Seven-Month-Old Infants' Haptic Perception of Texture in the Presence and Absence of Vision

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Abstract

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The present study was designed to assess 7-month-old infants' haptic perception of visible and nonvisible texture stimuli. Forty-eight 7-month-old infants participated in three phases; a familiarization phase, during which 30 seconds of tactile contact with one of the two textures (smooth or rough) was acquired, and two test phases each of 30 seconds duration. Infants in the touch-plus-vision condition were able to see and feel the stimuli while infants in the touch-no-vision condition could only feel the stimuli. Experimental infants within each condition received a novel texture during Test 1 and the familiarization texture in Test 2. Control infants received the same texture throughout. Tactile contact measures included total tactile contact, active manipulation (both relative to phase length and individual levels of total tactile contact), fingering, scrumbling and bimanual manipulation. Visual attention measures consisted of total attention and fixation. Texture discrimination abilities were reflected only on individually-based active manipulation. Vision appeared to have a guiding role on haptic manipulation by increasing active and bimanual manipulation and guiding visual attention toward the stimuli. The findings suggest: 1) that infants may be capable of haptic discrimination of textures in the absence of vision and 2) that vision guides exploration of and visual attention toward tactile stimuli. Implications of these findings for cognitive development and for blind infants are suggested.

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The visual and auditory systems have been traditionally regarded as the "higher" senses (cf. Kruger, 1982), however, a substantial amount of research has, more recently, been gathered in support of Katz' view of the primacy of touch in human functioning. Foremost in indicating a fundamental role for touch in human experience are the early development of the somaesthetic system in the human embryo (Montagu, 1971) and the fact that this system possesses the largest sensory surface: the skin. Research on both non-human and human species has established the importance of stimulation of this system for early development. For example, tactile stimulation in the form of handling has produced beneficial effects on rats' growth, development, and resistance to disease (Denenberg, 1968) as well as facilitating more adaptive responding to stress (Levine, 1956, 1960). Furthermore, Harlow's (1959) classic work highlighted the primacy and preference of contact comfort over satisfaction of the feeding drive in monkeys.

In addition to the importance of touch to the animal world, the human infant's sensitivity to tactile stimulation has also been established through studies on habituation to tactile stimuli (Kisilevsky & Muir, 1984), studies on soothing (Korner & Thoman, 1972), and through the positive effects of tactile stimulation on the outcome of high-risk infants (Scafidi, Field, Schanberg, Bauer, Vega-Lahr, Garcia, Power, Nystrom, & Kuhn, 1986). Further, deprivation studies have supported the importance of touch to normal growth and development (Casler, 1965). These studies have indicated that a lack of tactile stimulation may have been directly contributing to the developmental delays observed among institutionalized infants (Casler, 1965). Moreover, tactile stimulation is the primary means employed in reginens for premature newborns designed to help foster growth and development (Kisilevsky, Stack & Muir, 1991). For example, tactile stimulation in the form of body massage and passive movements of the limbs administered to preterm neonates has been found to result in significantly greater weight gains, more time in awake and active, and more mature behavior on Brazelton's (1973) Neonatal Behavioral Assessment Scale, relative to nontreated controls. In addition, treated preterm neonates were discharged earlier than controls (Scafidi et al., 1986; Scafidi, Field, Schanberg, Bauer, Tucci, Roberts, Morrow, and Kuhn, 1990). Findings such as the foregoing, have highlighted the potential of the tactile modality to greatly affect early adaptive development.

This strong impact of tactile stimulation on early adaptive development is not surprising given that infants, from a very early age, engage in tactile activity. Infants initially appear to use this modality simply for the sensory feedback or stimulation they attain through their actions with different objects (Warren, 1982; Bushnell & Boudreau, 1991). Gradually, they begin to use this modality, and particularly their hands, to acquire information about the physical world. This shift in the use of tactile stimulation is thought to be mediated by maturing cognitive processes (Warren, 1982). There also exists evidence that tactile information may be a more salient source of stimulation for infants than visual information. Klein (1963) observed that before the age of 8 years, and especially before 6.5 years, children tend to match objects on the basis of textural similarity after touching them, however, by age 8 they prefer to match on the basis of a common tactual form or shape (cf. Lederman, 1982). This trend from texture to form within the tactile system can be compared to the color to form transition in vision (Lederman, 1982). Gliner, Pick, Pick and Hales (1969) suggested that shape preference may be due to the fact that as children get older they learn that shape provides a better cue for the identification of objects than does texture. While this may very well be the reason, it also suggests that infants and young children may initially depend more on tactile information to gain an understanding of the stimulus world around them.

Little progress, however, has been made in determining the factors involved in the transmission of such information to infants, and in understanding the development of the tactile modality in terms of its sensitivity and acuity in the early years of life. Investigation of these issues is essential given that the somaesthetic system is a major sensory modality from which to process information about the physical world.

<u>Touch in Early Social Communication and Interaction</u>

a) Affect

It has been suggested that tactile stimulation may serve communicative functions by contributing to the social interaction between infants and caregivers. Until recently, however, researchers have not focused on tactile stimulation even when touch was included as an integral component of interactive sequences, beyond noting its frequent occurrence (Cohn & Tronick, 1983; Field, Vega-Lahr, Goldstein & Scafidi, 1987). In the SF procedure, typically used in infant-caregiver interaction studies, caregivers (typically mothers) are asked to keep a still or neutral facial expression while maintaining eye contact with their infants but not speaking to or touching them for brief 90-120 second periods. Early work on mother-infant interactions suggested that infants' negative affect and decreased gazing in the "still-face" (SF) situation was attributable to either the mother's change in voice, facial expression or both, but not to any other variables such as the mother's change in touch

(Tronick, Als, Adamson, Wise & Brazelton, 1978; Gusella, Muir & Tronick, 1988). However, in their second study, Gusella et al. (1988) found that 3-month-old infants in the SF group responded differently from the no-change (non-SF) control group only when their mothers were permitted to touch them. When touch was not permitted the 3-month-old infants in the control group were acting similarly to infants in the SF group, displaying reduced smiling at their mothers. Thus, the SF effects may have been partially due to the lack of touch in these mother-infant interactions, as well as to the mother's change in voice and facial expression (Gusella et al., 1988). These findings also suggest that quality, not quantity of stimulation is critical in maintaining infant positive affect since the no-touch control group behaved similarly to the SF group even though they received more stimulation than the SF group. Finally, these findings suggest that tactile stimulation can reduce the negative effects of the SF procedure (Stack & Muir, 1990).

More recently, Stack and Muir (1990) were able to demonstrate an independent role for touch in modulating infant affect during the SF procedure. They compared a SF-no-touch period with a SF period where mothers could touch their 3-, 6-, and 9-month-old infants. Infants smiled more, grimaced less and were more content in the SF-with-touch period than in the standard SF-no-touch period. In a subsequent study with 5-month-old infants, they examined whether these effects were due to the visual aspect of the hands touching the infants or to the tactile-kinaesthetic stimulation received from the hands (Stack & Muir, 1992). By using an opaque cover to prevent infants from seeing the adults' hands they were able to replicate the moderating effects of touch on infants' typical responses to the SF period even when touch was isolated from vision. Thus, they established an independent contribution for tactile stimulation in early social interaction since it was the actual tactile stimulation itself and not the visual aspect of observing the hands touching the infant that maintained the infants' positive affect. It was clear from these studies that adult facial and vocal expressions were not the only modulators of infant affect.

b) Attention

In addition to its hypothesized communicative role, an additional function touch has been proposed to serve is the maintaining and directing of attention. Touch has been found to maintain attention very early in life, i.e., in the fetus and the newborn (Kisilevsky et al., 1991), and has been used between experimental periods in infancy studies to increase infants' arousal and attentiveness. More recently, research has further established this role of touch among older infants. For example, Stack and Muir (1990) assessed the role of touch on infant attention and found that touch could moderate the reduced attention displayed by infants in the typical SF situation. The addition of touch during a SF period was found to result in sustained high levels of attention. In addition, touch, in the SF-with-touch periods, directed infant attention toward the caregivers' hands. In a second study they found that the direction of infant gaze however, did depend on the visibility or nonvisibility of the adults' hands (Stack & Muir, 1992). When the hands were visible, infants showed increased gaze at them. When the hands were concealed the infants continued to display high, sustained levels of attention, however, their gaze was directed at the adult's still face. These findings suggest that touch maintains and may even facilitate social interaction and the communication of social information by reducing negative affect in the SF situation and by eliciting, directing, and maintaining attention.

Infants' Tactile Information Processing Abilities

The ability of the tactile system to direct attention is another indication of its important role in infants' development. It can, like vision, elicit and maintain attention. Stack and Muir's studies demonstrated that touch alone, without the visual stimulation from the hands being present, can elicit attention and direct it to the source of the tactile stimulation, i.e., the experimenter and his/her face. Furthermore, the finding that infants displayed more attention when touch was present in the SF procedure, even in the absence of vision, than when it was not present, suggests that touch alone can serve to maintain attention.

Yet in order for tactile stimulation to be capable of regulating infant attention, infants must possess some capacity for processing tactile information. Research on infant tactile perception and processing abilities is, however, still in its early stages. Some issues that remain to be thoroughly examined include the parameters of the tactile system (the properties of tactile stimuli infants process), and the developmental progression of infants' tactile processing abilities, including the speed with which infants of different ages process tactile information, and differences in infants' manipulation of tactile stimuli as a function of age. Furthermore, the majority of studies on infant tactile perception have not isolated the component of vision from their paradigms and procedures (Lamb & Bornstein, 1987). Thus, infants' tactile information processing abilities, independent of vision, and infants' skills at manipulating tactile stimuli, warrant further documentation.

Tactile perception in infancy has been examined primarily through fixed-trials and infant-control procedures, often with the goal of studying habituation mechanisms. Intramodal and cross-modal transfer familiarization paradigms have also been used when research goals are related to studying intra- and intersensory equivalence. All of these procedures use the same two behavioral measures of decrement and recovery of attention from which to infer information processing (e.g. Kisilevsky & Muir, 1984; Stack & Bennett, 1990; Bornstein & Sigman, 1986), although psychophysiological measures such as heart rate accelerations and decelerations may also be employed as indices of information processing (Berg, 1972; Casey & Richards, 1988). Both decrement and recovery of attention entail stimulus information processing and have been widely used as means of studying perception and cognition in infancy (Bornstein & Sigman, 1986). Furthermore, decrement and recovery of attention have both been found to show significant levels of continuity with measures of cognitive competence in childhood. That is, infant behavioral measures of habituation and response to novelty have been found to predict IQ in later childhood (Rose, Feldman, Wallace & McCarton, 1989). The positive predictive relationships between these measures and later mental outcome lend support to the use of these measures as indices of information processing abilities in infancy (Rose, Feldman, & Wallace, 1988; Bornstein & Sigman, 1986).

Decrement of attention is the infant's behavioral response to an aspect of the environment that is unchanging, while recovery of attention is the infant's response to an aspect of the environment that is novel. Decrement of attention, also referred to as habituation, is usually indexed by the amount or rate of decay in looking, or the cumulative amount of looking infants show to a repeated or a constant stimulus. Greater decrements, quicker decays, or relatively lesser amounts of cumulative looking, that are not due to fatigue, are generally inferred to indicate more efficient styles of information processing once the possibility that these are not due to fatigue is controlled for. Furthermore, decrement of attention is assumed to reflect the occurrence of a variety of perceptual and cognitive processes such as mental representations, and internal comparisons (Bornstein & Sigman, 1986). Recovery of attention, also referred to as response to novelty, is measured by the relative amounts of looking infants pay to novel over familiar stimuli. Relatively greater amounts of looking at novel stimuli are interpreted as more efficient information processing (Bornstein & Sigman, 1986).

Both fixed-trials and infant-control procedures have, however, several limitations. In the fixed-trials procedure, stimulus presentations are experimentally determined, and infant attention is influenced by procedural parameters such as trial length, number of trials, and inter-trial intervals and thus, may be unrelated to processing of stimuli. Furthermore, infants may not be equally exposed to a stimulus for reasons that have little to do with processing (Bornstein & Sigman, 1986). The infant-control procedure corrects for the procedural limitations of the fixed-trial procedure in that it permits tracking of individual courses of habituation and equates infants on degree of habituation. However, behavior must be monitored online and so false judgments of infant behavior or chance satisfaction of the habituation criterion are strong possibilities. Furthermore, declining attention may be due to fatigue or state changes and be unrelated to processing.

Although sparse, findings from studies employing variations of the fixed-trial and infant-control procedures indicate that infants react to and process tactile stimuli in a manner similar to that displayed with visual stimuli (Kisilevsky & Muir, 1984; Stack & Bennett, 1990). Infant fixation to visual stimuli has been thought to be a combination of two processes: attention-getting and attention-holding. For example, Cohen (1972) found that the latency of 4-month-old infants to turn toward a checkerboard pattern was determined by the size of the checkerboard while the duration of fixation was more a function of the number of checks rather than size. These findings support the contention that infant attention consists of two separate processes.

This duality of attention to visual stimuli seems also to be reflected in infants' attention to tactile stimuli. In an attempt to study infant attention during the manipulation of objects, Ruff (1986) found that latency to examine, or focused attention, among 7- and 12-month-old infants upon presentation of the objects, did not decline with increasing familiarity. Nevertheless, the duration of examining, or focused attention, decreased sharply with increasing familiarity with the objects. Thus, 7- and 12-month-old infants took the same amount of time to initially attend to both familiar and unfamiliar objects, yet at both ages infant attention declined as they became more familiar with the objects. Ruff (1986) concluded that latency to and duration of examining reflect different aspects of attention. These two attentional response patterns, latency to and duration of examining tactile stimuli, correspond to those patterns observed when infants attend to visual stimuli (i.e., attention-getting and attention-holding).

A further indicator of the similarity between responses to visual stimuli and tactile stimuli is the integration and concordance of visual attention and tactile manipulation. Studies aimed at assessing visual attention and tactile manipulation as equally valid indices of tactile processing have suggested that by 6 months of age visual and motor responses to novel and familiar stimuli are integrated and concordant (Ruff, 1976). Infants are capable of directing their hands toward a visual object (integration) and display equal amounts of preference for, or attention to stimuli in both their manipulation and fixation responses (concordance)

(Ruff, 1976). That is, infants' visual attention and tactile manipulation responses correspond with each other in terms of the direction and extent of preference for stimuli.

Further research aimed at understanding the role of touch in early perceptual development and assessing infant tactile processing abilities has established that infants find tactile stimuli compelling and that tactile stimuli elicit attention (e.g. Stack, St. Germain, & Zelazo, 1992). For example, Stack et al. (1992) assessed 5.5- and 13.5-month-old infants' processing of two sequential tactile stimuli, texture and movement (tactile-passive and tactile-kinaesthetic stimuli, respectively). The texture stimulus consisted of the experimenter rubbing the infants' hands with silk or terry cloth mittens, and the movement event consisted of engaging the infants in a series of leg movements while holding their feet. A Standard-Transformation-Return (S-T-R) paradigm was used (Zelazo, 1988). Responses to six standard presentations (S), three presentations to a discrepant variation of complex stimuli (T), and finally to three presentations of the original standard stimulus (R) were compared to the responses of a no-change control group. Experimental infants were found to fixate more during the transformation and return phases, indicating that moderately discrepant variations of the standard stimulus elicited longer sustained attention and that processing of the moderate discrepancy was accomplished reasonably quickly. Greater fixation at the return phase among experimental infants, relative to controls, implied the occurrence of a memory representation of the standard stimulus and recognition of this stimulus following the discrepant stimulus in the Transformation phase. Furthermore, a developmental trend was found in processing rates of tactile stimuli and differential responding as a function of stimulus pattern; the 13.5 month-olds processed the stimuli more quickly, and the 5.5 month-olds attended more to the movement event than to the texture event. These findings imply that different types of tactile stimuli elicit different responses as a function of age. Younger infants may find tactile-kinaesthetic events more compelling than passive-tactile events, and they may find these easier to process, perhaps because younger infants are more attuned to kinaesthetic than textural properties of tactile stimuli. The findings from Stack et al. (1992) also suggest that infants create mental representations for complex tactile stimuli as they do for complex visual and auditory stimuli.

The Stack et al. (1992) study illustrated that tactile stimuli are compelling and that infants show sustained levels of attention to them. In addition, they documented developmental trends in processing rates and in responses to tactile stimuli. Such developmental progression in infant attention to tactile stimulation has also been documented by Ruff (1986). She found that infants' latency to examine or focus attention to objects being manipulated decreases with age; 12-month-old infants attended to objects faster than 7-month-old infants.

The ability of infants to process information through the tactile system and to create mental representations for tactile stimuli has also been examined successfully through studies of infant intramodal and cross-modal transfer abilities. Intramodal equivalence refers to the recognition of an object in the modality in which it was originally presented. Cross-modal transfer refers to the recognition of an object in a modality other than that in which it was initially experienced, for instance visually recognizing an object that has only been felt but never seen before (Rose, Gottfried, & Bridger, 1981a). Cross-modal abilities are considered to be an underpinning of cognitive functioning in humans and the ability to form such cross-modal associations is thought to provide one basis for human cognitive development (Gottfried, Rose, & Bridger, 1977).

Intramodal and cross-modal work also depends on infants' capacity for recognition memory within different modalities; that is, the ability to distinguish the old memory trace from that which is new (Rose, Feldman & Wallace, 1988). For successful cross-modal transfer to occur, and for infants to fixate or attend more to the novel stimulus, both a capacity for processing and recognition memory must be present within the familiarization modality.

Thus, visual recognition memory, tactile recognition memory and visual and tactile processing and discrimination abilities of infants can all be assessed by intramodal and cross-modal procedures (Rose, 1990).

Intramodal studies have demonstrated that although infants possess visual recognition memory, and can process visual information faster than tactile information, they are also capable of recognizing objects by touch alone when given adequate exposure to stimuli in the familiarization period. In tactile intramodal studies infants are given an object to manipulate in total darkness or out of view, for a 30- or 60-second familiarization period. In the test period the familiar object is presented alongside a novel object, again in the dark. Using this procedure, with tactile familiarization conducted in darkness, Rose, Gottfried and Bridger (1981b) found that 12-month-old infants engaged in significantly more mouthing and more hand to hand transfers of novel shapes. Rose et al. (1981b) concluded that infants seem to possess the ability to recognize an object they had previously touched and thus, during the test period, preferred to handle the new object even though they had never seen either one. In an extension of these findings, Streri (1987) found that infants as young as 2- to 3-months of age are not only capable of visual habituation to shape but also show tactile habituation to shape. Thus, from 2 months of age infants tactually explore objects for decreasing periods of time without any visual information. Her findings also indicated that total exploration times were identical for the two sensory modes. Thus, given that infants possess both visual and tactile recognition memories, their cross-modal transfer abilities can be assessed.

Cross-modal work employs a familiarization procedure in which infants are allowed to become familiar with a stimulus within a perceptual modality for a fixed period of time. It is also relevant to note that within this procedure infants are permitted to mouth and palpate stimuli as well as to handle them. After familiarization, the infant is tested with the familiar stimulus presented alongside a novel stimulus in a different perceptual modality. Novelty preference, or recovery of attention directed towards the novel stimulus, is presumed to indicate the occurrence of successful cross-modal transfer. This paradigm, however, has its limitations. During the familiarization phase the experimenter controls the duration of the stimulus presentation but not the infants' exposure to the stimulus and thus, variance in recovery may reflect this differential stimulus exposure rather than differential information processing (Bornstein & Sigman, 1986). Such research is also dependent on infants' abilities and their willingness to visually and tactually explore new stimuli.

There exists an accumulating body of evidence that young infants are capable of visual-tactile and tactile-visual equivalences (Rose et al., 1981a). That is, they can tactually recognize objects they have previously only seen and vice versa. There is however, little known about the emergence and development of these abilities or the mechanisms underlying them (Rose et al., 1981a). Cross-modal work has, instead, focused on infants' abilities to process amodal properties of stimuli such as intensity, duration and form which can be perceived and processed independently of the modality in which they are experienced. For example, Streri (1987), using an infant-control habituation procedure, found that visual-tactile and tactile-visual cross-modal transfer of shape is apparent at the young age of 2 to 3 months. Hence, she concluded that visuo-prehensile coordination is not a necessary condition for transfer, since it is not yet organized by this age. Hernandez-Reif (1993) studied transfer abilities of shape in 6-month-old infants. A visual baseline phase was employed in her procedure during which visual fixations to paired presentations of nubby and smooth objects were recorded for two 30-second trials. Infants were then assisted or unassisted in exploring one object shielded from view by a cover for either 10, 20, or 30 seconds. The final phase consisted of a visual-tactual test phase during which visual fixations to the nubby and smooth objects presented side-by-side were recorded for two 30-second trials while subjects continued to explore the tactile familiarization object shielded from view. Infants in the 20 and 60 seconds of assisted tactile familiarization groups displayed successful tactile-visual transfer. Hernandez-Reif (1992, 1993) concluded that tactile-visual transfer at this age may be dependent on assistance in exploration and on sufficient familiarization time.

Although findings on tactile-visual and visual-tactile transfer abilities have been replicated with infants over 6-months of age, less has been done with younger infants. Streri and Pecheux (1986a) studied visual-tactile cross modal transfer of shape using an infant control procedure with 4- to 5-month olds. They found evidence for visual-tactile cross-modal transfer but not for tactile-visual transfer. In an attempt to reconcile these findings with those from their study with 2- to 3-month old infants, in which tactile-visual transfer was displayed even in the absence of visuo-prehensile coordination, Streri (1987) suggested that the absence of tactile-visual transfer in 4- to 5-month olds was due to the developing visuo-prehensile coordination. At this age, handling of objects under visual control is being intensively practised, and thus this intense practice may be interfering with the transfer. The motor functions of the hand may, at this age, be dominating the perceptual functions. This hypothesis may also explain the presence of tactile-visual transfer observed in 6-month-old infants whose visuo-prehensile coordination is assumed to be established.

Integration of Transfer Research with Tactile Processing: Haptics and the Salience of Stimulus Properties

Interestingly, consistent asymmetries in cross-modal transfer abilities have been demonstrated in cross-modal research. That is, even among 12-month-old infants, visual intramodal transfer has been found to occur only after 15 seconds of familiarization, and therefore is superior to tactile intramodal transfer, which occurs only after approximately 30 seconds of tactile familiarization. However, tactile-visual cross-modal transfer, found to be only as difficult as tactile-tactile intramodal transfer, seems to be superior to visual-tactile cross-modal transfer (Rose, 1990). Since visual-tactile cross-modal transfer appears to be relatively more difficult than both visual and tactile intramodal transfer, it suggests that cross-modal failure or difficulty is due to difficulty in recognizing equivalences across modalities, (the transfer is difficult), and not to difficulties in processing within each sensory modality (Rose, 1990; Streri, 1987). The relatively greater difficulty of visual-tactile cross-modal tasks, compared to tactile-visual tasks, also suggests that it is easier to recognize equivalences when tactile rather than visual information is the basis from which judgments are made. This asymmetry also suggests that the eye and the hand may sample different stimulus characteristics rather than directly process or detect the same invariants or same amodal stimulus properties.

Many researchers share this view of differential stimulus saliency between the senses of vision and touch and agree that while shape or form, (the primary stimulus property assessed in cross-modal work), is more salient for vision, texture and hardness are more salient stimulus properties for haptics. Kennedy (1978) has defined touch and haptics as the following: touch refers to the cutaneous system and localized sensations on the skin's surface, whereas haptics refers to a perceptual system which incorporates information from both cutaneous and kinaesthetic receptors. Haptics allows for the assimilation and processing of information through the simultaneous functioning of the skin, muscles and joints (Klatzky & Lederman, 1987). Thus, the haptic perceptual system is a primary means by which infants acquire information about stimulus properties.

Gibson's (1962) distinction between active and passive touch parallels the distinction between touch and haptics and highlights the contribution of motor development to haptic perception. These distinctions demonstrate how the tactile manipulations that infants are capable of engaging in affect the acquisition of information about tactile stimuli. In the majority of studies, where habituation and familiarization procedures were used to assess infant tactile processing abilities, infants were allowed to actively explore the tactile stimuli. Active touching, as Gibson (1962) proposes, is a search for stimulation or an effort to obtain the kind of stimulation which yields a perception of what is being touched. Active touch is an exploratory sense that is a combination of kinaesthesis and proper touch and thus permits two components of stimulation; exterospecific and propriospecific, involving the excitation of both skin receptors and joint and tendon receptors. Likewise, Klatzky and Lederman (1987) and Lederman and Klatzky (1987) have described different exploratory procedures of the hand that adults use to learn about tactile stimuli, i.e., stereotypical hand movements, each of which is associated with the extraction of specific stimulus properties. Heller (1984) found that among adults, active touch was superior to either passive static (forms pressed on fingers) or passive sequential touch when they had to recognize by touch a stimulus they had previously seen. In a tactile-familiarization visual-recognition task he found that 5 seconds of active touch produced visual recognition accuracy equivalent to that produced by longer periods of passive stimulation. This work supports Katz's (cf. Krueger, 1982) emphasis on the importance of purposive touch in exploration and its facilitatory effects on the processing of tactile information.

Purposive touch and the exploratory strategies of the hand have been argued to be best suited for the perception of specific stimulus properties. Katz suggested that the fingers are relatively more sensitive to properties such as roughness and hardness than to shape (cited in Krueger, 1982). He noted that the eye can only obtain information about the outer surfaces of objects while touch can yield information about both outer surfaces and internal features (Krueger, 1982). Klatzky and Lederman (1987) have similarly argued that since information on properties such as temperature, weight, and hardness is generally available only to haptics, touch should dominate vision in such judgments (Krueger, 1982).

More recently, studies have confirmed that texture tasks are performed very well among adults by the haptic system and that texture and hardness are more salient for haptics than for vision (Klatzky, Lederman & Reed, 1987; Lederman, Thorne & Jones, 1986). For example, Klatzky et al. (1987) assessed the availability and salience of object attributes such as size, shape, texture and hardness under haptic exploration with and without vision. Adult subjects were asked to sort objects by similarity. Three groups used haptic exploration only and were differentiated by the experimenter's definition of object similarity: the unbiased haptics group was given no particular definition of similarity, the biased haptics group was told to sort objects according to how similar they felt, and the haptics plus visual imagery group were told to sort objects according to similar visual imagery. A fourth group used vision and haptics and were given the same instructions as the unbiased haptics group. The unbiased and biased haptics groups performed similarly, finding texture and hardness relatively salient. The haptics plus visual imagery group found shape to be salient. The vision plus haptics group showed salience to be more evenly distributed over the stimulus dimensions. Klatzky et al. (1987) concluded that the haptic and visual systems may have distinct encoding pathways since haptics seems to be oriented towards the encoding of substance (texture and hardness), while vision seems to be oriented towards the encoding of shape.

The aforementioned study also dispels Heller's (1982) conclusion that vision facilitates the discrimination of texture by permitting precise control of hand movements. The biased and unbiased groups sorted objects on the basis of texture and hardness without the benefit of vision. Furthermore, the unbiased group, having been given no definition of similarity, exhibited haptic exploratory procedures that were found to be rapid and accurate and appeared to permit a high ease of encoding. These exploratory procedures have been defined by Lederman and Klatzky (1987) as stereotypical hand movements that maximize the sensory input corresponding to a certain object property. Thus, the unbiased group used exploratory procedures that were most appropriate for substance discriminations. These exploratory procedures, displayed in the absence of vision, determined which object properties became salient.

Research on infants' sensitivity to texture involving exclusively haptic presentations of stimuli is sparse. Most of the evidence on infant processing of texture comes from studies that have allowed infants to see the stimulus objects as they handle them (Bushnell & Boudreau, 1991). The results of these studies are difficult to interpret since the textures of the stimuli are visible as well as palpable. However, the results from such studies do suggest that as of 6 months of age infants are sensitive to texture. For example, both Ruff (1984), using 6-, 9-, and 12-month olds, and Lockman and McHale (1989), using 6-, 8-, and 10-month olds, found infants fingered bumpy and rough objects more than smooth objects. In addition, Steele and Pederson (1977) found that 6-month-olds, familiarized with either a furry ball or a smooth ball, subsequently displayed both increased looking at and manual contact with the alternate stimulus during the test phase. Further, Ruff's (1984) investigations of 6- to 12-month-old infants' manipulations of objects differing in color, shape, texture and weight revealed that infants displayed more fingering when exploring objects that differed in texture, color and shape, engaged in more transferring and rotating when manipulating stimuli differing in shape, and engaged in more banging when exploring objects differing in weight. Finally, Palmer (1989) found that by 9 months of age infants waved light objects more than heavy ones and banged heavy objects more than light ones.

More recently, studies designed to eliminate the visual component of stimulation also find infants capable of texture discrimination. Bushnell and Boudreau (1991) presented surfaces that were textured on one side (soft bristles, or several short cylinders) and plain on the other to 7- to 8-month-old infants sitting in the dark. Infants touched the textured surfaces longer than the plain surfaces, indicating that they discriminated the two. Furthermore, Bushnell and Boudreau (1991) found that infants engaged in different manual behaviors according to the nature of the surface presented. This type of differential manipulation corresponds to the exploratory procedures demonstrated by adults in the Klatzky et al. (1987) study.

Further evidence that infants are capable of both processing texture haptically, without the aid of vision, and of using different manipulation skills (i.e., exploratory procedures) according to the specific textural properties is accumulating. Bushnell, Boudreau, Weinberger, and Roder (1992) expected, based on Heller's claim that vision facilitates texture discriminations, that 7-month-old infants would show more distinctive tactile manipulation during stimulus exploration when vision was available than when exploring the same stimuli in the dark. They found that while infants touched and explored both stimuli, (a shallow well of water and a patch of brush bristles), equally, they used two hands in the light and only one hand in the dark. This pattern of bimanual versus unimanual exploration was interpreted as indicating the infants' need to maintain their balance or their orientation in space with one hand when in the dark. Thus, vision may serve the purpose of providing a spatial framework for behavior. A second finding was that infants' exploratory activities varied according to the nature of the stimulus; they scrumbled, or alternately flexed and extended their fingers, on the brush more than the water and they banged the water more than the brush. This finding appears to indicate that infants can discriminate object properties and, like adults, use distinct hand movement patterns or exploratory procedures to evaluate specific object properties (Lederman & Klatzky, 1987). Finally, in contrast to Heller's claim, they also found that the differences in the exploratory procedures as a function of stimulus were more pronounced in the dark. This suggests that vision is not integral to the adaptations infants make with their hands to different stimuli.

Although these recent studies have eliminated visual information about tactile objects, their findings on infant texture perception remain difficult to interpret due to problems in the selection of stimuli. It appears that the tactile system is indeed better designed, than the visual system, for the perception of the stimulus property of texture, and that touch may be able to serve this function independent of vision. Perceiving the texture of a surface by touch involves the input of information from several different sensory channels: cutaneous, thermal and kinaesthetic input. This input may be more suited to the sequential processing capabilities of touch than to the simultaneous processing capabilities of vision. Thus, texture perception by touch offers an excellent opportunity to study the integrated and independent actions of sensory systems as well as the limitations and capabilities of the tactile system (Lederman, 1982). However, the results on infant texture perception in the dark, are confounded by the lack of control for other stimulus properties such as shape, size, weight and temperature. For instance, texture is confounded with shape when bumpy surfaces or brush bristles are paired with smooth surfaces. Further studies that systematically isolate texture from other stimulus properties, and touch from vision, are essential to accurately assess infants' tactile perception of texture.

Finally, results on infants' texture processing abilities must be also be interpreted cautiously since sensitivity to different stimulus properties may depend on the development of motor abilities, as well as on cognitive abilities (Bushnell & Boudreau, 1991). Infants' haptic perception of texture has been found to emerge between 6- to 12-months of age at which time there is a corresponding increase in display of fingering of objects (Bushnell & Boudreau, 1991). The previously reported findings on infants' abilities to use differential exploratory procedures to extract information as a function of stimulus properties, even in the absence of vision, amount to a strong indication that infants are using different forms of tactile manipulation, or exploration, to facilitate their processing of tactile stimuli. Among infants, however, the ability to explore tactile stimuli depends on sufficient motor development. Their motor skills determine their haptic manipulation of tactile stimuli which in turn, determines the amount of tactile information that is assimilated. Differential tactile processing and exploratory abilities among infants, as a function of age, may be the result of different levels of motor development. Thus, in order to document a developmental progression of tactile perception and processing abilities of infants, developing motor abilities must also be considered.

Summary

In summary, substantial evidence has been gathered in support of a primary role for the tactile modality in early adaptive, socio-communicative, and perceptual development. Infants, from a very young age, are affected by tactile stimulation and employ haptic exploration as a means of acquiring information about the physical world around them. The literature on touch demonstrates the considerable strides that have been made towards understanding infant processing of specific tactile stimulus properties including factors such as attentional and exploratory responses to tactile stimuli, sensitivity to different types of tactile stimulation, speed of processing and the developmental progression in each of these areas. Furthermore, the independent contribution of touch to early perceptual and cognitive development is gaining increasing support through recent innovative studies that eliminate visual information.

There are, nevertheless, a number of fundamental issues remaining that are central to clarifying the development of infant tactile perception. First, the properties of tactile stimuli that infants can process and discriminate remain to be assessed in a systematic, methodologically sound fashion. Second, the types of exploratory procedures infants use as a function of stimulus properties need to be documented. Third, the role of vision in tactile processing needs to be delineated. Thus, the purpose of the present study was to examine each of these issues with respect to texture, a stimulus property salient to the haptic system. The term haptic perception will be used throughout the thesis since infants were permitted to handle and move the stimuli.

Description and Hypotheses of the Present Study

The present study was designed to examine 7-month-old infants' haptic perception of texture, in conjunction with or in the absence of opportunities for visual perception. This examination was performed with a familiarization-test-retest procedure. Infants participated in either a touch-plus-vision condition or in a touch-no-vision condition. Thus, half the infants were permitted to visually and tactually explore the textures while half were permitted only tactual exploration. Vision in the touch-no-vision condition was occluded by the use of a plastic grey cover placed at approximately upper chest level, while in the touch-plus-vision condition a plastic transparent cover was employed. The stimuli were presented underneath the cover to the infants' hands in order to eliminate oral exploration. Both texture stimuli were similar in color, size, shape, hardness and weight. Thus, visual cues about the stimuli were unavailable.

All infants were permitted to freely manipulate and explore the stimulus being presented, a rough or smooth texture, in the familiarization (FAM) phase as well as in each of the two test phases. To control for individual differences in the amount of exploration, a familiarization criterion was established. Infants were required to obtain 30 seconds of tactile contact in this phase before proceeding to the test phases. Infants in the experimental group, in both touch-no-vision and touch-plus-vision conditions, were exposed to the novel texture during the first test phase (Test 1) and to the original familiarization stimulus during the second test phase (Test 2). Infants in the control groups received the same stimulus throughout all phases. The test phases were set at 30 seconds in duration.

The dependent variable categories were tactile contact and attention. Total tactile contact consisted of stimulus touch, and active manipulation (the percentage of time spent grasping and touching the stimuli, calculated both with respect to the length of each phase and with respect to individual levels of total tactile contact). Additional tactile contact measures included bimanual manipulation and the exploratory strategies of fingering and scrumbling. The attention measures consisted of total visual attention and visual fixation toward the stimulus. All measures were analyzed as a function of Condition (touch-no- vision, touch-plus-vision) and Group (experimental, control) membership.

The three primary goals of the study with regards to tactile processing of texture were the following. The first goal was to assess whether 7-month-old infants were capable of texture discriminations. Thus, experimental and control group differences at each test phase were of interest. The second goal was to examine whether infants would display differential exploratory strategies as a function of the two different textures. The final goal was to investigate the contribution of vision to both the processing of texture and to infants' manipulation strategies. Thus, differences between experimental and control groups as a function of touch-no-vision and touch-plus-vision conditions were of interest.

Three specific hypotheses were tested.

1) Haptic Discrimination of Texture in Test 1

Based on the literature on tactile perception, 7-month-olds were expected to process and discriminate the texture stimuli employed in this study. Given the precision taken in the selection of appropriate texture stimuli, unconfounded by other properties such as shape, temperature and size, a direct and systematic assessment of processing was possible. The ability to process and make fine texture discriminations in both the touch-no-vision and touch-plus-vision conditions was expected to be reflected in differential levels of total tactile contact, active manipulation, fingering, scrumbling and attention between experimental and control groups. Thus, if 7-month-old infants are capable of texture discriminations both in the absence and presence of vision, then experimental infants in both conditions were expected to display higher levels of tactile contact, active exploration and attention in Test 1 relative to control infants.

2) Haptic Discrimination of Texture in Test 2

Texture processing was expected to be indicated in Test 2 again by differential responding between experimental and control groups. Experimental infants were expected to show lower levels of total tactile contact, active manipulation, exploratory strategies, and attention in Test 2 relative to Test 1, however still maintain significantly higher levels of responding in Test 2 relative to control infants. The relatively higher levels of responding among experimental infants, compared to controls, in Test 2 would reflect processing of the difference in texture from Test 1. Simultaneously, the relative drop in the levels of responding from Test 1 to Test 2 among experimental infants would reflect recognition of the original familiarization stimulus. Control infants were expected to show a gradual decrease in tactual exploration across all phases reflecting increasing familiarity with the texture.

3) Guiding Role for Vision

Based on the literature that has indicated that vision is not integral to haptic processing of texture, it was expected that infants would be capable of processing the differences in texture independent of vision. Thus, overall, infants in both the touch-no-vision and the touch-plus-vision conditions were expected to discriminate between the texture stimuli. However, a specific guiding role for vision was anticipated. Stimuli presented in the presence of vision were expected to elicit more infant fixation toward the stimuli. Thus, infants in the touch-plus-vision condition, were expected to visually fixate the stimulus significantly longer relative to infants in the touch-no-vision-condition. In addition, based on the findings from Bushnell et. al (1992), the presence of a visible stimulus in the touch-plus-vision condition was expected to result in greater levels of bimanual tactile contact than in the touch-no-vision condition. In contrast, the exploratory strategies of fingering and scrumbling were expected to be more pronounced when stimuli were not visible. Thus, greater levels of fingering and scrumbling were expected in the touch-no-vision condition, relative to the touch-plus-vision condition.

Method

Subjects

The names of potential subjects were obtained from the Sir Mortimer B. Davis Jewish General Hospital in Montreal, Quebec, Canada. Parents were recruited by telephone. The original sample consisted of 71 7-month-old, healthy infants with no complications either before or after birth. Twenty-three infants were excluded from analyses due to fussiness (15), obstructed camera view of the infants' hands underneath the cover (1), viewing the stimuli presented under the opaque cover by pulling the cover off (1), equipment failure (5), and prematurity (1). The final sample thus consisted of 48 full-term infants (mean age= 7 months, 3 days, sd= 5 days), the majority of which were white and were from middle class families. Power analyses conducted before the study indicated that sufficient power (Cohen, 1977) would be obtained with 48 subjects (Appendix A). There were equal numbers of males and females within each condition and group.

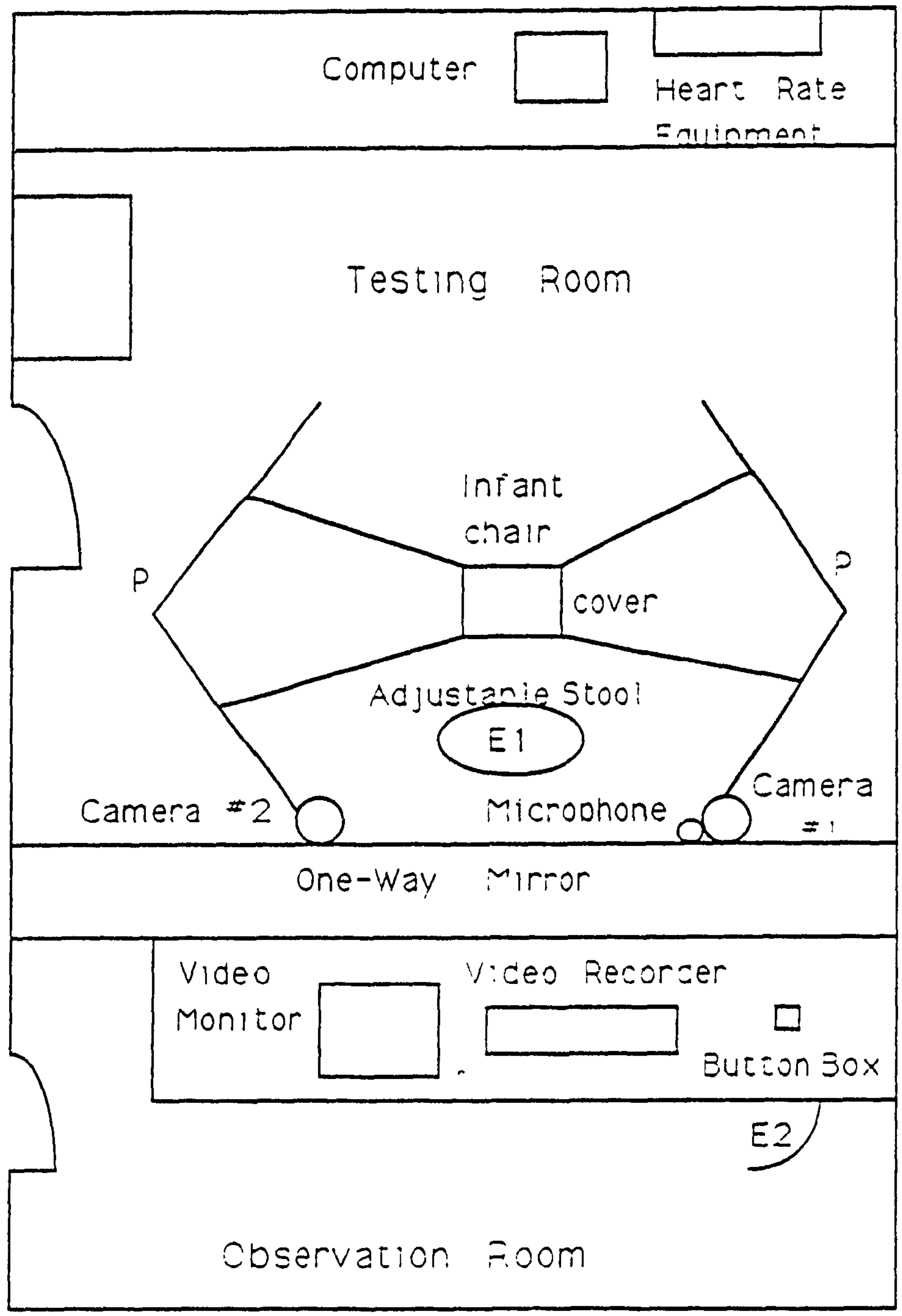
Seven-month-old infants were employed in this study given the evidence that perception of texture, as well as tactile intramodal transfer seem to appear after 6 months of age. In addition, at this age infants begin to display differential arm and shoulder muscle accommodations as well as a substantial gain in fine motor control.

Apparatus

The testing area was enclosed by two black partitions (8 by 6 feet in length and height, respectively) placed in a semicircle around the infant and the experimenter so to eliminate any sources of visual distraction in the testing room. Infants were seated in a high chair facing the first experimenter (E1) who was seated on a stool approximately 70 cm away. A rectangular opaque plastic cover or a transparent-plastic cover, resembling a large bib was attached comfortably around the infants' necks and attached at all four corners to the black partitions on either side of the infant. Figure 1 depicts a schematic diagram of the apparatus and layout of the testing room.

All testing sessions were videotaped on 8mm Sony video cassettes by a Hitachi VK-C350 camera mounted to the left of the infant that recorded a frontal view including the infant's face, body and his/her hands underneath the cover. The camera was connected to a NEC color video monitor located in the adjacent observation room which was separated from the testing room via a one-way mirror. A FOR VTG-22 stop watch adaptor was attached to a FOR-22 video timer and placed a time code on each video record in minutes, seconds, and milliseconds to permit precise coding of video records. A variable speed remote control with shuttle function was used in subsequent coding of the video records.

Figure 1. Schematic Diagram of Testing Room and Apparatus.



E= Experimenter
P= Partition

In the adjacent observation room, a second experimenter (E2) viewed the procedure through a one-way mirror and operated the video equipment and a button box which was connected to a Personal computer. A custom-designed computer program calculated the duration of the FAM and test phases. E1 pressed on a foot pedal to indicate the beginning of each phase and wore earphones through which she heard tones originating from the computer indicating the termination of each phase and the termination of each inter-phase interval.

Design and Experimental Stimuli

The design of the study was a 2 (Condition) x 2 (Group) x 2 (Sex) x 2 (Order) x 3 (Phase) mixed model with four between factors of Condition (touch-no-vision, touch-plus-vision), Group (experimental, control), Sex (male, female), and Order (smooth-rough, rough-smooth) and one within factor of Phase (FAM, Test 1, Test 2). The design of the study is illustrated in Table 1. Subjects were randomly assigned to touch-no-vision and touch-plus-vision conditions and to experimental and control groups.

Infants in the touch-no-vision condition could handle the stimuli but were not able to see the stimuli while infants in the touch-plus-vision condition could see and handle the stimuli. After the initial FAM phase, during which infants in both experimental and control groups were required to obtain 30 seconds of tactile contact with the

Table 1

Design of Study

CONDITION	STIMULUS ORDER					
	SMOOTH-ROUGH			ROUGH-SMOOTH		
	FAM. (30s)	TEST 1 (30s)	TEST 2 (30s)	FAM. (30s)	TEST 1 (30s)	Test 2 (30s)
Touch-no-vision						
Experimental (n=12) males=6 females=6	Smooth	Rough	Smooth	Rough	Smooth	Rough
Control (n=12) males=6 females=6	Smooth	Smooth	Smooth	Rough	Rough	Rough
Touch-plus-vision						
Experimental (n=12) males=6 females=6	Smooth	Rough	Smooth	Rough	Smooth	Rough
Control (n=12) males=6 females=6	Smooth	Smooth	Smooth	Rough	Rough	Rough

stimulus, two test phases of a fixed 30 seconds duration followed. The experimental group received a novel stimulus in Test 1, while in Test 2 the original familiarization stimulus was presented a second time. The control group received the familiarization stimulus in both test phases. The order of presentation of the stimuli within each group was counterbalanced. That is, half the infants in the experimental group received the smooth stimulus in the FAM phase, the rough stimulus in Test 1, and the smooth stimulus again in Test 2, while the other half of the experimental group received the rough stimulus in the FAM phase, the smooth stimulus in Test 1, and the rough stimulus again in Test 2. Similarly, half the infants in the control group received the smooth stimulus in all three phases, while the other half received the rough stimulus in all three phases.

The selection of the texture stimuli employed in this study were based on the results of a pilot study, conducted before the commencement of the present study, where adults rated a number of textures. Twenty blindfolded adults were asked to sort twelve different textures on the dimension of smooth to rough. Kendall's coefficient of concordance was calculated to be 0.84 indicating a high degree of agreement among subjects on the rank order positions attributed to the textures. Tukey's pairwise comparisons were then performed on the mean ranking for each texture (range from 1 to 12, indicating smoothest to roughest respectively) which was calculated across all twenty subjects. The two textures that yielded the greatest significant difference in mean ranking were selected as the smooth and rough stimuli for the present study.

The smooth and rough texture stimuli consisted of cotton flannel material and carpet lining, respectively, and were identical in color (white). The textures were each presented on cylindrical, wooden T-shaped poles of identical dimensions, thus controlling for differences in shape, size, and hardness. In addition, minimal differences in weight were controlled for by having the experimenter hold the stimuli by the edge of the vertical component of the pole when presenting the stimuli to the infants. The textured material for each of the smooth and rough stimuli was wrapped around each component of the T-shaped wooden pole so that it was completely covered. The horizontal component of the T consisted of a wooden cylinder of 7 cm in length and 3 cm in diameter, while the vertical component of the T consisted of a wooden pole of 24 cm in length and 2.5 cm in diameter. Both texture stimuli were thus identical in color, size, shape, hardness and weight. The stimuli, therefore, were controlled for a number of possible confounding stimulus properties by being identical on all but the texture dimensions.

Procedure

Caregivers and infants were greeted and escorted into a waiting room. E1 reviewed the procedure with the caregivers who were then asked to read and sign a consent form (Appendix B). Once in the testing room the infant was placed in the high chair and the caregiver was given the option of remaining seated, while silent, behind their infant during the testing or observing their baby on the video monitor in the control room where E2 was operating the video equipment. E1 attached the cover around the infant's neck while E2 set up the computer program. E2 then entered the observation room with or without the caregiver, turned on the video equipment and knocked on the observation window to indicate to E1 that she could proceed with the testing.

E1 remained still-faced and silent and made no eye contact with the infant throughout the testing. She pressed on the foot pedal to indicate the beginning of the FAM phase and presented the familiarization stimulus initially to the infant's right hand underneath the cover. If the right hand was inaccessible, only then was the stimulus initially presented to the infant's left hand. Throughout each phase E1 alternated presentation of the stimulus to each hand only if the infant let go of the stimulus. During the FAM phase, E2 pressed a button on the button box every time the infant's hand was in contact with the stimulus for the entire duration of the contact. The computer registered the duration of each button box press and once 30 seconds of tactile contact were accumulated, the computer signalled to E1, via a tone to the earphones, to remove the stimulus. Four seconds later E1 heard another tone indicating that the inter-phase interval was over and to proceed with Test 1. E1 indicated the beginning of each of the test phases by a press on the foot pedal. Both test phases were programmed to be 30 seconds in duration and at the end of each test phase a tone was once again heard by E1. A four second inter-phase interval also separated the two test phases. After the final tone indicating that Test 2 was complete, E1 waited 4 seconds before interacting with and then removing the infant from the cover and high chair.

At the end of the testing session, caregivers and infants were again escorted into the waiting room, by both E1 and E2, and demographic data was collected (Appendix C). Caregivers were then thanked for their participation and infants were awarded an Infant Scientist Certificate. All participants were informed that they would be mailed a report of the general findings of the study once completed. Finally, any infant who was distressed for over 20 seconds during the testing was eliminated from the analyses.

Dependent Measures

The coding of each video record was conducted using a frame by frame analysis. The onset and offset times of each behavior were recorded using the shuttle function of the variable speed remote. During coding the volume on the video monitor was turned off in order to ensure unbiased coding by reducing any interfering contextual cues. The video records were viewed three times during coding; once to code total tactile contact, (i.e., stimulus touch and active manipulation) and bimanual manipulation, once to code exploratory strategies, and finally once more to code attention.

Briefly defined, total tactile contact consisted of two behaviors: stimulus touch, and active tactile manipulation. Stimulus touch was coded when the stimulus touched the infant's hand. Active tactile manipulation consisted of the sum of grasping and touching. Grasping was coded when the infant's fingers and/or thumb surrounded the stimulus. Touching was coded when the infant initiated and made active contact with the stimulus but did not grasp. Bimanual manipulation was coded whenever infants actively manipulated with both hands. The two exploratory strategies coded were fingering and scrumbling. Fingering was coded when the infant was running one or more fingers over the surface of the stimulus, while scrumbling was coded when the infant was alternately flexing and/or extending the fingers in a repetitive manner on the stimulus. Finally, total attention was coded and consisted of search experimenter and fixation toward stimulus. Search experimenter was coded when the infant was looking at E1's upper torso and surrounding facial area. Fixation toward stimulus (to be referred to as fixation) in the touch-plus-vision condition was coded when the infant was looking directly at the stimulus, while in the touch-no- vision condition it was coded when the infant was looking in the direction of the stimulus. Since the measures of search experimenter and fixation are inversely related only fixation was analyzed. Detailed descriptions of the dependent variables and how they were coded are found in Appendix D.

Observers were trained on videotape examples prior to scoring the present data until they achieved high reliability with experienced raters. An independent rater, blind to the hypotheses of the study coded 30 % of the records upon completion of coding to assess inter-rater reliability. Intraclass reliability coefficients (Shrout & Fleiss, 1979) ranged from r= .93 to r= .99 (total tactile contact= .97; active manipulation= .99; fingering= .93; scrumbling= .99; bimanual contact= .99; total attention= .95; fixation= .98).

<u>Data Reduction</u>

Once coding was completed the raw data for each measure was reduced to obtain the percent duration of each behavior in each phase. Statistical analyses were conducted only on the percent durations of each behavior that occurred within the phases and not during the inter-phase intervals.

Total Tactile Contact. The duration of total tactile contact in the FAM phase was calculated as the sum of stimulus touch, grasping and touching, but was not analyzed since it was held constant, at 30 seconds, for all infants. The percent duration of total tactile contact in each test phase was obtained by dividing the duration of total tactile contact by the test phase trial length and multiplying the result by 100.

Active Tactile Manipulation. The percent duration of active manipulation was calculated in two ways for each of the two test phases. The first method of calculation was aimed at ascertaining the percentage of time spent in active manipulation relative to the entire length of each test phase to examine between group and between infant differences. Thus, the percent duration of active manipulation by this method was obtained by dividing the duration of active manipulation by the length of the test phase and multiplying the result by 100. The second method of calculation was aimed at obtaining the percent duration of active manipulation relative to each infant's total tactile contact in order to examine within-infant differences across phase. Thus, by this method, the percent duration of active manipulation for each of the two test phases was obtained by dividing the duration of active manipulation by each infant's individual duration of total tactile contact and multiplying the result by 100.

The amount of time spent in active manipulation in the FAM phase was, however, calculated in the same way for both methods of analysis since the FAM criterion was set at 30 seconds. That is, the percent duration of active manipulation in the FAM phase always consisted of the duration of active manipulation divided by each infant's amount of total tactile contact.

Exploratory Strategies. The percent durations of fingering and scrumbling were calculated in the same manner. The mean percent duration of each of these behaviors in the FAM phase was calculated by dividing the duration of each behavior by the amount of total tactile contact obtained and multiplying the result by 100. For each of the test phases, the percent durations were calculated by dividing the duration of each behavior by the length of each test phase and multiplying the result by 100.

Total Attention and Fixation. The mean percent durations of total attention and fixation were calculated in the same manner for all three phases. Percent durations of these measures in each phase were calculated by dividing the total durations of each behavior by the length of each phase and multiplying the result by 100.

Results

The design was a 2 x 2 x 2 x 2 x 3 mixed between-within. The between variables were Condition (touch-no-vision, touch-plus-vision), Group (experimental, control), Sex of infant (male, female), and Order of stimulus presentation (smooth, rough). The within variable was Phase with three levels (FAM, Test 1, Test 2). There were two major categories of dependent measures: tactile contact and visual attention. Analyses on the tactile contact measures of total tactile cor⁺act, active tactile manipulation, fingering, scrumbling, and bimanual tactile manipulation, will be presented first. Analyses on measures of visual attention including total attention, and fixation will follow. Descriptive statistics were conducted on each dependent variable first to observe the distribution of the data and determine skewness and levels of kurtosis, as well as the number of significant outliers. Transformations on the data were not required.

Following the descriptive analyses, repeated measures analyses of variance (ANOVA), and analyses of Covariance (ANCOVA) with four between variables and one within variable were used to analyze the data, using the BMDP statistical package (Dixon, Brown, Engelman, & Jennings, 1990). ANCOVAs for mixed between-within designs were conducted on measures of tactile contact whenever simple effects analyses on overall ANOVA results revealed differences between the experimental and control groups during the FAM phase. ANCOVAs were conducted to adjust the means in the two test phases while controlling for initial differences in the FAM phase (Tabachnick & Fidell, 1989). Any potential Sex or Order effects or interactions were tested for each variable, using Sex and Order as between variables. If no Sex or Order main effects or interactions were obtained, these variables were collapsed and a 2 x 2 x 3 between-within ANOVA and/or ANCOVA was conducted with the between factors of Group (experimental, control) and Condition (touch-no-vision, touch-plus-vision) and one within factor of Phase (FAM, Test 1, Test 2).

If an interaction was significant, planned a priori simple effects analyses, followed by Tukey HSD comparisons or Bryant-Paulson comparisons where relevant (for ANOVA and ANCOVA analyses, respectively) were conducted to isolate the source of effects contributing to the interaction (Keppel, 1982; Tabachnick & Fidell, 1989; Stevens, 1990). These findings are summarized in tables located in the appropriate appendix for each dependent variable. A critical alpha level of 0.05 was chosen as the criterion for statistical significance, and the more conservative Greenhouse-Geisser Adjusted F-score was used to assess significance. Only significant findings will be reproduced in the text. Non-significant results can be found in the ANOVA and/or ANCOVA summary tables for each variable, in Appendices E to L.

Tactile Contact Measures

Infants required a mean of 36.02 seconds (sd = 3.73 seconds) to reach the tactile contact familiarization criterion of 30 seconds. Although the duration of each of the test phases was programmed to be 30 seconds, some infants' firm grasp of the stimuli made it difficult to remove them when the tone was heard and thus resulted in longer exposure time to the stimuli. In addition, E1's reaction time to remove the stimuli, once the tone was heard, may have had the same effect. Thus, the actual time of the test phases was calculated on the basis of the video tape records. The actual mean length of Test 1 was 31. 98 seconds (sd = 1.32 seconds) and that of Test 2 was 31.79 seconds (sd = 0.94 seconds).

Total tactile contact

The FAM phase was not included in the repeated measures ANOVA for total tactile contact since the amount of tactile contact in this phase was set at 30 sèconds and thus, did not vary across infants. The ANOVA on test phases 1 and 2 revealed a significant Phase main effect $F(1, 46) = 5.96$, $p < .05$ and a Phase by Condition interaction, $F(1, 44) = 9.11$, $p < .0001$, (Appendix E, Table 1). A subsequent simple effects analysis holding Phase constant revealed no differences between Conditions in Test 1 $F(1, 46) = 0.50$, $p > .05$, however, in Test 2 infants in the touch-plus-vision condition (M = 85.97%) engaged in significantly greater amounts of tactile contact than infants in the touch-no-vision condition (M = 73.16%), $F(1, 46) = 5.81$, $p < .05$. This finding is illustrated in Figure 2.

Active Tactile Manipulation

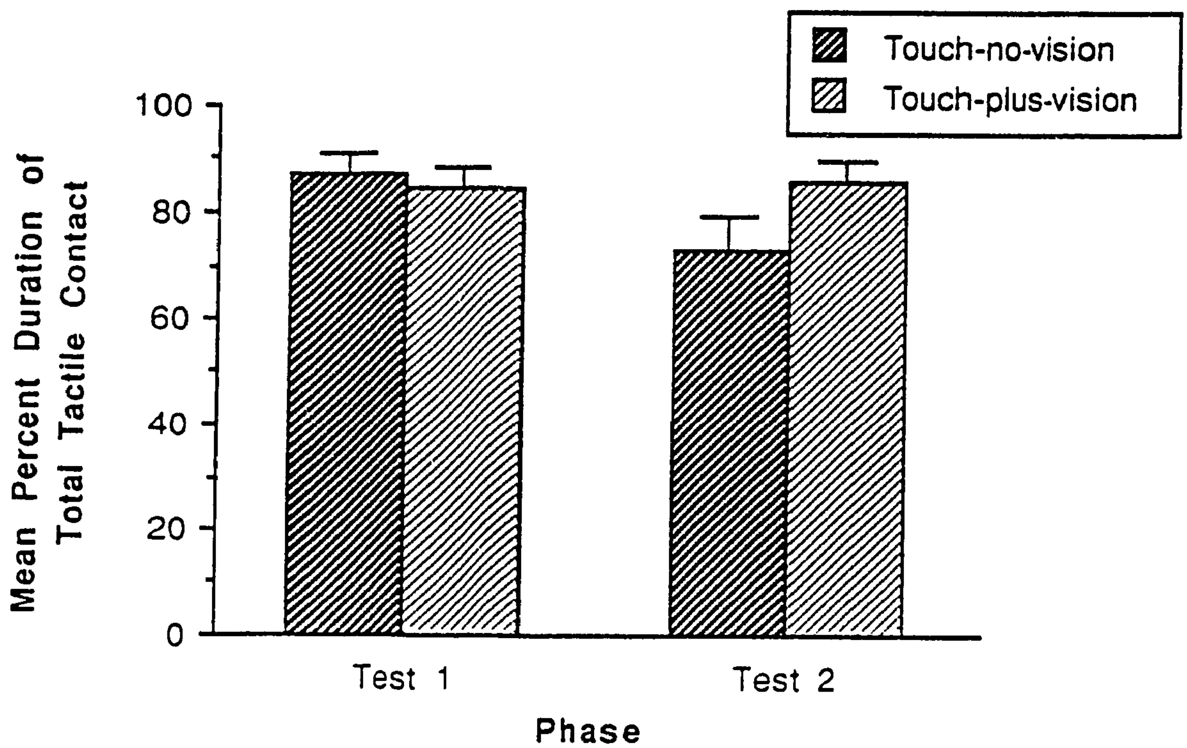
The measure of active tactile manipulation (the sum of grasping and touching) was calculated and analyzed in two ways: (1) as a function of phase length; (2) relative to each infant's own level of total tactile contact during each phase. The analyses of active tactile manipulation calculated as a function of phase length will be presented first, followed by the analyses of active tactile manipulation calculated relative to individual levels of total tactile contact.

Active Tactile Manipulation Relative to Phase Length

A significant Phase main effect $F(2, 88) = 25.81$, $p < 0.001$, Condition by Phase $F(2, 88) = 4.22$, $p < .05$, and Group by Phase interactions were obtained by an ANOVA $F(1,46) = 4.06$, $p < .05$, (Appendix F, Table 1). A subsequent simple effects analysis on the Group by Phase interaction (Appendix F, Table 2), holding Phase constant, revealed that the experimental (M = 84.47) and control (M = 91.71) groups differed in the percentage of time spent in active manipulation during the FAM phase $F(1, 46) = 4.06$, $p < .05$. Thus, an ANCOVA was conducted on the two test phases.

The ANCOVA revealed a marginally significant Group main

Figure 2. Mean percent duration of total tactile contact as a function of Condition (Touch-no-vision, Touch-plus-vision) and Phase (Test 1, Test 2). Standard errors are shown by vertical bars.

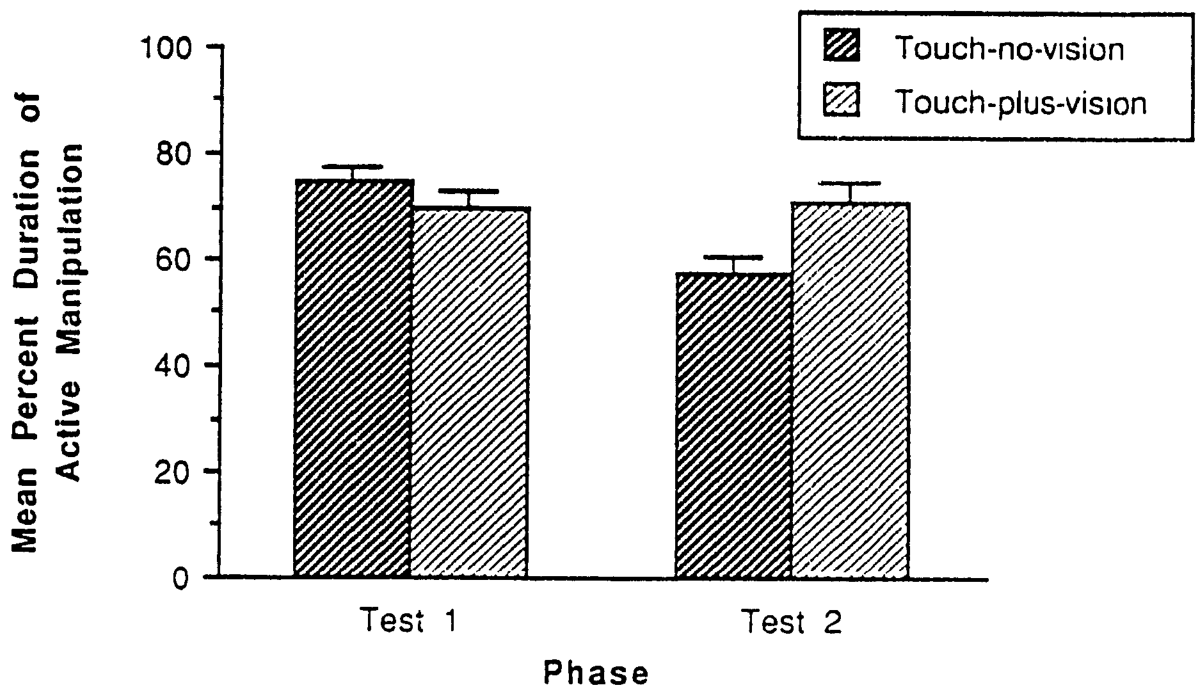


Touch-no-vision
Touch-plus-vision
Mean Percent Duration of Total Tactile Contact
100
80
60
40
20
0
Test 1
Test 2
Phase

effect $F(1, 43) = 3.54$, $p < .10$, a significant Phase main effect $F(1. 44) = 7.13$, $p < .05$, and a significant Phase by Condition interaction $F(1, 44) = 9.16$, $p < .01$, (Appendix F, Table 2). Experimental infants engaged in more active manipulation ($M = 74.00$) across both test phases than control infants ($M = 62.10$), and the percent duration of active manipulation decreased for both groups in Test 2 ($M = 63.97$) relative to Test 1 ($M = 72.19$). As illustrated in Figure 3, the Phase by Condition interaction revealed that infants in the touch-plus-vision condition maintained their levels of active manipulation across both test phases ($M = 69.72$ and $M = 70.82$ for Test 1 and Test 2 respectively) relative to infants in the touch-no-vision condition, who displayed a sharp decrease in active manipulation over the two test phases ($M = 74.65$ and $M = 57.13$, for Test 1 and Test 2, respectively; Appendix F, Table 3). Bryant-Paulson comparisons revealed a significant difference between infants in the two conditions only during Test 2, $BP(40) = 3.8$, $p < .05$.

Active Manipulation Relative to Individual Levels of Total Tactile Contact. A significant Group by Phase interaction was obtained by an ANOVA $F(2, 88) = 5.58$, $p < .05$, (Appendix G, Table 1) and a subsequent simple effects analysis, holding Phase constant, revealed that the experimental ($M = 84.47$) and control ($M = 91.71$) groups differed in the percentage of time spent in active

Figure 3. Mean percent duration of active manipulation, relative to phase length, as a function of Condition (Touch-no-vision, Touch-plus-vision) and Phase (Test 1, Test 2). Standard errors are shown by vertical bars.

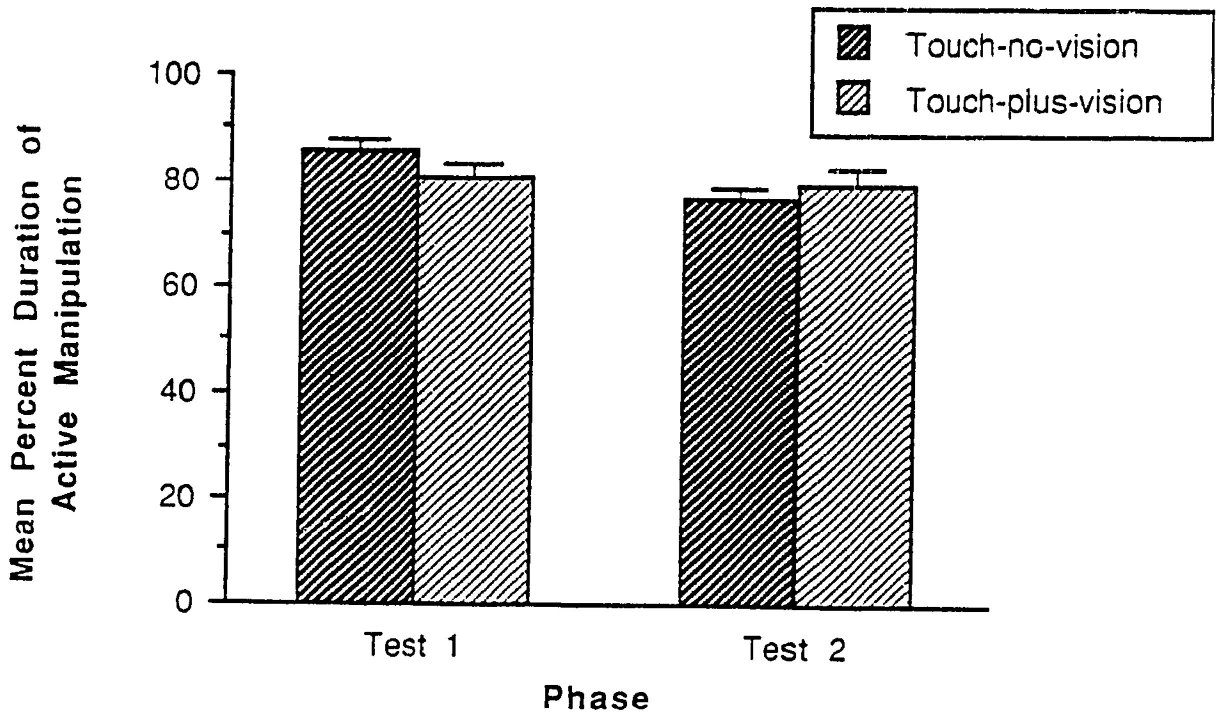

Mean Percent Duration of Active Manipulation
100
80
60
40
20
0
Touch-no-vision
Touch-plus-vision
Test 1
Test 2
Phase

manipulation in the FAM phase, $F(1,46) = 4.06$, $p < .05$. Thus, an ANCOVA was then conducted on this measure. The ANCOVA revealed a significant main effect of Phase $F(1, 32) = 6.68$, $p < .05$, a significant Phase by Condition interaction $F(1, 32) = 3.07$, $p < .10$, a significant Sex by Group by Phase interaction $F(1, 32) = 5.30$, $p < .05$, as well as a significant Order by Group by Phase interaction $F(1, 32) = 9.33$, $p < .01$ (Appendix G, Table 2).

The Phase main effect indicated that the percentage of time spent in active manipulation decreased over the two test phases (M's = 83.16 and 77.91 for Test 1 and Test 2, respectively). The Condition by Phase interaction indicated that while infants in the touch-plus-vision condition showed sustained levels of active manipulation over the two test phases (M = 80.82 and M = 79.13 for Test 1 and Test 2, respectively) infants in the touch-no-vision condition displayed a sharp decline in active manipulation in Test 2 relative to Test 1 (M = 85.49 and M = 76.68 for Test 1 and Test 2, respectively). This finding is illustrated in Figure 4.

The Sex by Group by Phase interaction revealed that male experimental infants displayed more active manipulation (M = 88.61) than male control infants in Test 1 (M = 79.57), but approximately equal levels of active manipulation in Test 2 (M = 79.46) relative to their control counterparts (M = 76.40). Female experimental infants displayed sustained

Figure 4. Mean percent duration of active manipulation, relative to individual infants' levels of total tactile contact, as a function of Condition (Touch-no-vision, Touch-plus-vision) and Phase (Test 1, Test 2). Standard errors are shown by vertical bars.

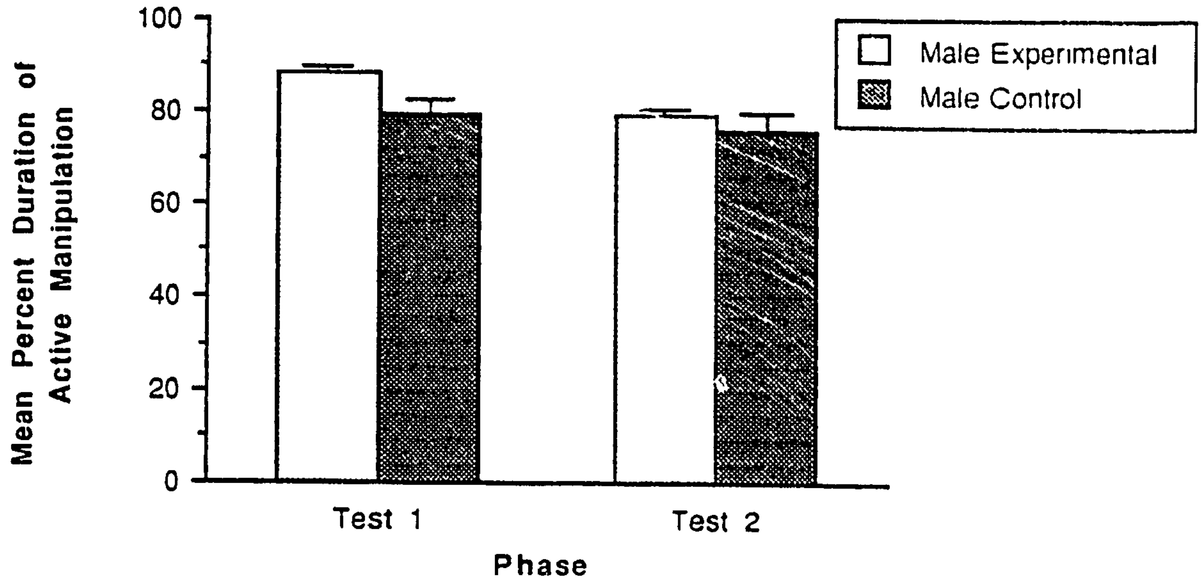

Touch-no-vision
Touch-plus-vision
100
80
60
40
20
0
Mean Percent Duration of Active Manipulation
Test 1
Test 2
Phase

levels of active manipulation across the two test phases (M's = 84.31, 86.34 for Test 1 and Test 2, respectively) and, unlike male experimental infants, similar levels as female controls during Test 1 (M = 80.13). However, female experimental infants engaged in significantly higher levels of active manipulation relative to female control infants in Test 2 (M's = 86.34 and 69.44 for female experimentals and female controls respectively). These findings are illustrated in Figure 5.

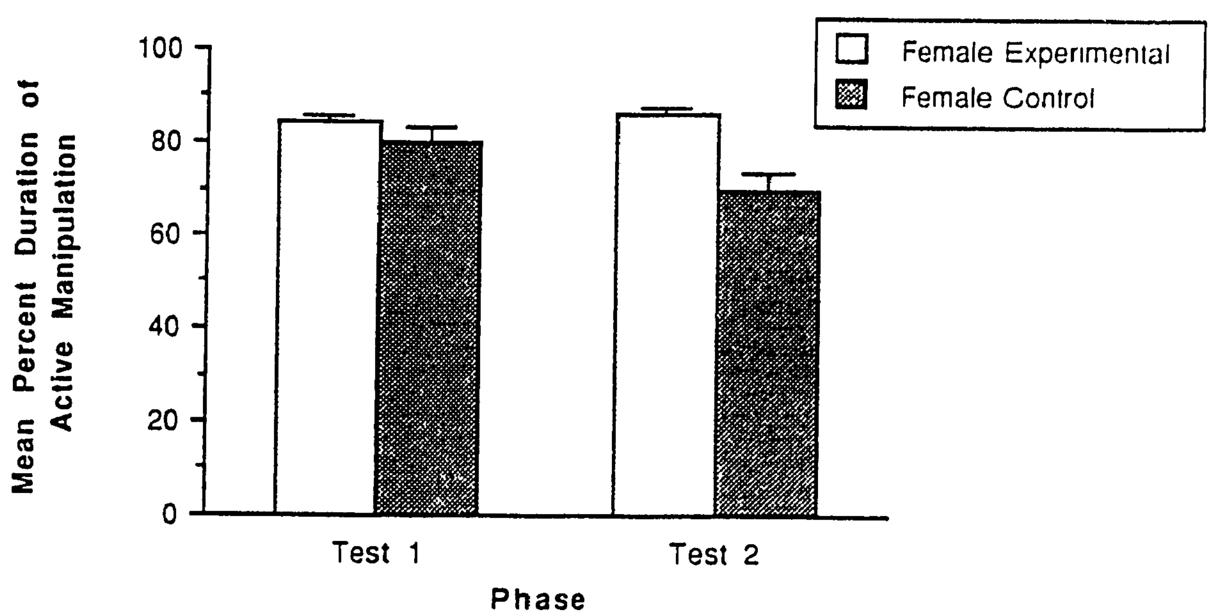
The Order by Group by Phase interaction revealed that for the first order, when experimental infants received the stimuli in the order of smooth, rough, smooth, while controls received the smooth stimulus in all three phases, experimental infants differed from controls only in Test 1 (M = 84.83 and M = 70.90) when they received the rough stimulus. There was no difference between experimental and control infants' active manipulation of the smooth stimulus in Test 2 (M = 75.75, and M = 70.84 for experimentals and controls respectively). However, in Order 2, in which the experimental infants received the stimuli in the order of rough, smooth, rough and the controls received the rough stimulus in all three phases, the experimental and control infants showed similar levels of active manipulation in Test 1 (M = 88.08 and M = 88.80 for experimental and control infants respectively). Experimental infants, however, showed sustained higher levels of active manipulation in

Figure 5. Mean percent duration of active manipulation, relative to individual levels of total tactile contact, as a function of Group (Experimental, Control) and Phase (Test 1, Test 2) for a) males and b) females. Standard errors are shown by vertical bars.

a. Males



b. Females



Test 2 (M = 90.05) than control infants (M = 74.99). These findings are illustrated in Figure 6.

Fingering

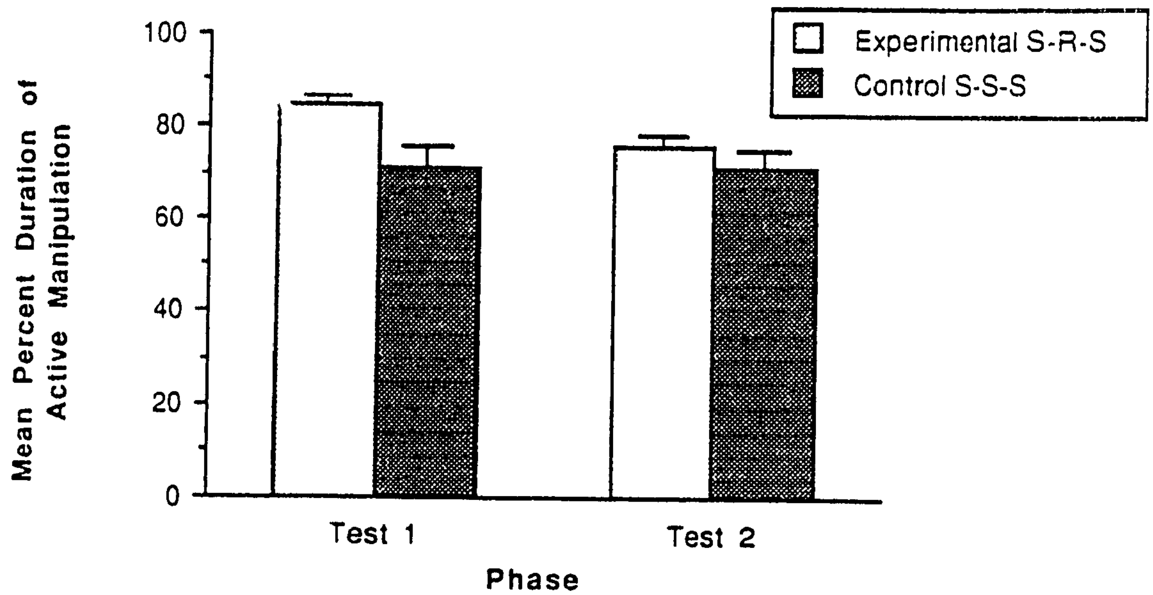
The ANOVA conducted on the percentage of time infants spent fingering the stimuli revealed a Phase main effect, $F(2,88) = 10.84$, $p < .001$ (Appendix H, Table 1). Mean percentages of fingering in FAM, Test 1 and Test 2 were 6.07, 4.69, and 3.02, respectively. Tukey's comparisons revealed that the percentage of fingering in the FAM phase was significantly greater than that displayed in Test 2 (Appendix H, Table 2). No other effects were significant.

Scrumbling

The ANOVA on mean percent duration of scrumbling revealed a Group by Condition interaction, $F(1,44) = 5.43$, $p < .05$ (Appendix I, Table 1). Simple effects analyses revealed that the experimental infants in the touch-no-vision condition displayed a significantly greater amount of scrumbling (M = 6.11) than control infants in the same condition (M = 0.484), $F(1,44) = 4.39$, $p < .05$. However, experimental infants in the touch-plus-vision condition displayed approximately the same amount of scrumbling (M = 0.57) as control infants in the touch-plus-vision condition (M = 2.47). These findings are illustrated in Figure 7.

Figure 6. Mean percent duration of active manipulation, relative to individual levels of total tactile contact, as a function of Group (Experimental, Control) and Phase (Test 1, Test 2) for a) Order 1: Smooth-Rough and b) Order 2: Rough-Smooth. Standard errors are shown by vertical bars.

a. Order 1: Smooth-Rough



b. Order 2: Rough-Smooth

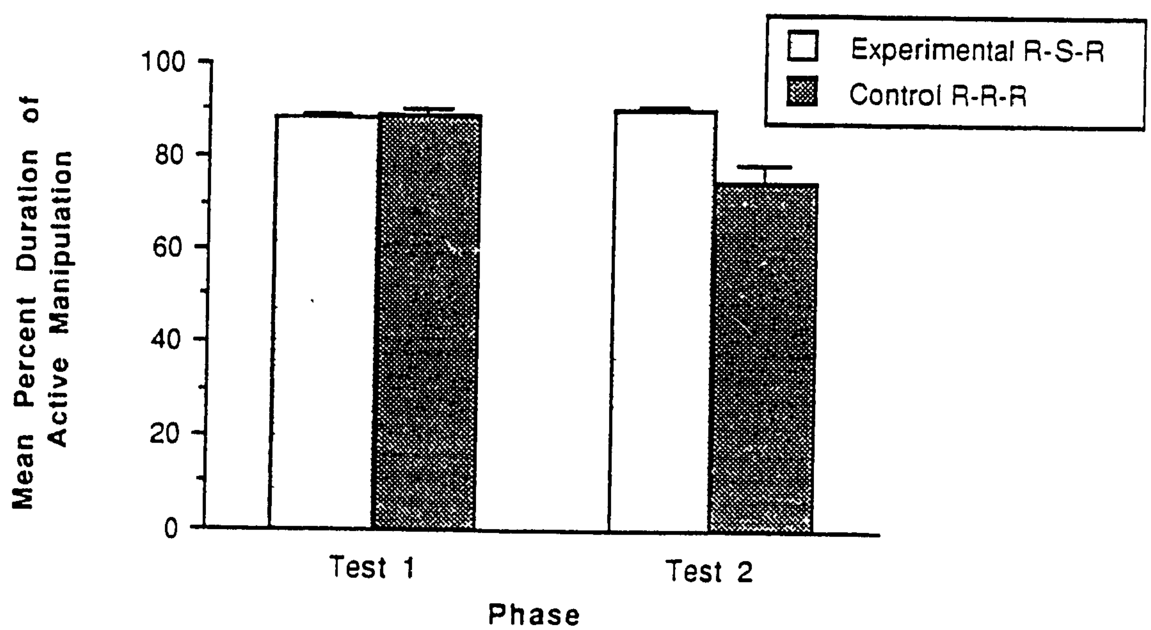
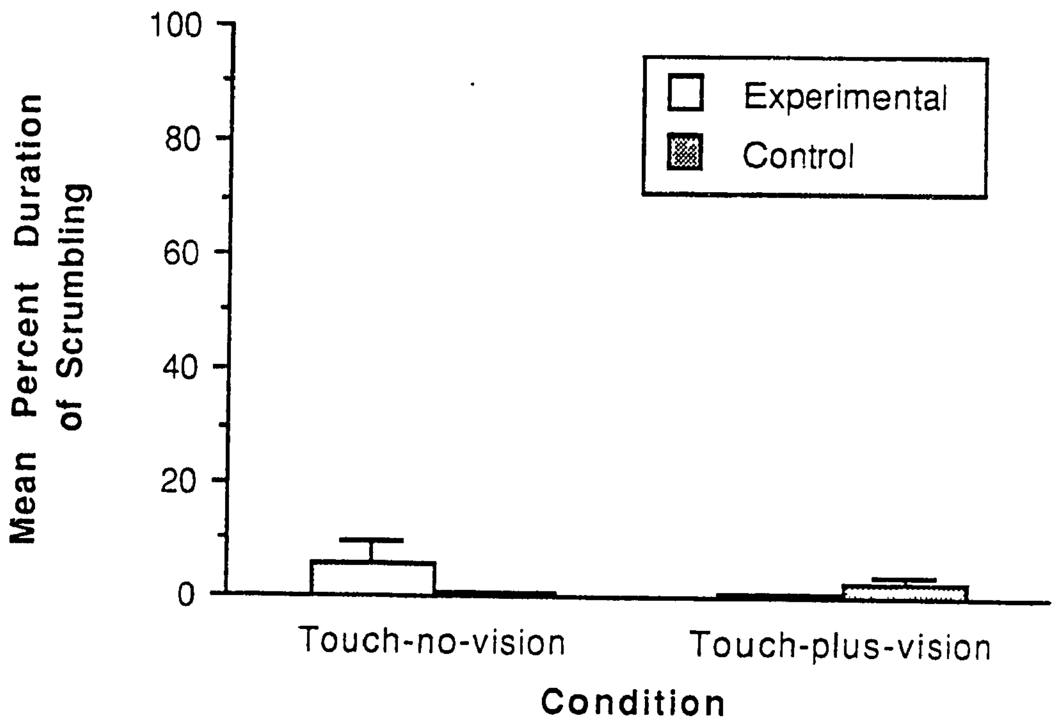


Figure 7. Mean percent duration of scrumbling as a function of Condition (Touch-no-vision, Touch-plus-vision) and Group (Experimental, Control). Standard errors are shown by vertical bars.



100
80
60
40
20
0
Mean Percent Duration of Scrumbling
Experimental
Control
Touch-no-vision
Touch-plus-vision
Condition

Percent Duration of Bimanual Manipulation

The ANOVA on the percent duration of bimanual exploration revealed a main effect of Condition, $F(1,44) = 4.52$, $p < .05$ (Appendix J, Table 1). Infants in the touch-plus-vision condition manipulated the stimuli with both hands for significantly longer amounts of time ($M = 14.92$) than infants in the touch-no-vision condition ($M = 4.62$).

Attention Measures

Total Attention

A two way ANOVA revealed a Condition main effect, $F(1,44) = 6.89$, $p < .05$ and a Phase main effect, $F(2,88) = 8.38$, $p < .001$ (Appendix K, Table 1). Infants in the touch-plus-vision condition attended more ($M = 69.70$) than infants in the touch-no-vision condition ($M = 60.50$). Infants' total attention also declined across phases (M's = 71.64, 64.95 and 58.71 for FAM, Test 1 and Test 2, respectively). A subsequent Tukey's comparison (Appendix K, Table 2) revealed that total attention in the FAM phase was significantly greater than in Test 2.

Fixation

An ANOVA conducted on the percent duration of fixation revealed only a Condition main effect, $F(1,44) = 83.48$, $p < .001$ (Appendix L, Table 1). Infants in the touch-plus-vision condition fixated the stimulus significantly more ($M = 47.50$) than infants in the touch-no-vision condition ($M = 13.09$).

Discussion

In general, the results of the present study indicate that 7-month-old infants manipulate and attend to both visible and invisible texture stimuli. The first and second hypotheses on texture discrimination abilities in Test 1 and Test 2, respectively, were supported only on the individually-based measure of active manipulation. That is, experimental infants responded to novel textures with significantly higher and sustained levels of active manipulation relative to control infants. The third hypothesis, on the guiding role for vision on bimanual haptic exploration and fixation was fully supported. Infants in the touch-plus-vision condition displayed greater levels of bimanual exploration of, and higher levels of fixation toward the texture stimuli, relative to infants in the touch-no-vision condition. The specific prediction that exploratory strategies, fingering and scrumbling, would be more pronounced when the stimuli were not visible was supported only for scrumbling.

The results of the present study are intriguing given the stringent controls employed. The stimuli selected differed only in the stimulus property of texture, thus, the typical methodological limitation of the presence of confounding stimulus properties found in past studies was eliminated. The visual similarity of the stimuli also controlled for the possibility of visual cues providing additional information about the stimuli. Controlling for these potential confounds ultimately permitted a more accurate assessment of infants' haptic perception of texture. Finally, typical limitations found in past research such as individual differences in infants' willingness or abilities to manipulate and explore as well as unequal experience with the stimuli were controlled for by ensuring that all infants received an equal amount of tactile familiarization with the stimuli.

The results for texture discrimination in each test phase will be discussed first, and will be followed by a discussion of the results for the role for vision in haptic perception. The implications of the results for infant haptic perception and cognitive development will be presented within each section.

Evidence for Texture Discrimination: Response to Novelty

The hypothesis that texture discrimination abilities would be reflected in all tactile contact and attention measures was only partially supported. That is, texture discrimination abilities were observed only with the individually-based measure of active manipulation. Both indices of active manipulation, however, revealed high levels of responding across phases indicating that the texture stimuli, whether visible or not, were tactually engaging. In addition, the relatively greater levels of active manipulation, as compared to those of finer exploratory strategies, suggests that 7-month-old infants' haptic exploration of objects, at least those in the form of the present stimuli, consists primarily of grasping and forms of touching that include patting, stroking, and hitting. Thus, haptic exploration at this age consists primarily of grosser hand movements, rather than of finer movements of the fingers such as those involved in fingering and scrumbling.

The expected pattern of results for Test 1 was observed, however, only on the individually-based measure of active manipulation; that is, when active manipulation was calculated relative to each infant's amount of total tactile contact with the stimulus. This finding supports the use of behavioral measures designed to account for, or control for, inter-individual differences in infants' tendencies to manipulate. The importance of addressing individual differences has been consistently demonstrated in past literature. Individual differences in infant responding have been found to be reliable and stable and have been linked to differential cognitive performance (Colombo, Mitchell, Goldron & Freeseman, 1991).

Interestingly the expected pattern of greater levels of active manipulation, calculated relative to individual levels of total tactile contact, among experimental infants relative to controls during Test 1 was obtained only among the male infants. The higher level of responding to the novel stimulus by male experimental infants relative to male controls, in Test 1, suggests that they discriminated between the FAM texture and the novel texture in Test 1.

In contrast, response to novelty was not as evident in Test 1 among female experimental infants. Female experimental and control infants displayed similarly high levels of active manipulation during Test 1. This response pattern among female infants is inconsistent with past findings of increased responding to novel stimuli relative to familiar ones (Bushnell, Shaw & Strauss, 1985; Ruff, 1976). The high levels of active manipulation displayed by female controls in Test 1 suggests that the texture experienced in the FAM phase remained equally interesting in Test 1. This finding does not, however, negate the possibility that the experimental females, like the experimental males, discriminated between the textures presented in FAM and Test 1.

This possibility is further substantiated by the high and sustained levels of active manipulation displayed by female infants during Test 2, relative to the female controls. In Test 2, the female experimental infants demonstrated a response to the novel texture. Thus, if they discriminated between the textures presented in Test 1 and Test 2, as indicated by the response to novelty at Test 2, then they should have been able to perceive the novelty of the texture presented in Test 1.

Thus, support, as reflected in the responses to novel textures, exists for texture discrimination at 7 months of age. However, the difference in the test phase in which this ability was reflected for males and female experimental infants is due to the different response patterns of the male and female control groups. Female control infants maintained high levels of active manipulation during Test 1, and displayed a sharp decline only during Test 2. Male controls, in contrast, displayed an earlier decline (in Test 1), however, maintained similar levels of active manipulation across the two test phases. The difference between the two control groups in Test 1 suggests that male infants required less time to become familiar with the repeated texture. This, however, is inconsistent with past literature on sex differences. Typically, when sex differences have been found, female infants have been found to be the faster processors. For example, sex differences have been documented by Baillargeon and DeVos (1991) in the area of object permanence. Four-month-old female infants demonstrated more reliable indications of object permanence relative to male infants.

An alternative explanation, is suggested, however, by the sustained levels of active manipulation among male control infants across the two test phases, relative to the sharp decline in Test 2 among female control infants. Female and male infants may differ in their patterns of exploration. That is, females may be more thorough explorers of texture stimuli, and be capable of actively manipulating at high and sustained levels, however, cease to do so quickly once familiar with objects. Males, in contrast, appear to actively manipulate at more moderate levels, however, do so over a longer period. This interpretation is, however, speculative. Further replication of these findings with a larger sample is warranted in order to support the reliability of the findings and for stronger interpretations of potential sex differences to be justified.

Evidence for Texture Discrimination: Recognition Memory

The evidence for recognition memory in Test 2 is not as strong as for texture discrimination abilities. Contrary to the expected recovery of manipulation to the original texture during Test 2, male experimental infants displayed reduced levels of active manipulation in Test 2, relative to Test 1, and did not differ from male controls in Test 2. There are a number of interpretations for the equal levels of active manipulation between male experimentals and male controls during Test 2. First, it is possible that male experimental infants did not process the texture differences between the two textures in Test 1 and Test 2. This is, however, unlikely given that they seem to have discriminated the textures between FAM and Test 1. The stronger possibility is that they processed the difference between

Test 1 and Test 2, however, they immediately recognized the stimulus in Test 2 as being the same stimulus from the FAM phase. Thus, their recovery of active manipulation at Test 2 may have been too short to be detected with the measures used (i.e., the measure of percent duration of active manipulation calculated over the entire 30 seconds duration of Test 2).

Evidence for recognition memory among the female experimentals was not obtained. Although female experimentals engaged in significantly greater levels of active manipulation relative to female controls during Test 2, they did not display a decrease in responding in Test 2 relative to Test 1. The sustained high levels of active manipulation in Test 2, relative to female control infants, suggest only that the difference in texture between Test 1 and Test 2 was perceived. It does not indicate recognition of the texture in Test 2 as being that presented during the FAM phase.

Overall, the pattern of results obtained with the individually-based measure of active manipulation, suggests that both sexes appear capable of making texture discriminations by 7 months of age. The indications of texture discrimination abilities imply that 7-month-old infants are capable of haptically processing texture. However, the results do not clearly reflect recognition memory at this age for haptically perceived textures.

These infant haptic perception and discrimination abilities are impressive given the relatively stringent controls, over confounding stimulus properties, employed in the present study relative to past studies. It is also relevant to note that the infants in this study were at the age when these abilities are only just emerging (Bushnell & Boudreau, 1991). Thus, the possibility exists that some infants in the current sample did not yet possess the ability to haptically discriminate textures, and thus may have depressed the change scores across test phases. Finally, the familiarization time allotted may not have been sufficient for full processing and familiarity with each texture and, in turn, for the creation of strong memory representations for the textures presented during the FAM phase. This is again not surprising given the lack of any additional stimulus cues, either tactile or visual, that typically facilitate processing. In future studies the use of longer familiarization times may reveal stronger patterns of experimental and control group differences in the test phases and clearer patterns of processing that are more consistent with the expected patterns of response to novelty and response recovery. In addition, the use of individual, multiple test trials, that are of shorter duration than the test phases employed in the present study, may prove more effective in detecting and distinguishing between responses to novelty and decrements in responding. The use of shorter, multiple test trials, rather than longer test phases, may also aid in identifying and clarifying the nature of any differences in patterns of processing between male and female infants.

An additional, interesting pattern of active manipulation between groups was obtained as a function of the order of the texture presented at each phase. Levels of active manipulation across phases differed as a function of Group and Order of stimulus presentation. Experimental infants in both orders of stimulus presentation displayed high levels of active manipulation in Test 1, indicating that both the smooth and the rough stimuli, when novel, were engaging. However, the two control groups differed in Test 1. The control group that received the rough stimulus in Test 1 displayed higher levels of active manipulation relative to control infants who received the smooth stimulus in Test 1. This finding suggests that while the rough stimulus continued to be engaging for the rough control group, the smooth stimulus for the smooth control group did not.

In Test 2, the rough-smooth-rough experimental group continued to display significantly higher levels of active manipulation than the smooth-rough-smooth experimental group. This pattern of differential responding between the two experimental groups at Test 2 is also suggestive of the more interesting nature of the rough stimulus.

These patterns of active manipulation as a function of Group and Order across the three phases suggest that the difference between the smooth and rough textures was perceived haptically. However, rough textures resulted in higher levels of active manipulation than smooth textures for 7-month-old infants suggesting that processing of the rough stimulus may require more time than processing of the smooth stimulus. This may be a function of the greater number of features of the rough stimulus. It may be also that infants are more familiar with smooth textures than rough textures in their daily experiences. This would, however, also imply that familiarity with textures might be reflected in the processing data obtained during testing.

Hernandez-Reif (1993) attempted to assess whether previous experience or familiarity with objects prior to testing served as a basis for cross-modal matching by familiarizing 6-month-old infants either visually, haptically, or bimodally, for 120 cumulative seconds 24 hours prior to a cross-modal task. Infants were then tested after 10 seconds of tactile familiarization. The results did not reveal a significant effect of mode of familiarity (visual, haptic, or bimodal) nor any evidence of cross-modal matching. On the basis of these findings, she concluded that prior familiarity does not enhance matching after 10 seconds of experience.

However, Hernandez-Reif's conclusion is not inconsistent with the explanations for the present data. Only cross-modal transfer was assessed in her study. It is still possible that prior familiarity may, as indicated by the results of the present study, facilitate tactile intramodal processing. Furthermore, the primary stimulus property assessed in her study was not solely texture, for responses to a nubby stimulus (a pink porcupine toy painted with blue dots) and a smooth stimulus (a small black and white soccer ball) that differed in haptic and visual characteristics were compared. Infants may not have shown differences in attention, even after some prior familiarity, simply because other visual stimulus properties, such as shape and color may have been attractive. Finally, 120 seconds of cumulative experience with a toy is a relatively small amount of experience when compared to the exposure infants have with smooth textures. Thus, the possibility that infants manipulated the rough texture more than the smooth texture because of the relative lack of familiarity with rough textures in their daily experiences, remains plausible.

In summary, intriguing differences between experimental and control groups were observed, however, only when processing was assessed with an individually-based measure of active manipulation. It is important to note, however, that the results on the other dependent measures, although not significant, were in the expected direction.

Nonetheless, on the basis of the present findings, the conclusions that can be drawn about 7-month olds' haptic exploration and perception of texture discriminations are limited to the active manipulation measure. Four conclusions can be drawn: (1) 7-month-old infants' haptic discrimination of textures is accomplished primarily by gross hand movements, such as grasping and touching, relative to finer movements of the fingers such as fingering and scrumbling; (2) male and female infants appear to be capable of haptically discriminating between two textures; (3) infants manipulate rough textures more than smooth textures, suggesting that rough stimuli may be more interesting at this age; (4) the limitation of these conclusions to an individually-based measure of active manipulation suggests that measures that are more sensitive to and address the high inter-individual variability may be more effective at detecting infant capabilities.

These conclusions have implications for the role of haptic perception in infant cognitive development. The first issue is the contribution of motor development to haptic perception. The use of gross-motor hand movements by infants to haptically explore and discriminate textures is consistent with their existing motor abilities. By 7 months of age infants typically have progressed from grasping and holding objects in the center of the palm by all fingers to being able to use the thumb in opposition to several fingers and the index fingers. Use of the forefingers is only firmly established between 9 and 12 months of age (Sarafino & Armstrong, 1980). Support was obtained for texture discrimination at this age on the individually-based measure of active manipulation which consisted of grasping and all remaining forms of touch. This is consistent with Gibson's (1962), proposal that active or purposive touch is a superior means by which to haptically explore. Infants, at 7 months of age, seem to be adept at active manipulation as a means of acquiring information.

However, optimal texture perception has been found to depend on relative motion between skin and textured surface (Lederman & Klatzky, 1987). Given this, and the correspondence between the emergence of texture perception and the increase in fingering (Bushnell & Boudreau, 1991), it is likely that there were some motor constraints on the perception of texture. More stable and consistent texture discrimination abilities may be observed with older infants who are capable of finer hand and finger strategies. The relationship between developing motor abilities and haptic perception of texture then, seems to account for the later emergence of these abilities relative to the haptic and visual perception of amodal stimulus properties such as shape.

Although evidence for tactile intramodal and tactile-visual cross-modal transfer of texture between 6 and 12 months of age has also been accumulated (Bushnell & Boudreau, 1991), it has been difficult to interpret these results because of the confounds in the selection of the texture stimuli. The results of the present study, in which stimulus confounds were controlled, suggest that infants form mental representations of textures they have felt and distinguish these from novel textures, (they recognize that the old memory trace is not the same as the new one). However, they may be able to do so only within a short delay between two presentations of texture stimuli, i.e., a 4 seconds inter-phase interval in the present study. They do not seem to be capable of retaining the mental representation of, or memory trace for, the FAM stimulus for a sufficient amount of time to be able to recognize the Test 2 stimulus as being the same as that presented in the FAM phase. If this is the case, then the conclusions regarding texture perception abilities as investigated by intramodal and cross-modal paradigms need to be reevaluated. Tactile-tactile transfer of texture, as well as tactile memory representation capacities, may be magnified by these paradigms since infants are presented with a preference task during the test phase that immediately follows the familiarization phase.

The lack of support in the present study for recognition memory for the original familiarization texture is not surprising given the motor constraints at this age on haptic perception and discrimination of texture. Further evidence for the limitations placed by infant motor development on optimal texture perception and discrimination is provided by the low levels of infant exploratory strategies observed in the present study.

Infant Exploratory Strategies: Fingering and Scrumbling

Texture discrimination was not indicated by differential levels of fingering and scrumbling between experimental and control infants in each of the two test phases. These behaviors were, nonetheless, exhibited during haptic exploration of the textures. This is consistent with past literature indicating that this exploratory strategy is more specific to the exploration of textured stimuli (Ruff, 1984). The low levels of these behaviors, compared to active manipulation, are also consistent with the developmental trends in infant haptic exploration abilities and motor development. Thus, 7-month-old infants seem to display strategies more specific to the exploration of texture stimuli, however, demonstrate relatively low levels of these strategies due to their limited motor abilities.

A second interpretation for the lack of group differences on these measures is that the test phases may have been too short for infants to display different amounts of these exploratory procedures. It is possible that finer exploratory procedures are displayed for further information acquisition only after texture differences are perceived by grosser hand manipulations such as grasping and touching. As previously discussed, the strongest indication of texture discrimination was obtained with active manipulation which consisted of grasping and touching. Perhaps longer test phase durations may have revealed a progression from gross hand manipulations (grasping and touching) to finer exploratory strategies (fingering and scrumbling).

A third explanation is that the shape of the texture stimuli presented, although identical for both textures, may have suppressed the expression of higher levels of exploratory procedures such as fingering and scrumbling that were expected for haptic exploration of texture. These types of procedures may have been more predominant if the textures had been presented on a flat, large surface to permit a greater range in possibility of hand movements. For example, lateral hand motions may be increased under these situations (Lederman, 1982), relative to the present situation in which a cylinder that fit into the infants' hands was used and thus, may have been more amenable to grasping.

Attention Measures

The hypothesis that texture discrimination abilities would be reflected in differential amounts of total attention and fixation between experimental and control groups at each test phase was not supported. Although infants displayed high levels of attention throughout the phases, attention declined in Test 2 relative to FAM. Given past findings on the reliability of visual attention as an index of processing, in conjunction with the previously discussed evidence suggestive of texture discrimination on the measure of active manipulation, the lack of group differences in attention were surprising. Similarly, given the literature on the concordance between infant visual fixation and manipulation, the lack of group differences in fixation were also surprising. Since infants demonstrated some capacity for texture discrimination on the basis of active exploration, this capacity would be expected to be reflected in total attention and fixation as well. It is likely that concordance between manipulation and visual attention found in past studies was largely a function of the presence of both visual and tactile differences in the stimuli.

In the present study, texture discrimination abilities may not have been reflected in the attention measures simply because the stimuli were visually identical. Experimental infants in the touch-plus-vision condition did not display greater amounts of fixation to novel textures relative to control infants in the same condition. One interpretation for this inconsistency is that the texture stimuli employed in this study could not be distinguished by any visual properties. It is possible that experimental infants fixated novel textures once they had perceived the differences in texture by touch, but only for a brief amount of time. Fixation, unlike active manipulation, may not have been sustained among experimental infants because of the lack of any visual differences between the stimuli. This suggests that infants, once tactually perceiving the difference in texture, may have fixated towards the stimulus, but after seeing nothing new visually did not continue to employ the sense of vision to further explore the stimuli. Thus, they continued their processing using the modality through which the novelty could be optimall' perceived. This interpretation is consistent with the duality theories of visual attention and examining (Cohen, 1972; Ruff, 1986). In the present study, there were no novel visual stimulus properties to sustain visual attention once the stimulus had attracted infants' visual attention. However, novel tactile properties were available and hence, tactile manipulation was sustained.

This interpretation is also consistent with the views of many researchers, such as Katz (cf. Krueger, 1982) and Lederman, Klatzky and Reed (1987) on the salience of texture to haptics relative to vision. Since the stimulus property of texture has been shown to be more salient for haptics than for vision, it is possible that texture discrimination abilities would be reflected primarily in haptic manipulation measures rather than visual attention measures. If this is the case, then it would imply that the differentiation between the visual and haptic modalities in terms of their sensitivity for different stimulus properties is established by 7-months of age and that infants are capable of employing the appropriate perceptual modality to assimilate information. Further interpretations for these results and support for the independent role for touch in the perception of specific stimulus properties such as texture is provided in the following section.

Evidence of a Role for Vision: Condition Differences

The hypotheses on the directive role of vision on tactile manipulation and attention were supported. The presence of a visible stimulus, in the touch-plus-vision condition, resulted in greater amounts of total tactile contact and active manipulation only during Test 2, relative to the absence of a visible stimulus in the touch-no-vision condition. Thus, while the texture stimuli were still apparently compelling in Test 1, both in the presence and absence of vision, vision worked to sustain high levels of tactile contact in Test 2. It appears that when the tactile stimuli were visible, tactile manipulation was increased and vision seemed to elicit or promote contact with and manipulation of the tactile stimuli. This finding is consistent with Piaget's theory of the development of prehension, in which vision is thought to gradually influence the hand, as the hand remains more and more within the visual field.

The role of vision for haptic perception of texture seems, however, to be limited to guiding or influencing the hand. Infants in the touch-plus-vision condition, although they displayed more active manipulation in Test 2 relative to infants in the touch-no-vision condition, did not demonstrate superior texture discrimination abilities. Further evidence for the role of vision as being limited to that of a guiding one, and not as a facilitator of texture discrimination is provided by the condition effects observed on the measures of bimanual exploration and scrumbling.

The visibility of the stimuli also promoted greater levels of bimanual tactile contact in the touch-plus-vision condition, relative to the touch-no-vision condition. This finding replicates that of Bushnell et al. (1992) in which infants employed both hands significantly more when tested in light as compared to infants tested in the dark. The presence of vision, thus, seems to result in higher levels of haptic manipulation by enabling infants to use both hands, relative to only one. These findings are consistent with those drawn from past research that indicate that vision plays a guiding, goal-setting role for infants' manual explorations (Bushnell & Weinberger, 1987; Bushnell et al., 1992). However, there was no indication that the additional haptic exploration of stimuli provided by bimanual exploration in the touch-plus-vision condition facilitated texture perception and discrimination. That is, group differences as a function of Condition on the measure of bimanual exploration were not obtained. Once more, there is no indication that vision facilitates tactile perception and discrimination by resulting in greater amounts bimanual exploration.

The visibility of the stimuli also had a guiding role on infants' visual attention. Infants in the touch-plus-vision condition, who could see the stimuli, displayed significantly greater amounts of fixation relative to the infants in the touch-no-vision condition. This finding is again consistent with past literature. Gratch and Landers (1971) found that 6-month-old infants would display sustained visual attention to a visible object, whereas infants, until about 7.5 months of age, continued to grasp a hidden object but looked around for something to see (cf. Warren, 1982). This has been interpreted as an indication that infants are not able to recognize the presence of an object through touch and thus, visual information was clearly capable of mediating object awareness earlier than haptic information.

This interpretation is defeated in the context of the present findings of texture discrimination abilities on the haptic measure of active manipulation and the lack of any indication of superior texture discrimination in the touch-plus-vision condition. Infants in the touch-plus-vision and touch-no-vision condition did not differ in their ability to discriminate textures. Thus, it can be inferred that infants in both conditions were aware of the presence of an object through touch and, in addition, were able to discriminate differences between the textured objects on the basis of haptic exploration.

Interestingly, the presence of vision seemed to have interfered with the display of the fine motor tactile exploration strategy of scrumbling. Experimental infants in the touch-no-vision condition engaged in significantly greater amounts of scrumbling relative to control infants in the same condition. However, experimental and control groups in the touch-plus-vision condition displayed equally low levels of scrumbling. This finding is consistent with that of Bushnell et al. (1992) in that exploratory strategies seem to be more pronounced in the absence of a visible stimulus. In the present study, this was true of infants who were experiencing tactile differences in textures over the course of approximately 90 seconds (i.e., the approximate total duration of all three phases). This implies that when infants are presented with tactile discrepancies in textures that are not visible they will engage in finer exploratory strategies, such as scrumbling, as a means of acquiring tactile information. The greater display of scrumbling under these conditions is consistent with past findings indicating that fingering and scrumbling seem to be employed more frequently when exploring textures

(Bushnell & Boudreau, 1991; Bushnell et al. 1992), and provides further support for the contention that infants at this age are employing their developing adaptive hand movements for the acquisition of information. Furthermore, the present data, like that of Bushnell et al. (1992), refute Heller's (1982) claim that vision facilitates texture discriminations, and suggests that the adaptations infants make with their hands for the perception of tactile information are not dependent on vision.

In turn, the lack of the experimental and control group differences in the touch-plus-vision condition seem to suggest that vision interfered with the exhibition of finer, more adaptive exploratory strategies. The lack of visually detectable discriminations among stimuli may have produced this effect on any existing exploratory strategies.

Overall, the results of the present study seem to suggest that the contribution of vision to haptic perception of texture seems to be limited to guiding the hand toward objects. Vision results in more active manipulation, bimanual exploration and fixation, however, does not, through these effects, appear to facilitate haptic discrimination of texture.

Contributions and Limitations of the Present Study

The contributions of the present study are many. First, the issue of appropriate measures of haptic perception was addressed. The use of haptic manipulation measures that control for individual differences in infant motor abilities and tendency to manipulate was supported. Second, the inclusion of no-change control groups in the design permitted direct assessments of processing and responses to novelty observed in the experimental groups. Third, the paradigm and the procedure employed have controlled for past methodological confounds in the area of haptic perception such as uncontrolled variation in infant behavior and the presence of vision. The use of a tactile familiarization criterion controlled for differences in tactile familiarization with the stimulus in the FAM phase. The amount of familiarization was equal across all infants, and thus, the validity of the test phase data was increased. Likewise, placing the stimulus, in both touch-no-vision and touch-plus-vision conditions, on the infants' hands in order to remind the infants of its presence controlled for infants' lack of manipulation due to forgetting about the presence of the stimulus, while still leaving the infants free to manipulate if they wished. Another advantage of the paradigm was the naturalistic manner by which visual information was occluded, by the use of a cover, relative to testing infants in the dark. Furthermore, the use of a cover in both conditions ensured that both groups of infants were being tested in the same environment as opposed to testing some infants in the dark and some in the light. Fourth, the role of vision in haptic perception was directly assessed by the use of and comparisons between the touch-no-vision and touch-plus-vision conditions and by employing visually identical stimuli. Finally, the systematic selection of texture stimuli that permitted an unconfounded assessment of infants' processing of texture has corrected a common methodological confound of past research.

Although there were a number of strengths in the design and methodology of the present study, it was nonetheless rather surprising to find few group differences as a function of Phase. Some methodological reasons for this are possible. The first is the familiarization criterion selected and this criterion is related to the second factor, the selection of texture stimuli for the present study. Past findings of sensitivity to texture and the ability for texture discrimination after 30 seconds of familiarization, by 6 months of age, may have been inaccurate due to the presence of confounding stimulus properties. Thus, given that the task in the present study, in which stimulus confounds were controlled, was a more sophisticated one, 30 seconds of accumulated familiarization may not have been sufficient to result in the expected group differences on the tactile contact measures. It is possible that stronger indications of texture discrimination may be obtained with the use of a longer familiarization time. This implies that the strong conclusions drawn about infants abilities to discriminate texture in past studies must be regarded with caution.

Summary and Theoretical Implications

The findings from the present study suggest that 7-month-old infants are capable of haptic perception and discrimination of texture in the presence of only tactile cues. They seem to be capable of employing and adapting their developing tactile-kinaesthetic abilities (i.e., active manipulation) in order to acquire information about the stimulus property of texture, even though their fine motor abilities, relative to those required for optimal perception of texture, are limited. The results also suggest that infants may be capable of employing the optimal modality of haptics, rather than vision, to maximize perception and discrimination of stimuli that differ in tactile, rather than visual cues. This is reflected in the observation of infant processing and discrimination of texture in the measure of active manipulation, rather than on the visual attention measures. The use of haptics rather than vision by infants may be because, as indicated by the present data, vision does not facilitate haptic perception of texture (as indicated by the lack of superior texture discrimination in the touch-plus vision condition). Furthermore, vision does not appear to be integral to the adaptations infants make with their hands (as reflected by the increase in scrumbling among experimental infants in the touch-no-vision condition). The role for vision in haptic perception, may be limited to that of guiding the hands and the eyes toward tactile stimuli. Vision was able to elicit higher levels of total tactile contact, active and bimanual manipulation as well as to direct visual attention toward visible tactile stimuli.

These findings support the view of the importance of the haptic modality for cognitive development during infancy. It appears that by 7-months of age information about stimulus properties, such as texture, that are salient to haptics can best be acquired by this modality, rather than by vision. Furthermore, infants seem to possess the capacity to appropriately employ their haptic abilities for the acquisition of such information. These findings highlight the importance of the haptic system for cognitive development in that this system seems to be more efficient, than vision, at the acquisition of specific types of sensory information within a complex stimulus world.

The basis of cognitive growth during infancy has been proposed by Piaget, and believed by many, to lie in simple sensorimotor behaviors and experiences (Lamb & Bornstein, 1987). Haptics constitutes a large part of sensorimotor experience in that infants' knowledge about their senses and objects in their environment comes from their actions on these objects. Since haptics is better designed for the acquisition of stimulus properties such as texture then it is the primary modality by which such information is acquired. The infants in the present study seemed to have been able to use their haptic abilities, rather than vision, to perceive and discriminate the textures presented. As has been suggested by Klatzky et al. (1987), the lack of vision as a facilitator of texture discrimination suggests that cognitive representations of objects are encoded through haptic exploration.

The greater suitability, and independent, capacity of the haptic modality, relative to vision, for the perception and encoding of texture has been suggested to indicate that the haptic system has its own encoding processes and pathways (Klatzky et al., 1987). The results of the present study indicate that, although the two systems may be specialized for the perception of specific stimulus properties, vision may contribute to cognitive development by guiding infants' eyes and hands toward stimulus objects, thus eliciting haptic exploration. Stated more simply, infants who can see a tactile object will be more likely, relative to infants who cannot see it, to reach out and manipulate it. However, both groups of infants may be capable of equal haptic perception of the object's tactile properties. Thus, vision increases the likelihood of haptic manipulation, but may not be integral to the process of haptic perception. It may be in this manner that vision may contribute to the effects of the haptic exploration on cognitive growth.

With the results of the present study implications arise for the direction of future research on the development of haptic perception and discrimination abilities in infancy and the contribution of these abilities to cognitive development, as well as for the significance and importance of touch to blind infants. Future research might assess infants of different ages in order to determine when haptic texture discrimination abilities emerge. Furthermore, testing these different age groups using a range of texture discriminations differing in difficulty would assist in establishing the development and acuity of the haptic system as a function of age. Once more is learned about the development of the haptic system, in terms of its acuity as a function of age, this knowledge can be applied to blind infants, where haptics may be an even more salient system for the acquisition of information and a primary vehicle by which to foster cognitive growth in infants who have a major sensory deficit.

In conclusion, the results of the present study suggest that vision is not integral to 7-month-old infants' haptic perception and discrimination of textures, nor to the adaptations they make with their hands when haptically exploring stimuli that can be distinguished only on the basis of touch. Furthermore, infants seem to be capable of engaging in haptic manipulation, rather than visual fixation, when it is the optimal modality by which to acquire information. The contribution of vision to haptic perception has been found to be that of eliciting or guiding haptic exploration of objects. Vision does not appear to facilitate haptic perception of texture. Haptics, therefore, appears to be an important perceptual modality by which information about specific stimulus properties may be acquired, and on the basis of these findings, provides a significant contribution to cognitive development in infancy.

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Appendix A

Power Analysis

k = number of cells N = number of subjects from table

n_c = subjects per cell u = degrees of freedom

f_{med} = medium effect p = probability level

a = critical alpha level

Study: Condition (2 levels) x Group (2 levels) x Phase (3 levels)

Sample size:

1. Condition and Group Effects (2 levels each) and Condition by Group Interaction

   $u = df_c = df_g = df_{cg} = 1$ $a = .05$ $f_{med} = .25$ $p = .80$

   N to detect = 64

   $$n_c = \frac{(N-1)(u+1)}{k} + 1$$

   $$= \frac{(63)(2)}{12} + 1$$

   n_c = 11.5 subjects per cell, therefore 46 subjects are needed in total to obtain 80% power.

2. Condition by Phase, Group by Phase and Condition by Group by Phase Interactions

   $u = df_{cp} = df_{gp} = df_{cgp} = 2$ $a = .05$ $f_{med} = .25$ $p = .80$

   N to detect = 52

   $$n_c = \frac{(N-1)(u+1)}{12} + 1$$

   $$= \frac{(51)(3)}{12} + 1$$

   = 13.75 subjects per cell, therefore 14 subjects are needed in total to obtain 80% power.

Therefore, 46 subjects in total are required for an 80% chance of detecting a medium effect size at a = .05.

Appendix B

Consent Form

Consent Form

This study is designed to look at infants' responses to tactile stimuli; more specifically, how infants explore tactile stimuli and what fine discriminations they can make using tactile information in the presence and absence of visual information.

I understand that my baby will participate in one session lasting about 60 minutes. My baby will be seated in an infant seat directly facing an experimenter. A plastic non-toxic cover, either transparent or opaque, will be placed at approximately upper chest level to permit or prevent my baby from seeing the objects he/she will be touching. The procedure will consist of one period lasting about 5 minutes, where objects differing in texture will be presented to my baby. I understand that heart rate recordings may be taken. No manipulation will be obtrusive or harmful to my baby. I may be seated directly behind my baby or view my baby from the video control room. The entire session will be videotaped so that at a later point my baby's responses can be scored. However, the recordings are kept in the strictest of confidence and are not shown to others without my permission.

I understand that my participation in this study is totally voluntary. I know that I may withdraw at any time and for any reason. I also understand that I may request that the videotape recording be erased. In the event that the results of the study are published, my name and the name of my baby will be kept confidential.

In the event that I have any unanswered concerns or complaints about this study, I may express these to Dr. Dale Stack (848-7547) of the Psychology Department at Concordia University. In addition, the patient representative at the Jewish General Hospital is Roslyn Davidson (340-8220, local 5833).

Thank you for your cooperation.

I ______________________________ do hereby give my consent for my baby ______________________ to participate in a study conducted by Dr. Dale Stack and Mary Tsonis at Concordia University and with the cooperation of the Jewish General Hospital. A copy of the consent form has been given to me.

Signature: ___________________________ Date: ____________

Witness: _____________________________ Date: ____________

Signature of Principal Investigator: ______________________

Appendix C

Demographic Questionnaire

Demographic Information

Infant #: ______________ Test Date: ______________
Infant's Name: ____________________________
D.O.B.: ____________ E.D.O.B.: ____________ Age: _________

Mother's Name: _________________________ Age: ____________
Lang.'s Spoken: ____
Father's Name: _________________________ Age: ____________
Lang.'s Spoken: ____

Phone #: _______________
Address: ____

Sex: _______ Birth Weight: _______ Length of Labour: _____

Preg. Complications and Delivery Status: __________________
____

Medical History: ____

Breast Fed: _____ Bottle fed: _____

Siblings:	Age	Sex
	________	___________
	________	___________
	________	___________

Father's Occupation: ___________________
Education: ________________
Mother's Occupation: ___________________
Education: ________________

Mother's Recent Work History (full/part-time/home):
____
Father's Work History (full/part-time/home):
____

Hours spent with infant all day:
Mother: all day 3/4 1/2 1/4 < 1/4
Father: all day 3/4 1/2 1/4 < 1/4

Caretaking History (# of caretakers, day/homecare, hours):
____

Previous tactile games: ____________________________________
____

Amount relative to Aud. & Visual Games: ____________________
____

Comments: ____

Appendix D

Operational Definitions for Coded Behaviors

Tactile Contact Measures

Total Tactile Contact:

Consisted of the sum of stimulus touch, touching and grasping.

Active Tactile Manipulation:

Consisted of the sum of touching and grasping.

Stimulus Touch:

Stimulus touch was coded when 1) the stimulus touched the infants' hand and when 2) the experimenter placed/rested stimulus on the back of the infant's hand and fingers or on the infants' palm.

Touching:

Touching was coded when infant actively made contact with the object with his/her hand but did not grasp the stimulus. Touching included all types of touch (pat, stroke, fingering) except grasping.

Grasping:

Grasping was coded when the infants' fingers surrounded the stimulus including and/or excluding thumb or when the thumb and one or more fingers surrounded the stimulus and were capable of independently holding it.

Fingering:

Fingering was coded when infants ran one or more fingertips over the surface of the stimulus.

Scrumbling:

Scrumbling was coded when infants were flexing and/or extending one or more fingers in a repetitive manner over the surface of the stimulus. In scrumbling, the wrist was usually anchored and there was minimal arm and shoulder movement.

Bimanual Manipulation: Bimanual tactile contact was coded when the infants were manipulating the stimulus with both hands simultaneously.

Attention Measures

Total Attention:

Consisted of the sum of search experimenter and fixation.

Search Experimenter:

Searching the experimenter was coded when the infants were looking directly at the experimenter's face, surrounding facial area and upper torso (upper chest level).

Fixation:

a) In the Touch-plus-vision condition: fixation was coded when the infants were looking directly toward the stimulus, including the part of the stimulus held by the experimenter.

b) In the Touch-no-vision condition: fixation was coded when the infants were looking in the direction of the stimulus that they were in contact with. When infants lost contact with the stimulus while fixing toward it, but continued to look in the same direction, then fixation was coded until the stimulus was again in contact with the infant elsewhere on their other hand.

Appendix E

ANOVA Summary Table for Total Tactile Contact

Table 1

Phase by Condition ANOVA Table for Total Tactile Contact

Source	df	SS	MS	*F*
Condition	1	613.47	613.47	1.73
Error	46	1635.62	355.45	
Phase	1	942.63	942.63	5.96*
P x C	1	1440.73	1440.73	9.11**
Error	46	7275.79	158.17	

*$p < .05$
**$p < .0001$

Appendix F

ANOVA and ANCOVA Summary Tables and Adjusted Means for Active Manipulation Calculated Relative to Phase Length

Table 1

ANOVA Summary Table for Active Manipulation Calculated Relative to Phase Length

Source	df	SS	MS	*F*
Condition	1	100.73	100.73	0.14
Group	1	541.65	541.65	0.76
C X G	1	361.19	361.19	0.51
Error	44	31443.99	714.64	
Phase	2	14429.00	7214.50	25.81**
P X C	2	2358.50	1179.25	4.22*
P X G	2	2415.38	1207.69	4.32*
P X C X G	2	149.40	74.70	0.27
Error	88	24602.12	279.57	

*$p < .05$
**$p < .001$

Table 2

<u>ANCOVA Summary Table for Active Manipulation Calculated Relative to Phase Length</u>

Source	df	SS	MS	$\underline{F}$
Condition	1	456.69	456.69	0.52
Group	1	3079.76	3079.76	3.54*
C X G	1	455.57	455.57	0.52
Error	43	37459.55	871.15	
Phase	1	1619.67	1619.67	7.13**
P X C	1	2080.23	2080.23	9.16**
P X G	1	187.71	187.71	0.83
P X C X G	1	18.90	18.90	0.08
Error	44	9990.96	227.07	

*$p < .10$
**$p < .05$

Table 3

Adjusted Means for Active Manipulation, Calculated Relative to Phase Length, as a Function of Group and Condition

	Phase	
Condition	Test 1	Test 2
Touch-no-vision	74.65 (2.89)	57.13 (3.35)
Touch-plus-vision	69.72 (3.18)	70.82 (3.83)

Note. Numbers in parentheses indicate standard errors.

Appendix G

ANOVA and ANCOVA Summary Tables and

Adjusted Means for Active Manipulation

Calculated Relative to Individual Levels of Tactile Contact

Table 1

ANOVA Summary Table for Active Manipulation Calculated Relative to Individual Levels of Total Tactile Contact

Source	df	SS	MS	F
Group	1	493.65	493.65	1.01
Order	1	2439.70	2439.70	5.00*
G X O	1	0.84	0.84	0.00
Error	44	21480.47	488.19	
Phase	2	2488.15	1244.08	6.24**
P X G	2	2226.15	1113.08	5.58*
P X O	2	67.22	33.61	0.17
P X G X O	2	1133.62	566.81	2.84
Error	88	17550.55	199.44	

*$p < .05$
**$p < .0001$

Table 2

ANCOVA Summary Table for Active Tactile Manipulation Calculated Relative to Individual Levels of Total Tactile Contact

Source	df	SS	MS	F
Sex	1	21.27	21.27	0.03
Condition	1	28.94	28.94	0.04
Group	1	1448.84	1448.84	1.84
Order	1	2116.32	2116.32	2.68
S X C	1	1152.83	1152.83	1.46
S X G	1	121.22	121.11	0.15
C X G	1	230.03	230.03	0.29
S X O	1	132.14	132.14	0.17
C X O	1	295.42	295.42	0.37
G X O	1	29.34	29.34	0.04
S X C X G	1	266.46	266.46	0.34
S X C X O	1	302.50	302.50	0.38
S X G X O	1	67.79	67.79	0.09
C X G X O	1	8.67	8.67	0.01
S X C X G X O	1	1170.40	1170.40	1.48
Error	31	24460.52	789.05	
Phase	1	660.35	660.35	6.68**
P X S	1	20.15	20.15	0.20
P X C	1	303.67	303.67	3.07*
P X G	1	68.34	68.34	0.69
P X O	1	10.84	10.84	0.11
P X S X C	1	283.66	283.66	2.87
P X S X G	1	524.16	524.16	5.30**
P X C X G	1	8.86	8.86	0.09
P X S X O	1	0.16	0.16	0.00
P X C X O	1	1.02	1.02	0.01
P X G X O	1	922.81	922.81	9.33***
P X S X C X G	1	0.37	0.37	0.00
P X S X C X O	1	95.08	95.08	0.96
P X S X G X O	1	0.86	0.86	0.01
P X C X G X O	1	41.45	41.45	0.42
P X S X C X G X O	1	133.48	133.48	1.35
Error	32	3163.44	98.86	

*$p < .10$

**$p < .05$

***$p < .01$

Table 3

<u>Adjusted Means for Active Manipulation, Calculated Relative to Individual Levels of Total Tactile Contact, as a Function of Condition and Phase</u>

	Phase	
Condition	Test 1	Test 2
Touch-no vision	85.49 (2.06)	76.68 (2.07)
Touch-plus vision	80.82 (2.38)	79.13 (3.31)

Note. Numbers in parentheses indicate standard errors.

Table 4

Adjusted Means for Active Manipulation, Calculated Relative to Individual Levels of Tactile Contact, as a Function of Group, Sex, and Phase

	Group			
	Experimental		Control	
Sex	Test 1	Test 2	Test 1	Test 2
Males	88.61 (1.36)	79.46 (1.46)	79.57 (2.93)	76.40 (3.31)
Females	84.31 (1.34)	86.34 (1.72)	80.13 (3.26)	69.44 (4.27)

Note. Numbers in parentheses indicate standard errors.

Table 5

Adjusted Means for Active Manipulation, Calculated Relative to Individual Levels of Tactile Contact, as a Function of Group, Order, and Phase

	Group			
	Experimental		Control	
Phase	S-R-S	R-S-R	S-S-S	R-R-R
Test 1	84.83 (1.55)	88.08 (1.16)	70.90 (4.51)	88.84 (1.67)
Test 2	75.75 (2.41)	90.05 (0.78)	70.84 (3.94)	74.99 (3.64)

Note. Numbers in parentheses indicate standard errors.

Appendix H

ANOVA and Tukey Summary Tables for Fingering

Table 1

Anova Summary Table for Fingering

Source	df	SS	MS	F
Phase	2	527.87	263.94	10.84*
Error	94	2288.37	24.34	

*$p < .001$

Table 2

Tukey Multiple Comparisons on Phase for Fingering

Comparisons	Mean Absolute Difference	Critical Difference	Prob. Level
FAM vs Test 1	1.39	2.42	N.S.
FAM vs Test 2	3.05	2.42	<.05
Test 1 vs Test 2	1.66	2.42	N.S.

Note. FAM = Familiarization phase

Appendix I

ANOVA Summary Table for Scrumbling

Table 1

Phase by Condition by Group ANOVA for Scrumbling

Source	df	SS	MS	F
Condition	1	113.85	113.85	1.21
Group	1	125.40	125.40	1.33
C X G	1	510.76	510.76	5.43*
Error	44	4137.80	94.04	
Phase	2	2.84	1.42	0.08
P X C	2	23.83	11.92	0.66
P X G	2	30.78	15.39	0.86
P X C X G	2	3.74	1.87	0.10
Error	88	1581.49	17.97	

*$p < .05$

Table 2

Mean Percent Durations of Infant Scrumbling as a Function of Condition and Group

Group	Condition	
	Touch-no-vision	Touch-plus-vision
Experimental	6.12 (3.34)	0.57 (0.32)
Control	0.48 (0.32)	2.47 (1.26)

Note. Numbers in parentheses indicate standard errors.

Appendix J

ANOVA Summary Table for Bimanual Manipulation

Table 1

ANOVA Summary Table for Bimanual Manipulation

Source	df	SS	MS	*F*
Condition	1	3946.14	3946.14	4.52*
Error	46	40188.76	873.67	
Phase	2	411.71	205.85	0.90
P x C	2	137.11	68.55	0.30
Error	92	21000.48	228.27	

$^{*}p < .05$

Appendix K

ANOVA and Tukey Summary Tables for Total Attention

Table 1

ANOVA Summary Table for Total Attention

Source	df	SS	MS	*F*
Condition	1	3048.24	3048.24	6.89*
Error	46	20344.40	442.27	
Phase	2	4016.99	2008.50	8.38**
P x C	2	547.94	273.97	0.32
Error	92	22052.64	239.70	

*p < .05
**p < .001

Table 2

Tukey Multiple Comparisons on Phase for Total Attention

Comparisons	Mean Absolute Difference	Critical Difference	Prob. Level
FAM vs Test 1	6.69	9.56	N.S.
FAM vs Test 2	12.93	9.56	<.01
Test 1 vs Test 2	6.24	9.56	N.S.

Note. FAM = Familiarization phase

Appendix L

ANOVA Summary Table for Fixation

Table 1

ANOVA Summary Table for Fixation

Source	df	SS	MS	*F*
Condition	1	42613.69	42613.69	83.48*
Error	46	23482.30	23482.30	
Phase	2	161.91	80.95	0.46
P x C	2	2.07	1.04	0.01
Error	92	16[illegible]9	174.89	

$*p < .001$