-modal Transfer; Development

Introduction

The use of perceptual information obtained in one modality - for example, haptics – for use in a task in another modality - for example, a visual task - involves cross-modal information transfer. Cross-modal transfer is important because it allows for inter-sensory predictions. For example, being able to anticipate what an object will look like given that you have only touched it allows for efficient and quick interactions with the world. Adults appear to have no difficulty transferring novel information gathered in one perceptual modality for use in a second modality (e.g., Abravanel, 1971, 1973; Easton, Srinivas, & Greene, 1997; Reales & Ballesteros, 1999). However, there are reports that preschool-aged children have difficulty in cross-modal transfer. In particular, children perform poorly in object recognition tasks requiring the transfer of information from haptics to vision. Two explanations for these findings have been proposed. The first proposal is that there are qualitative differences between the representations that children form from visual and haptic experience, so that translation between the two modalities is hampered. The second proposal is simply that young children have poor haptic perception. The present study explores these two possibilities.

Qualitatively different representations

Bushnell and Baxt (1999) used real-world familiar and novel objects to test 5-year-olds in object recognition requiring either intra- or cross-modal use of haptic or visual information. The children did well in object recognition in intra-modal tasks with both familiar and novel objects, and in cross- modal tasks with familiar objects. Children's performance was markedly poorer, however, with novel objects. Bushnell and Baxt (1999) suggested that "hand-mages" – representations formed entirely from haptic exploration – differ importantly from visual images ("eye-mages"). They proposed that attention during haptic exploration might be focused on material-based properties (texture, mass, rigidity) whereas in vision attention is focused more on shape and color. These differences in perceptual focus would then presumably lead to qualitatively different representations and therefore poorer performance in cross-modal tasks as compared to intra-modal tasks.

Kalagher and Jones (2010) used a novel name extension tasks to test Bushnell and Baxt's (1999) hypothesis that representations formed through experiences in different modalities are qualitatively different. In the standard version of this task (c.f., Landau, Smith, & Jones, 1988), children are visually presented with a novel object (the exemplar) and told its novel name. Children are then visually presented with three test objects; each matches the exemplar on one perceptual dimension – color, texture, or shape - and differs from the other two test objects on the other perceptual dimensions. Children are asked to indicate the object that has the same novel name as the exemplar. Past experiments have shown that children by 2 years of age typically choose shape-based matches predominately over texture- or color-based matches (e.g., Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002). This "shape-bias" is thought to reflect an acquired attentional bias. Kalagher and Jones (2010) tested children 2 ½ to 5 years of age and adults in a modified version of this task. Children in their experiment explored exemplar objects either haptically or visually. Test objects were then presented visually. All ages 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 5- years- old chose test objects at random. Importantly, when older children and adults did choose matches systematically after haptic exploration, they did not make texture matches as Bushnell and Baxt (1999) might predict. Instead, they chose shape-based object matches just as they did after visual exploration. This finding suggests that representations in the two perceptual modalities are not qualitatively different.

Haptic perception

The mature haptic perceptual abilities of adults have been studied extensively. Lederman and Klatzky (1987) studied the hand and finger movements of adults who were attempting to extract information about specific object properties using haptics alone. The researches identified a number of stereotyped manual movements that they called "exploratory procedures" (EPs). EPs are thought to be driven primarily by top-down processes such as task goals but also, to a lesser extent, by bottom-up sensory information. What then is known about young children's haptic perception? A number of studies have reported poor haptic perception in young children (e.g., Abravanel, 1972; Rose, Blank, & Bridger, 1972). For example, Milner and Bryan (1970) asked 5 to 7 year olds to make same/different judgments about object shape in both intra- and cross-modal conditions. The magnitude of the improvements made between 5 and 7 years of age were comparable in both the intra- and cross-modal conditions. The authors therefore concluded that the developmental change was due to gains in children's haptic abilities. However, other researchers have found that 5-year-old children's haptic perception is actually quite advanced, at least when they are asked to explore familiar objects (e.g., Bigelow, 1981). Kalagher and Jones (2010) found mature haptic exploratory behaviors in 5- year- olds but fewer such behaviors in younger children. Their analysis of children's hand movements during haptic exploration showed that certain movements reliably predicted subsequent shape- or texture-based matches: however, children younger than 5 produced these hand movements at very low frequencies.

In summary, young children's difficulties with haptic-to-vision information transfer appeared in a previous study to stem from their failure to execute mature hand movements rather than from qualitative differences of object representations in the two modalities. In the present study, we asked whether additional tests of children's haptic exploratory abilities would point to the same conclusion. More specifically, children in the present study participated in two new conditions: (1) a visual exemplar exploration – to – haptic recognition condition; and (2) a haptic exemplar exploration – to – haptic recognition condition. The visual exemplar exploration – to – haptic recognition condition, like the haptic exemplar exploration - to – visual recognition condition in the previous research, required children to transfer information across perceptual modalities. However, because children's attention during visual exploration is consistently biased towards object shape (e.g., Smith et al., 2002), we speculated that children might make more systematic choices using information from vision to make haptic object matches than they had made using information from haptic to make visual matches. In the former case, they would know what they were looking for: that is, their visual explorations would lead them to focus on object shape. A finding that children did not make systematic shape-based matches in this condition would be further evidence against the idea that representations in the two perceptual modalities are qualitatively different and do not translate.

The haptic exemplar exploration – to – haptic recognition condition eliminated the need to transfer perceptual information across modalities. Thus, this condition tested children's haptic perception only. A finding that children made systematic matches in this condition would indicate that their haptic perceptual abilities were good. Systematic texture matches would support Bushnell and Baxt's (1999) idea of "hand-mages". A failure to match objects systematically would suggest that neither shape nor texture had been perceived well enough during object exploration for subsequent use in object recognition in the haptic mode.

Methods

Twenty four- year- old children (range = 46.8 to 56.1 months; *Mean* = 51.65; 10 males) participated in the study. Participants reflected the local community in social class, ethnicity, and racial identity: almost all participants were from white, middle class families.

The stimuli consisted of 16 object sets, each with one exemplar, and three test objects. Exemplars and test objects were 3-dimensional, novel objects constructed from a variety of materials including wood, clay, and cloth. Sizes ranged from 7 to 17 cm. Colors, textures, shapes and masses were widely varied. Each of the test objects shared a different attribute –its color, texture, or shape – with the exemplar, and differed from the exemplar and the other two test objects on the other two dimensions (See Figure 1 for a sample stimulus set).

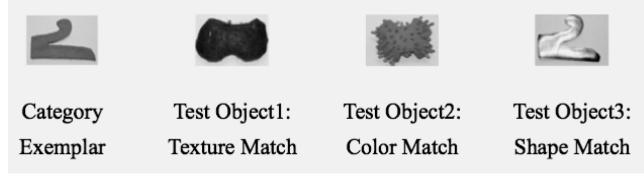

Figure 1: Sample stimulus set: 1 exemplar object, and 3 test objects, each matching the exemplar on 1 dimension – shape, texture, color – and differing from the exemplar and each other on the other 2 dimensions.

All participants completed two blocks of trials, each consisting of three warm-up trials and eight test trials. In one block of trials, children were limited to visual exploration of the exemplars ("Visual Exemplar Exploration" condition). In the other block of trials, children were limited to haptic exploration of the exemplars ("Haptic Exemplar Exploration" condition). The order of conditions was counterbalanced across participants. The 16 stimulus sets were divided into two groups and the stimulus groups were counterbalanced within conditions. Thus, half of the participants saw Stimulus Group 1 in the Visual Exemplar Exploration condition, and the other half of the participants saw Stimulus Group 2 in that condition.

Each participant was seated at a table next to his or her parent and across from the Experimenter who explained that they were going to play a "matching game". The procedure began with three warm-up trials to ensure that participants understood the task. Warm-up trials differed between the two conditions. In each warm-up trial in the Visual Exemplar Exploration condition, participants were simply handed a familiar object and told its name (e.g., "Look, here is a spoon). After three seconds, the Experimenter retrieved the object. In each warm-up trial in the Haptic Exemplar Exploration condition, participants placed their hands and forearms inside a box; a piece of cloth was pulled over their arms to prevent participants from seeing inside the box. The Experimenter put a familiar object into the hands of the participant within the box, identified it by name, and asked the participant whether he or she could feel it (e.g., "This is a spoon. Can you feel the spoon?"). For the test trials in both conditions, participants had their hands and forearms inside the box and a piece of cloth draped over their arms to prevent them from seeing inside the box. On each trial, three test objects were placed inside the box (e.g., a cup, a comb, and a spoon) and the child was asked to pull out the test object with the same name as the exemplar (e.g., "Can you find me the spoon?).

Test trials followed warm-up trials immediately and were structured in the same way: participants were shown or handed the exemplar from one object set at a time and told its novel name (e.g., "This is a teeka") then asked to find a haptic match for the exemplar (e.g., "Can you find me another teeka?") from among the three test items inside the box. Children were given a sticker after each trial regardless of which choice they made. The experiment was digitally recorded, and records were later scored for the test objects – shape match, texture match, or color match – chosen on each trial.

The recordings were also coded for the children's hand movements while exploring test objects in the Visual Exemplar Exploration condition, and category exemplars and test objects in the Haptic Exemplar Exploration condition.

Results

Object Recognition To determine whether visual or haptic exemplar exploration led predominantly to shape or texture matches, the proportions of shape and texture matches in each condition were calculated. This resulted in 4 categories of scores: (1) visual exemplar exploration resulting in shape match (V->SH), (2) visual exemplar exploration resulting in texture match (V->TX), (3) haptic exemplar exploration resulting in shape match (H->SH), and (4) haptic exemplar exploration resulting in texture match (H->TX). The mean proportions of children's scores in each category can be found in Table 1.

Table 1. Means and Standard deviations for proportions of shape- and texture- based matching in the Visual Exemplar Exploration and the Haptic Exemplar Exploration conditions.

	Mean	SD
V-SH	0.54	0.27
V-TX	0.32	0.22
H-SH	0.42	0.14
H-TX	0.39	0.13

The proportions were first entered into a 2 Order (Visual Exemplar Exploration first or second) x 2 Gender (male/female) x 2 (Exemplar Exploratory Modality: Haptic/Visual) x 2 (Match Type: Shape/Texture) mixed analysis of variance. There were no between subjects main effects for either Gender ($F_{(1,16)} = 2.67$, $p = ns$) or Order ($F_{(1,16)} = .17$, $p = ns$). There was a significant main effect of Match Type ($F_{(1,16)} = 4.5$, $p < .05$) with more shape-based matches exceeding texture-based matches. We did not find a main effect of Exemplar Exploratory Modality ($F_{(1,16)} = .79$, $p = ns$). Figure 2 graphs the marginally significant Exploratory Modality by Match Type interaction and illustrates the fact that shape choices dominated choices after visual exploration ($F_{(1,16)} = 3.82$, $p = .06$).

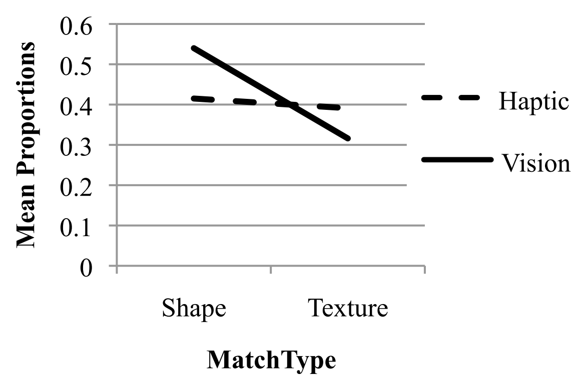

Figure 2. Match Type by Exploration Modality interaction

The proportions of shape and texture choices shown in Table 1 were also compared to chance (.33) using one-sample t-tests. Children chose same-shape matches at above chance levels in both conditions (H->SH: $t_{(19)} = 2.59$, p< .05; V->SH: $t_{(19)} = 3.46$, p< .05). Their texture-based matches were marginally above chance following haptic exemplar exploration of the exemplar ($t_{(19)} = 2.05$, $p =$

.054), but not following visual exploration ($t_{(19)} = -.34$, p = *ns*).

In sum: children showed the previously well-documented bias to preferentially attend to shape in object matching (e.g., Smith et al., 2002) in the Visual Exemplar Exploration condition. However, children in the Haptic Exemplar Exploration condition were equally likely to pick a shape or texture match. Thus, after visual exemplar exploration, children systematically chose shape-based matches suggesting that the representations they formed focused predominately on shape. After haptic exemplar exploration we do not see a similar systematic preference and therefore cannot claim that children's representations formed through haptic experiences are or are not qualitatively different from their representations formed through visual experiences.

We next examined children's hand movements during the test phase in the Visual Exemplar Exploration condition and during both the exemplar exploration and the test phase portions of the Haptic Exemplar Exploration condition.

Hand movements Initially, we attempted to use the taxonomy of exploratory hand movements developed by Lederman and Klatzky (1987) to code children's hand movements while exploring objects in both conditions. However, children in the present study did not produce these movements. Therefore, 5 categories of manual exploratory behavior identified by Kalagher & Jones (2010) in the same age group were used instead. The categories are: (1) "sequential finger movements" (rotating the object around only with fingertips), (2) "fingers palpating" (fingers palpating/ squeezing the object), (3) "static fingers" (fingers placed on object but not moving), (4) "hand grasping" (grasping the object with one hand), and (5) "hand press" (pressing the object between both hands with fingers outstretched).

We also coded instances of children's verbalization specifically recording shape-related verbalizations (e.g., "This feels like the letter 'Z'") and texture-related verbalizations (e.g., "This feels fuzzy"). However, such verbalizations were rare, occurring in fewer than 15% of trials, and were therefore not analyzed.

Hand movements were clearly visible in 108 exemplar exploration trials and 101 test trials in the Haptic Exemplar Exploration condition (H.E.E. and H.E.T.O., respectively) and in 97 test trials in the Visual Exemplar Exploration condition (V.E.E.). Figure 3 shows the frequencies of the 5 kinds of hand movements produced by children in each of these kinds of trials.

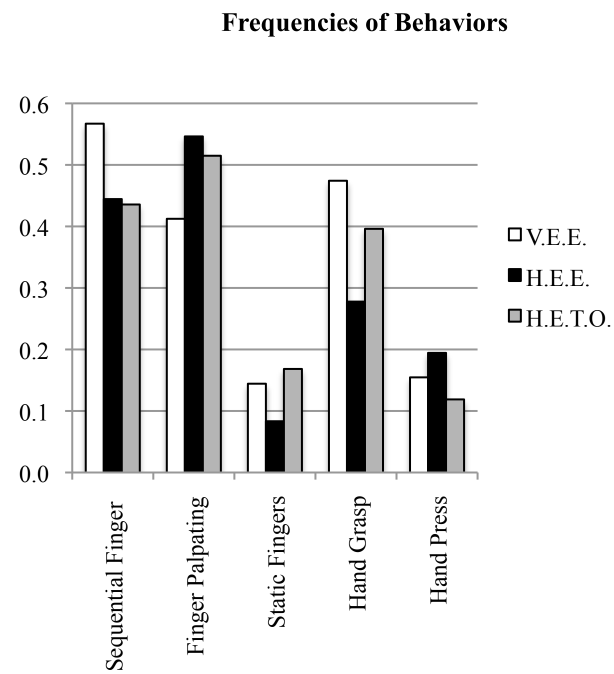

Figure 3. Frequencies of exploratory hand movement behaviors.

We then asked whether any of these five behaviors predicted whether children would make a shape-based, texture-based, or color-based (i.e., random) object match. We used multinomial logistic regression to address this question. Multinomial logistic regression is a generalization of the binomial regression and is useful when the dependent variable has more than two discrete choices. In a multinomial logistic regression model, the estimates for the parameter can be identified compared to a baseline category. For our analyses, we used a dependent variable SCORE (1= shape match, 2 = texture match, and 3 = color match), and independent predictor variables of hand movement patterns. A SCORE value of 3 was specified as the baseline category. The test then estimated the effects of the independent variables on choosing texture or shape matches over making a color-based match.

When the multinomial logistic regression test was carried out on the data the Likelihood Ratio (LR) chi-square test that at least one of the predictors' regression coefficients was not equal to zero yielded significant results, $\chi^2_{(2,14)} = 118.5$, $p < .0001$. This outcome indicated that particular hand movement behaviors affected subsequent matches (i.e., the participant's score). From the results of the multinomial logistic regression analysis, 2 main effects were significantly predictive of SCORE. The significant main effects were: *sequential finger movements* ($\chi^2_{(2,14)} = 48.22$, $p < .0001$), and *hand press* ($\chi^2_{(2,14)} = 24.4$, $p < .0001$). Further chi- square analyses showed that children's use of *sequential finger movements* was predictive of later shape matches, $\chi^2_{(2,14)} = 73.34$, $p< .0001$, while the absence of the hand movement pattern *hand press* was also predictive of later shape matches, $\chi^2_{(2,14)} = 30.36$, $p< .0001$.

The fact that two specific hand movements (i.e., *sequential finger movements*, and *hand press*) during haptic exploration predicted children's subsequent choice of a same-shape match suggests that children were able to obtain shape information and use that information intra and inter-modally.

Item Analysis Individual items were classified into three categories by the extent to which each was matched predominately by shape, texture, or color. These categories and their criteria are as follows: (1) "dominant match" criterion: one feature (shape or texture) is matched more than twice as often as the second more frequently used feature; (2) "selective match" criterion: item is selectively matched but differently by different children (both shape and texture matches separately are chosen at least twice as often as color); (3) "random matches" – remainder. Figure 4 displays the results of applying these criteria to the objects in both conditions.

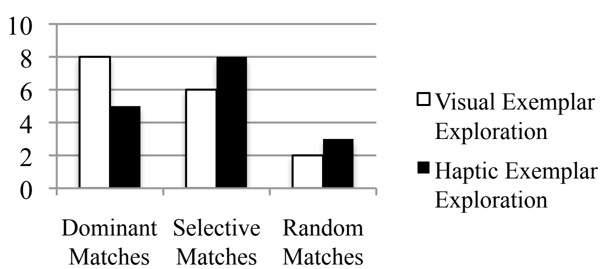

Figure 4. Frequencies of item analysis match types for the Visual Exemplar Exploration condition (white bar) and the Haptic Exemplar Exploration condition (black bar).

When the 16 category exemplars were explored visually, eight objects were subsequently matched consistently and by different children on one dominant perceptual dimension (shape-6 and texture-2). When those same objects were explored haptically, only 5 were matched on one dominant dimension (shape-3 and texture-2). A chi square analysis found no difference between conditions in the kinds of dominant matches (shape or texture) that children made ($\chi^2_{(1)} = .33$, $p= ns$).

Discussion

Our primary interest was in whether restricting exemplar exploration to either vision or haptics would have consequences for the kinds of test object that children chose in the haptic modality to match the exemplar objects. When children explored category exemplars visually, they were more likely to pick a same-shape match than if they had explored the exemplar haptically. This finding is consistent both with Bushnell and Baxt's (1999) suggestion that "eye-mages" represent different perceptual information than "hand-mages", and with the abundant evidence that young children's attentional focus on shape in visual object perception leads to a predominance of shape-based object matches (e.g., Smith, et al., 2002).

When category exemplars were explored haptically, children were equally likely to pick a shape- match or a texture- match. This finding is not consistent with Bushnell and Baxt's (1999) idea that "hand-mages" formed from haptic input predominantly represent object texture, mass, and rigidity. Instead, children in this study appeared to be matching each item on whatever perceptual information gained from exploration of each exemplar object was most salient to them. They do not appear to be using a top-down perceptual focus that would allow them to match objects systematically by either shape or texture.

Overall, we did not find compelling evidence of qualitative differences in the object representations from visual and haptic inputs. Instead, children's use of representations formed through haptic experience seemed to be affected by the most salient properties of the exemplar object (bottom- up), rather than by a particular perceptual focus such as the "shape bias" seen in vision (top-down).

The item analysis provides further support for this last point. When comparing children's consistency in making shape or texture matches in the Visual Exemplar Exploration condition to the children's consistency in making shape or texture matches in the Haptic Exemplar Exploration condition, we did not find a reliable difference in the number or kinds of *dominant matches* made. This result suggests that representations from input in the two modalities are not qualitatively different.

A secondary goal of this experiment was to further examine the status of young children's haptic abilities. Examination of haptic exploratory behavior indicated that when children executed *sequential finger movements* it was likely that they would make a subsequent shape-based match. This finding replicated the results Kalagher and Jones (2010). However, we found no parallel relation between particular hand movements during haptic exploration and children's later choices of texture matches. Again this finding suggests that children's haptic exploratory behavior is not guided by a particular perceptual focus or goal.

Interestingly, the present results show that 4- year -olds can haptically obtain shape information when they have a clear idea of what they are looking for as reflected in the predominance of shape matches in the Visual Exemplar Exploration condition. This predominance suggests that when children visually explored exemplar objects, they formed representations that contained and perhaps emphasized shape information. Guided by these representations, children's haptic abilities were good enough to obtain the shape information needed for a same-shape match. This finding is consistent with previous reports that found that young children have good haptic perception of familiar objects (Bigelow, 1981; Bushnell & Baxt, 1999; Morrongiello, Humphrey, Timney, Choi, & Rocca, 1994).

In summary, 4 year olds' representations of novel categories experienced haptically do not appear to be focused on either texture or shape. However, the object representations constructed from haptic perceptual input appear to be good enough to support object matches on whichever perceptual dimension is most salient. Thus, the present results indicate that children younger than 5 years of age have functional haptic abilities.

Although haptic perceptual exploration did not appear to be bias towards one kind of perceptual information over another, visual experience of novel categories appeared in this study, as in many previous studies, to lead to the formation of representations focused of shape. A new finding in the present study is evidence that representations built from visual input can transfer, complete with their focus on shape, into the haptic mode. Specifically, the present findings of a predominance of same-shape object matches in the haptic modality given only visual experience of the exemplar object suggests that representations of that visual experience guided the haptic identification of a matching objet. Thus, it appears that the shape bias in visual object matching remained intact during the transfer of perceptual information about exemplar objects from the visual into the haptic realm.

References

Abravanel, E. (1971). Active Detection of Solid-Shape Information by Touch and Vision. *Perception & Psychophysics, 10*(5), 358-360.

Abravanel, E. (1972). Short-Term Memory for Shape Information Processed Intramodally and Intermodally at 3 Ages. *Perceptual and Motor Skills, 35*(2), 419-425.

Abravanel, E. (1973). Division of Labor between Hand and Eye When Perceiving Shape. *Neuropsychologia, 11*(7), 207-211.

Bigelow, A. E. (1981). Children's Tactile Identification of Miniaturized Common Objects. *Developmental Psychology, 17*(1), 111-114.

Bushnell, E. W., & Baxt, C. (1999). Children's haptic and cross-modal recognition with familiar and unfamiliar objects. *Journal of Experimental Psychology-Human Perception and Performance, 25*(6), 1867-1881.

Easton, R. D., Srinivas, K., & Greene, A. J. (1997). Do vision and haptics share common representations? Implicit and explicit memory within and between modalities. *Journal of Experimental Psychology-Learning Memory and Cognition, 23*(1), 153-163.

Landau, B., Smith, L. B., & Jones, S. S. (1988). The Importance of Shape in Early Lexical Learning. *Cognitive Development, 3*, 299-321.

Lederman, S., & Klatzky, R. (1987). Hand movements: A Window into Haptic Object Recognition. *Cognitive Psychology, 19*, 342-368.

Milner, A. D., & Bryant, P. E. (1970). Cross-Modal Matching by Young Children. *Journal of Comparative and Physiological Psychology, 71*(3), 453-458.

Morrongiello, B. A., Humphrey, G. K., Timney, B., Choi, J., & Rocca, P. T. (1994). Tactual Object Exploration and Recognition in Blind and Sighted Children. *Perception, 23*(7), 833-848.

Reales, J. M., & Ballesteros, S. (1999). Implicit and explicit memory for visual and haptic objects: Cross-modal priming depends on structural descriptions. *Journal of Experimental Psychology-Learning Memory and Cognition, 25*(3), 644-663.

Rose, S. A., Blank, M. S., & Bridger, W. H. (1972). Intermodal and Intramodal Retention of Visual and Tactual Information in Young Children. *Developmental Psychology, 6*(3), 482-486.

Smith, L. B., Jones, S. S., Landau, B., Gershkoff-Stowe, L., & Samuelson, L. (2002). Object Name Learning Provides On-The-Job Training for Attention. *Psychological Science, 13*(1), 13-19.