Perception of Texture During Unimodal Haptic and Bimodal Haptic-Plus-Visual Conditions in 3- and 6-Month-Old Infants

Mary Tsonis

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ABSTRACT

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Mary Tsonis, Ph.D.
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The importance of the haptic system (cutaneous and kinaesthetic processes) in development is widely acknowledged. Yet little is known about infants' haptic perceptual abilities during the first half-year of life. This is due, in part, to the view that haptic perceptual abilities are limited prior to the development of fine-motor exploratory skills and visual prehension. The methodology of existing studies (e.g., the visibility of stimuli and confounding properties, selection of stimuli, and fixed-trials habituation procedures) has also limited clear interpretations with respect to infants' haptic perception. The present research consisted of two studies designed to assess early haptic perceptual abilities by employing a stimulus property salient to this system, texture. Study 1 examined unimodal haptic perception at 3 and 6 months of age, just before and after gains in fine-motor and visual prehension are made. Vision was occluded by an opaque plastic cover and the textures were presented underneath the cover to infants' hands. An infant-controlled Habituation (HAB)-Novelty (NOV)-Return-to-Familiar (RFAM) procedure was employed. Following habituation, experimental group infants received a novel texture for 3 NOV test trials and the original texture for 3 RFAM test trials. Control group infants received the same HAB texture during all test trials. Study 2 was designed to assess the influence of vision on haptic perception of texture. Using the same textures as in Study 1 and presenting them under a transparent cover, infants were permitted both haptic and visual exploration during the HAB phase. However, the test phases were unimodal haptic. Results of infants' haptic manipulations indicated that both 3- and 6-month-olds habituated following similar amounts of haptic manipulation, and that levels of haptic manipulation to habituation did not differ across Studies 1 and 2. In addition, infants discriminated novel textures during NOV, and recognized the original texture during RFAM in both studies. These results suggest that haptic perception and discrimination of texture may not be dependent on visual guidance. However, infants in Study 2 haptically manipulated for shorter amounts of time during NOV and RFAM, relative to Study 1, suggesting that the visual input during HAB may have facilitated discrimination and recognition of textures. Facilitation effects may reflect the integration of visual and haptic input during HAB and the detection of amodal relations across haptics and vision. Vision also suppressed the novelty responses observed in Study 1 on the measure of exploratory procedures (EPs). The EPs may have been suppressed by the lack of salient visual features, again suggesting that visual and haptic input was integrated. Suppression of EPs was less pronounced for the 6-, relative to 3-month-olds, who engaged in more EPs in response to the rough texture in both studies, suggesting that among infants with more developed fine-motor skills, the haptic features of stimuli may alone elicit exploration in this modality. Overall, the findings: 1) support haptic perception of texture during the first half-year of life, 2) suggest an important and unique role for haptics in early perceptual learning; and 3) contribute to the understanding of infants' haptic perception during bimodal exploration. The methodological contributions of the present studies in accessing infants' haptic abilities are discussed and future research directions are proposed.

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CHAPTER 1: Introduction

Primacy of Touch in Development

The sense of touch is the earliest to develop and become functional in human, animal, and bird species (Gottlieb, 1971; Montagu, 1978). The skin is the organ of this sensory modality and it is the largest sensory organ of the body (Smith, 1989). In humans, the earliest differentiation in the nervous system occurs in the part of the trigeminal nerve which is responsible for the transmission of pain and general tactile sensations (Streri, 1993). Myelinization, as an index of growth, of somatosensory afferents into the midbrain areas and of the neocortex also begins earlier (at 4 and 1 month prenatally, respectively) than myelinization of the corresponding visual afferents (at 2 months prenatally and at birth, respectively; Bronson, 1982; Williams, 1983). The human infant is sensitive to tactile stimulation both in utero and shortly after birth. The human embryo at less than six weeks gestation, less than an inch long, and with neither eyes nor ears, is sensitive and will react to light stroking of the upper lip or wings of the nose by bending of the neck and trunk away from the source of stimulation (Hooker, 1952). By 14 weeks gestation, almost the entire surface of the embryo is sensitive to tactile stimulation (Hooker, 1952; Humphrey, 1964; Snow, 1998). At birth, alert neonates will turn their heads reliably toward a tactile stimulus applied to the mouth, the cheek, and the forearm (Kisilevsky, Stack & Muir, 1991). They also respond to noninvasive touch with increased movement and increased heart rate (Kellman & Arterberry, 1998; Rose, Schmidt & Bridger, 1976).

A substantial amount of research has supported the primacy of touch in early infant development in both animal and human species. Tactile stimulation, in the form of natural handling of animals (e.g., licking, tooth-combing, grooming of young) soon after birth and for some time afterwards, appears to be an indispensable necessary condition for their survival (Montagu, 1978). Handling generally leads to increased functional efficiency in the organization of all systems of the body including the skeletal, gastrointestinal, genitourinary, endocrine and immune systems, and the nervous system (Montagu, 1978; Smith, 1989). Handling has produced beneficial effects on rats' growth and development, learning, and resistance to disease (Denenberg, 1968; Denenberg & Karas, 1959, 1960, 1961) as well as facilitating more adaptive responding to stress or noxious stimulation (Levine, 1956, 1958, 1960). Handling is also necessary for healthy behavioural development in the domains of feeding, social, emotional and sexual functioning, and maternal behaviour (Montagu, 1978; Smith, 1989). For example, handled males display greater sexual responsivity and activity (Larsson, 1963, 1970). In addition, Harlow's (1959) classic work demonstrated monkeys' preference for contact comfort over satisfaction of the feeding drive. Furthermore, the lack of normal gratification of contact-clinging in infancy leads to disturbed social behaviour and sexual functioning, as well as inadequate, and even violent maternal behaviour among females (Harlow, Harlow & Hansen, 1963; Smith, 1989).

Parallel influences of tactile stimulation have been documented among humans. Touch and related proprioceptive and vestibular sensations provide stimulation, organization, communication and emotional exchange in human infants (Barnard & Brazelton, 1990). Touch influences parent-infant attachment, cognitive development, sociability, ability to withstand stress, and immunological development (Gottfried, 1984). René Spitz's (1946) classic observations of "failure to thrive" infants dramatically highlighted the importance of a loving caregiver and caregiver-infant interaction, an important component of which is touch (Mitchell & Black, 1995; Spitz & Wolf, 1946). While the physical needs of children left in a foundling home since birth were met, the prolonged deprivation of any nurturing interaction led to depression, withdrawal, illness, and motor retardation. By the end of the second year, one third of these children had died. By the fourth year, few of the surviving children could sit, stand, walk, or talk. If the mother returned within the first three months of life the deteriorating course reversed itself. Since other forms of stimulation in addition to touch were also unavailable to these children, it is difficult to attribute these effects solely to the lack of touch. However, touch is considered an essential component in fostering a nurturing, protective attachment relationship between primary caregivers and their infants, which in turn fosters growth and development, and establishes the foundation for learning, emotional regulation and social interactions (Rose, 1990; Reite, 1990; Smith, 1989).

The research on the beneficial effects of touch has been applied to fostering adaptive development in human infants. Kangaroo care, or the skin-to-skin holding of preterm infants, is now a standard practice given its beneficial effects on physiological state, and attachment outcomes (Browne, 2000; Adamson-Macedo & Attree, 1994). Tactile stimulation administered to preterm high risk neonates, in the form of body massage and passive movements of the limbs, has resulted in improved outcomes such as greater weight gains, more time awake and active, more mature behaviour on Brazelton's (1973) Neonatal Behavioural Assessment Scale, and earlier discharge, relative to nontreated controls (Scafidi et al. 1986, 1990; de Roiste & Bushnell, 1996). The relative contribution of tactile, compared to other simultaneously available, stimulation in exerting such effects on infant physiology and behaviour is still unclear (Stack, in press). Nonetheless, tactile stimulation, in the form of massage, is now a common and often central component of regimens designed to foster growth and development among premature newborns (Field, 1998; Kisilevsky et al., 1991).

While the importance of touch in development is recognized, very little is known about the tactile modality and the mechanisms by which it contributes to development (Streri, 1993). Little is known about the distribution and development of manual tactile receptors (both in terms of their numbers and specialization), and their processing abilities (Streri, 1993). This is partly due to the status bestowed to vision as the "spatial modality par excellence" as a source of information about the environment (Hatwell, 1993). Most psychologists now assert that vision is in control of most of our activities (Streri, 1993). The superior status of vision is, in part, based on a tremendous amount of research on the infant visual system which has documented its structural maturity from birth. The peripheral retina is structurally fully mature at birth, and the entire retina attains its adult form during the first few months after birth (Abramov, Gordon, Hendrickson, Hainline, Dobson, & Laossière, 1982). In contrast, while all the specialized cutaneous receptors are present at birth, they have not fully matured. For example, Meissner's corpuscles are sensitive to pressure and are particularly numerous in the palm of the hand, the genital organs and the foot, however are not fully encapsulated even in one-year-old infants. In addition, while the tactile system has a much greater receptive surface than the visual system, its principal organs for receiving information and the most frequently studied, are the hands and the mouth (Streri, 1993). In an attempt to understand the role of the arms and the hands in infants' exploration of the environment, research has been concerned primarily with the motor functions of the arms and the hands, to the relative neglect of the sensory and perceptual aspects of the tactile modality. In fact, the perceptual functions of the hand are thought to be very rudimentary during the first few months of life due to the immaturity of the motor pathways which allow control of distal finger movements. Babies are thought to be able to extract only a small amount of perceptual information due to their immature motor-manual functioning (Hatwell, 1993). The predominating notions regarding the visual and tactile modalities has resulted in a greater research focus on tactile-motor skills. However, a substantial amount of data supporting the sensitivity of young infants to tactile stimulation and information, as well as the importance of touch in development warrant further investigation into the perceptual abilities of the tactile modality.

The present studies were designed to extend the knowledge of infants' tactile perceptual abilities. In the introduction, the theory and research on the role of touch in early infant development are reviewed. First, the primacy of touch is reviewed in the context of its functional onset relative to other sensory systems. Second, the theories of perceptual and cognitive development (i.e., integration, differentiation, and information processing theory) which hold important roles for touch are reviewed. Third, the research on infants' tactile perceptual abilities during the first year of life, with a focus on shape and texture perception, is reviewed. Finally, the rationale and general objectives for the present studies are presented.

The Primacy of Touch: Sensory and Perceptual Organization

The primacy of the tactile modality in fostering development has been hypothesized to be due to the timing or sequence of the development of this modality relative to other sensory systems (Lewkowicz, 1991; Turkewitz & Kenny, 1982, 1985). Gottlieb (1971) provided compelling evidence that the maturation and functional onset of the sensory systems follows an invariant sequence in a wide variety of species including humans (Lewkowicz, 1991; Lickliter, 1993). The first sensory system in this sequence is the somasthetic (tactile/cutaneous), followed by the vestibular, chemical, auditory and visual. It has been postulated that this invariant sequential onset of systems serves two functions (Gottlieb, 1971; Turkewitz & Kenny, 1982, 1985). The first is the promotion of sufficient development in each modality by limiting sensory functioning and decreasing interference or competition from later developing systems. Supportive of this function is research demonstrating that premature stimulation of the visual system interferes with the functioning of earlier developing systems; it has been found to disrupt normal, expected functioning in both the auditory and olfactory systems (Gottlieb, Tomlinson & Radell, 1989; Lickliter, 1990, 1993).

The second function is the organization of intersensory relationships by earlier developing systems. Intersensory perception is the ability to make information that is acquired in one sensory modality available to another modality (Gottfried & Rose, 1986). The development of intersensory relationships is thought to serve as the basis for cognitive development (Brown & Gottfried, 1980; Meltzoff, 1990), and as such has been the focus of a tremendous amount of research. Turkewitz and Kenny (1982, 1985) found evidence that earlier functional modalities help to establish intersensory relationships with regard to environmental stimuli. An early sensory dominance of the auditory system over the visual system has been found in both animal and human infants. Species-typical auditory cues are preferred over species-typical visual cues in animals (Johnston & Gottlieb, 1981, 1985; Lickliter & Virkov, 1989), and human infants' responding to simultaneous and competing auditory and visual inputs appears to be dominated by the auditory modality (Lewkowicz, 1988a, 1988b). The earlier development and functioning of the auditory system and thus its longer stimulation history, relative to vision, are thought to underlie this sensory dominance or hierarchy phenomenon in the organization of intersensory relationships (Turkewicz & Kenny, 1985).

Similarly, the early development and in turn, longer stimulation history of the tactile system may account for the beneficial effects and organizational functions documented in the animal and human literatures reviewed above. As the earliest developing and functional system, touch becomes a primary sensory and perceptual modality through which information is acquired about the world, and touch may serve to organize intersensory relationships between tactile and later developing systems, including vision. Information obtained through touch may be better used, early in development, for sensory integration than information gained through a later developing system. This integrative function of the tactile modality implies a large contribution for touch to perceptual and in turn, cognitive development.

Theoretical Perspectives on the Role for Haptics in Early Development

The tactile modality is considered a primary contributor to perceptual learning and cognitive development. There are three general schools of thought that have contributed to understanding how information obtained through touch fosters cognitive development. The first two are the integration and differentiation theories of development (for review see Bahrick & Pickens, 1994; and Bloch, 1994). The third school of thought has emerged from the information processing framework of cognitive development (McShane, 1991; Siegler, 1991; Snow, 1998). Common to all three theoretical perspectives is the premise that cognitive development begins with meaningful descriptions of external reality delivered by perceptual mechanisms. Within all three perspectives touch is considered to be part of a larger perceptual-action system referred to as "haptics" (Kennedy, 1978), and it is this larger perceptual-action system that has implications for cognitive development. While "touch" has been used to refer to the cutaneous system and localized sensations on the skin's surface, "haptics" refers to the assimilation and processing of information obtained through the simultaneous functioning of the skin, muscles, and joints (Klatzky & Lederman, 1987). Thus, information is incorporated from both cutaneous and kinaesthetic receptors (Kennedy, 1978). Haptic activity and exploration is considered a primary means through which infants acquire information about their physical world (Bushnell & Boudreau, 1991). The term haptics will henceforth be employed since it more accurately reflects the tactile modality as a perceptual system.

In infancy both the mouth and the hands are regarded as the primary organs of the haptic system (since they are both used to acquire information about the quality of objects such as their shape, texture, hardness, size, temperature and weight; Katz, cf. Kruger, 1982; Bushnell & Boudreau, 1991; Rochat & Senders, 1991). From birth, infants use the mouth as a perceptual/haptic instrument and not merely as a "sucking" device (Rochat & Senders, 1991). Like the hands, the mouth combines tactile as well as kinesthetic reception from the mobility of the jaws, tongue and lips (J.J. Gibson, 1966). The mouth (and its activities such as tonguing, gumming, and lipping) is initially the primary instrument used to contact, capture, and explore objects. Oral capture and mouthing (i.e., tonguing, gumming, and lipping) appear to drive and organize early exploratory behaviour; infants have a strong tendency to explore orally, to bring the hands to the mouth, and to transport objects within the vicinity of the mouth (Rochat & Senders, 1991). The mouth, like the hands, can also be considered a perceptual instrument from a physiological standpoint. The body surfaces in and around the mouth, as well as the extremities of the fingers, have the highest concentration of tactile receptors (Rochat & Senders, 1991). Somatotropic and motor homunculus representations indicate that fingers and lips have a relatively large cortical projection corresponding to the greater tactilokinesthetic sensitivity of these regions (Carlson, 1986).

Given the understanding of the haptic modality as a perceptual-action system, haptics holds a large place in the theoretical perspectives of integration and differentiation since they both regard perception-action relationships as the building blocks of cognition (Piaget, 1952; E.J. Gibson, 1969; J.J. Gibson, 1966; Bloch, 1994). The theoretical contributions of primary proponents within each school of thought, namely Piaget for integration theory, and J.J. Gibson and E.J. Gibson for differentiation theory, will be reviewed as they pertain to the role for haptics in cognitive development. Piaget and J.J. Gibson were among the first to consider the role of perception-action relationships in cognitive development (Bloch, 1994). While their theories differ in their account of perception and the relationships between perception and action (Bloch, 1994), they both consider haptics as an important contributing modality in cognitive development. Finally, the information processing framework will be reviewed since it has contributed substantially to the understanding of infants' processing of information through haptics (Stack & Bennett, 1990; Stack, St. Germain & Zelazo, 1992; Streri, 1993) .

Integration Theory

The integration view holds that the senses are initially distinct and independent at birth, and that intersensory coordination emerges gradually though development (Piaget, 1952; Bahrick & Pickens, 1994). Piaget's theory of cognitive development holds many implications for haptics since it considers the coordination of haptic schemas with those developed in other modalities (i.e., intersensory coordination) as the process underlying cognitive development. Initially, infants do not aim their eyes at tactile stimuli, nor their hands toward visual stimuli. According to Piaget (1952, 1954), the separate sensory impressions are first incorporated into distinct schemata, but become integrated through experiences that activate the distinct schemas simultaneously. For example, infants learn that an object that is grasped can also be looked at, and actions such as "touching a toy" gradually become coordinated with actions such as "looking at or hearing the toy" (Bushnell, 1981; Bahrick & Pickens, 1994). The gradual accumulation and coordination of schemata ultimately leads to true internal representations of external reality.

In "The Origins of Intelligence in the Child", Piaget (1952) explains cognitive development in a series of stages, the first of which defines the first two years of life and is called the sensorimotor period. During this period, actions, beginning with reflexes, become encoded along with their sensory consequences as sensorimotor schemata (Kellman & Arterberry, 1998; Sutherland, 1992). The development of prehension is also described as it occurs in substages within the sensorimotor period (Warren, 1982). The first stage of prehension consists of the reflex stage (between 0 and 1 month) during which impulsive movements occur, with reflexive grasping (no thumb used). Therefore, the reflex stage is regarded as a stage of mere mechanical response to outside stimuli. The grasping is reflexive in that it is involuntary but at least momentarily attracts the infant's attention (Warren, 1982).

It is during the next, second, stage of primary circular reactions (between 1 and 4 months) that infant hand actions become increasingly voluntary. At this stage, infants perform repetitive actions upon objects presented to them simply because of the aesthetic consequences of the actions for themselves, or for the sake of the pleasant stimulation produced by the action (Bushnell & Boudreau, 1991). While the infant grasps and holds for the sake of the repetitive activity, the hand is not yet being used as a tool to operate on the environment. However, the hand is clearly delivering sensations that the infant prolongs and repeats. The ability to repeat an act distinguishes this stage from the reflex stage, and is therefore thought to represent the dawning of memory (Kellman & Arterberry, 1998; Warren, 1982).

While hand behaviour, at this stage, is considered to yield important sensory information, the tactual and visual schemas remain uncoordinated. That is, while infants repeat hand movements for the sake of sensory stimulation, bring an object to the mouth for further exploration, and the hands tend to remain more and more within the visual field by 3 or 4 months, infants still do not grasp an object for the purpose of bringing it into view. The hand by this age moves to grasp a viewed object, but such eye-hand coordination occurs only when the hand is in the visual field with the object to be grasped.

During the subsequent stage of secondary circular reactions (between 4 and 8 months) infant hand behaviour becomes more deliberately exploratory and under visual control. The infant now repeats actions not only for the sensory stimulation, but in order to achieve a goal in the environment. The development of eye-hand coordination during this stage considerably extends the infant's range of possible actions. During this stage, a visually perceived object serves as the stimulus for reaching wherever the hand may be. That is, if an object is in the visual field and the hand is not, the hand will be brought from out of sight to grasp an object (Warren, 1982). The cognitive units of this stage consist of the forerunners of what Piaget called classes, concepts, or schemas. Infants at this stage can be said to be engaging in deliberate or intentional haptic exploration, however, given the developing visual control of the hands, vision is thought to dominate haptic behaviour by 6 months of life.

Piaget's theory clearly illustrates the substantial contribution of haptics to infant cognitive development. First, the hand's behaviours, even before becoming functionally integrated with vision, are considered to be independently delivering interesting information to the infant (Warren, 1982). Second, both before and after integration with vision, the hand is conceptualized as a "tool" employed for further action on the environment, action which engenders perception and learning. Third, Piaget's adoption of an "action centred" perspective (his emphasis that perceptual knowledge derives from action) during the sensorimotor period clearly holds a large role for haptics. This perspective reflects the "activity" inherent in the haptic modality, even in its earliest form, mouthing. Piaget acknowledged that even very early, reflexive, haptic activity constitutes a rich source of sensory stimulation (Warren, 1982; Bushnell & Boudreau, 1991). Moreover, it is consistent with the conceptualization of haptics in all its forms (i.e. oral and manual) as consisting of both kinesthetic and somatosensory components. Finally, Piaget's premise that a child's active experiences with the environment are important for constructing intermodal knowledge, also underscores an important role for haptics. Haptics, with its inherent kinesthetic and somatosensory components provides a rich source of interactive experiences with the environment; it serves as an "interactive tool" (Warren, 1982; Rochat & Senders, 1991). The haptic actions on the environment, while initially coincidental, are eventually paired with simultaneous exploration and perception in other modalities to yield a more complete understanding of the physical world (Bushnell, 1981; Warren, 1982).

There is some support for the role of haptics in perceptual development as held by Piaget's theory. Bushnell and Boudreau (1991) related Piaget's substages of the sensorimotor period to the developmental timetable of haptic perception of various object properties. They proposed that some object properties are probably more sensorially interesting or pleasing, while others may be more relevant to the functions for which an object may be used. Specifically, an object's temperature, texture and hardness may primarily hold an aesthetic value for an infant. Skin contact with objects of varying temperatures can be soothing or uncomfortable. Similarly, pleasant or unpleasant tactile feedback can by obtained by different textures and by squeezing or poking a compressible object. In contrast, properties such as weight or shape are more relevant to an object's utility (e.g., only light things can be picked up easily, and only round things roll). Bushnell and Boudreau (1991) proposed that the aesthetic versus functional relevance of object properties may have implications for the emergence of haptic sensitivity to them. That is, if younger infants are particularly focused on the pleasurable or interesting sensory feedback that results from their actions with objects, one would expect them to haptically perceive the more aesthetically relevant properties of objects, namely, hardness, temperature, and texture. The developmental timetable of haptic perception of various object properties that Bushnell and Boudreau (1991) charted based on empirical research findings, supported this hypothesis. They found that infants are able to perceive these aesthetic properties earlier (by 6 months of age) relative to weight and configurational shape (at 9, and after 12 months, respectively).

However, any conclusions regarding earlier perception of aesthetic properties are limited by a number of factors. First, there is very little research on the haptic perception of hardness and temperature with infants under 6 months of age, and no research on texture perception. Studies of featural shape differences were employed as analogues of texture perception and to infer that infants probably do not perceive texture before 6 months of age. Second, most of the evidence for hardness and texture perception has been obtained in the context of cross-modal perception studies and from observations of infants' naturalistic play with objects. Thus, the visibility of the objects limits conclusions that can be drawn vis-à-vis haptic perception of these properties. The perception of aesthetic properties before functional properties lends support to Piaget's observations that haptic activity is pursued for the sake of sensory stimulation. However, there is clearly a need for research on haptic perception of different properties during the first half-year of life before Piaget's ideas on haptic perception can be conclusively supported.

In contrast, research in the area of intersensory coordination conducted with infants during the first half-year of life challenges the central assumption of early independence between the sensory systems. According to Piaget's integrationist view, independent sensory systems are gradually integrated as infants learn to associate modality-specific sensations, and learn correspondences between information picked up by initially distinct and uncoordinated systems (e.g., the eyes, ears, and hands; Bahrick & Pickens, 1994). However, research on cross-modal abilities (i.e., the recognition of objects, and the transfer of information about objects, across modalities) and detection of amodal information (i.e., information that is not specific to a particular sensory modality, but rather is completely redundant across one or more senses; Bahrick & Pickens, 1994) suggests that correspondences between systems are present from birth or achieved quite early, during the first six months of life (Meltzoff, 1990; Bahrick & Pickens, 1994).

The early detection of relationships between visual and auditory events has been reliably documented. When presented with soundtracks and films of rigid and elastic objects in motion, infants detect the rigidity versus elasticity of substance for moving objects (Bahrick, 1983). They also detect the composition of moving objects (i.e., whether they were composed of a single element or a cluster of smaller elements) when presented with films and soundtracks of objects colliding against a surface (Bahrick, 1987, 1988). Both substance and composition are considered to be amodally specified properties across vision and audition through temporal information. Visual-auditory cross-modal abilities are also reflected in infants' abilities to match faces and voices on the basis of voice-lip synchrony (Dodd. 1979; Spelke & Cortelyou, 1980; Walker, 1982), their selective attention to one of two superimposed films guided by a synchronous and appropriate soundtrack (Bahrick, Walker, & Neisser, 1981), and sensitivity to auditory and visible information of objects changing in depth (Walker-Andrews & Lennon, 1985; see also Bahrick & Pickens, 1994). Infants' success in auditory-visual intersensory tasks is based on the detection of amodal relations (Lickliter & Bahrick, 2001). Thus, the evidence of early detection of a wide range of amodal, invariant relations challenges the integrationist premises of independence between the sensory systems and of intersensory perception as a process of integration of input from separate modalities (Bahrick & Pickens, 1994).

A substantial amount of research has similarly documented haptic (both oral and manual) and visual cross-modal abilities among very young infants. The well-replicated phenomenon of imitation of facial actions among neonates has been thought to reflect that neonates can apprehend, at some level of processing, the equivalence between body transformations they see and body transformations of their own that they "feel" themselves make (Meltzoff, 1990). In addition, haptic and visual cross-modal transfer of specific object properties has also been documented. Meltzoff and Borton (1979) demonstrated oral-visual transfer among 1 month-old infants. Infants were familiarized orally for 90 seconds with nubby or smooth spheres and were then presented both objects simultaneously during a 20-second visual discrimination test. Infants demonstrated a preference for the familiar object, rather than the novel. Pêcheux, Lepecq and Salzarulo (1988) replicated and extended this effect. They also examined oral to visual transfer among 1-month-olds using similar shapes and 90 seconds of oral familiarization. Infants who had not habituated demonstrated a preference for the familiar shape, while those who had showed a preference for the novel shapes. Familiarity preferences in infancy are believed to suggest insufficient processing of the familiarization stimulus and adequate familiarization has been found to be a prerequisite for novelty preferences (Hunter, Ames & Koopman, 1983; Rose, Gottfried, Melloy-Carminar & Bridger, 1982). Thus, the familiarity preferences, like the novelty preferences, were interpreted to indicate recognition of the familiar shape, and discrimination between the familiar and the novel stimulus in the new modality. E. J. Gibson and Walker (1984) corroborated the Meltzoff and Borton (1979) and Pêcheux et al. (1988) studies using different stimuli. Rochat (1983) confirmed that infants in the first month succeeded on shape discrimination tasks when differently shaped nipples were inserted in their mouths. These studies suggest that some primitive ability to detect correspondences between haptics and vision is basic to the perceptual system of infants (Meltzoff, 1990). Moreover, these early findings of haptic-visual cross-modal abilities support a much earlier and greater role for haptics in the development of intersensory coordination, than proposed by Piaget.

Intermodal studies during the first year of life have also reliably shown infants to be capable of manual-haptic to visual cross-modal transfer. Collectively, this literature suggests a superiority of haptic-visual transfer, relative to transfer in the opposite direction. Haptic-visual cross-modal abilities have been observed in infants as young as 2- to 3- months of age. Streri (1987) and Streri and Milhet (1988) showed that 2-to 3-month-old infants displayed a novelty preference during visual testing following manual-haptic exploration of shapes. However, recognition of shapes in the opposite direction, that is, from vision to touch was not obtained. The superiority of haptic-visual transfer is also observed at older ages; haptic-visual transfer is more reliably observed during the second half-year of life, and haptic-visual transfer is superior to, or occurs faster, than visual-haptic transfer at 12 months of age.

The faster transfer of information from haptics to vision occurs despite the faster speed of processing within the visual modality, and the faster speed of visual-visual, relative to tactile-tactile, intramodal (or within modality) transfer. The relative efficiency of haptic to visual transfer implies a greater efficiency for haptics in the transfer of information across these two sensory modalities. Haptic-visual transfer has been documented to be mainly under the constraint of sufficient tactile familiarization. In contrast, visual-haptic transfer has been documented to be dependent on the presence of more than one stimulus property, and on the salience of the visual cues available, in addition to adequate familiarization (Rose, 1990b, 1994). The information acquired during visual exploration is also thought to impede visual-tactile transfer by limiting subsequent tactile exploration (Rose, 1990b, 1994). As proposed by Turkewitz and Kenny (1982, 1985), the earlier development and functional onset of haptics may contribute to the greater efficiency in the transfer of information across modalities. Finally, during the second half-year of life, tactile experience and tactile novelty have been found to modify visual preferences, to incite both haptic and visual exploration and at times to guide visual exploration (Bushnell, Shaw & Strauss, 1985; Rubenstein, 1974; Ruff, 1976; Steele & Pederson, 1977). The early haptic-visual transfer abilities, the unidirectional nature of this transfer, and the more efficient transfer of information from haptics to vision challenge the idea of sensory independence, and suggest that the haptic modality may have an early and important role in the organization of intersensory relationships.

Differentiation Theory

The vast body of research documenting the existence of intermodal relationships very early in life supports the differentiation view of development. Differentiation theorists, such as Bower (1974), E.J. Gibson (1969), and J.J. Gibson (1966) argue that the senses are unified early in development and that perceptual development consists of differentiation of increasingly finer aspects of stimulation. According to this perspective, at least some intermodal perceptual abilities are considered to be innate (Bahrick & Pickens, 1994). Moreover, differentiation theory posits that perceptual systems are more than receptor surfaces in that they actively pick up stimulus information. In other words, perception does not consist of receiving stimulations and then processing them in modality-specific schemata, but consists from birth, of an active process of obtaining information about the world (E.J. Gibson & Spelke, 1983).

According to the differentiation framework, the contents of perception are not specified according to their sensory input; we do not perceive stimuli or even any momentary representation of them on a receptor surface, such as a retinal image. What is perceived are the events and things in the world. As E. J. Gibson and Spelke (1983) explained: "To perceive anything, the information in stimulation must correspond to it in the sense of specifying it. Events and things are specified in many ways for us, for example in light, sound, and in pressure patterns on the surfaces of the body. These sources of energy provide information to the visual system, the auditory system, and the haptic system. But through the activity of the perceptual systems, we perceive a unitary world, not separate collections of visual, auditory and tactile impressions" (p. 2). Infants are viewed as being richly endowed with the means of finding out about the environment. An infant's looking, listening, feeling, smelling and tasting are thought to be inherently coordinated for obtaining information. These precoordinated systems provide a way of learning about the world from birth and infants are motivated to actively use their perceptual systems to seek information (E.J. Gibson & Spelke, 1983). Thus, active exploration begins, and has a purposive intent, from birth. Eventually, exploratory skills increase with maturation and practice.

E. J. Gibson's (1969, 1982) "invariant" detection view is the most popular current example of a differentiation theory which accounts for infants' innate capacity to perceive properties of objects. Newborns are viewed as actively oriented toward the discovery of "affordances" (or possibilities for action) that are offered by objects, people, and places (E.J. Gibson & Spelke, 1983; J. J. Gibson, 1979). The affordances of the environment (i.e., what it offers, provides or furnishes for action) are related to the individual's action capabilities. An affordance is an objective relationship between the physical properties of an actor and those of the environment (Adolf, Gibson & Eppler, 1990). When this relationship changes, the scope of possible actions changes. Affordance is therefore a functional term that emphasizes the utility of some aspect of the environment given an individual's capabilities for action (E. J. Gibson, 1982). For example, a floor affords support and it can be walked on, and water affords drinking.

Affordances are discovered by seeking out and detecting "invariants". Invariants are constant, higher order relationships in the flow of stimulation (E.J. Gibson & Spelke, 1983; J.J. Gibson, 1966, 1979). That is, objects and events are multimodal and specified by redundant information which is abstracted by coordinated sensory systems (Walker-Andrews, 1994). The same higher order relationship may be constant over changing stimulation to the eye, the ear, and the skin. For example, a characteristic of an object perceived visually is not specified initially as visual because the same object can be specified by equivalent information in other modalities, which make it amodal. Mature perceivers are skilled at detecting invariant relationships that characterize the information about an object that reaches their senses.

Similarly, infants possess coordinated perceptual systems that allow for the detection of many invariant relations. Detection of amodal information that specifies properties of objects and events, and their affordances, is what permits infants to appear to experience a world of perceptual unity (J.J. Gibson, 1966, 1979). Some mechanisms for detecting invariants are present at birth, but sensitivity to invariants increases as new perceptual and exploratory abilities mature or become modified by experience. While there is a primitive unity of sensory systems at birth and infants are not aware of whether an object is seen, heard or felt, with experience infants become sensitive to new invariant relationships and come to detect additional properties of objects and events (Walker-

Andrews, 1994). Furthermore, the child's developing perceptual systems provide information that is increasingly accessible for new purposes. For very young infants, perception of an affordance might guide only a limited repertoire of adaptive actions. As a child ages, perception of an affordance will come to guide a greater variety of actions. According to this theory, infants respond to both quantitative (e.g., size, brightness, loudness, duration and rate of stimulation) and qualitative aspects (e.g., rhythm, melody, texture and shape) of stimulation from birth (Bahrick & Pickens, 1994).

Taken from this theoretical framework, the intersensory abilities of very young infants reflect that, from birth, infant behaviour is remarkably complex and organized. As such, the infant's repertoire of behaviours is not random, but reflects an ensemble of functional organizations, or a collection of "action systems" which are defined by the function they serve (Rochat & Senders, 1991). For instance, sucking behaviour is viewed as part of the nutritional or feeding system. Behaviours are identified as "acts" from birth, rather than as mechanistic "responses" or "reflexes" and infant action is seen as inextricably and functionally tied to the environment and its resources or affordances (E.J. Gibson, 1982; E.J. Gibson & Spelke, 1983; J. J. Gibson, 1979; Rochat & Reed, 1987).

J.J. Gibson (1962) wrote specifically on the topic of haptics and argued that it is a purposive search for stimulation. He defined haptics as active, not passive, touch consisting of a blend of two modes of sensation, i.e., kinesthesis and proper touch which permits exterospecific and propriospecific stimulation or the excitation of skin, joint and tendon receptors. He regarded the hand as a sense organ distinguished from the skin of the hand. According to Gibson, exploration with the hand and the movements of the fingers are purposive in that an organ of the body is being adjusted for the registering of information. The purpose of the exploratory hand movements is to isolate and enhance the component of stimulation which specifies the characteristics of the object being touched. In other words, active touching is a purposive effort to obtain the stimulation which yields a perception of what is being touched, or the affordances or functional possibilities an environment offers. Based on experiments with adults, J.J. Gibson (1962) concluded that a great number of environmental properties can be perceived through active touch alone, and in the absence of vision. His views have also been supported by relatively more recent research indicating that infants are capable of haptic perception of object properties (Bushnell & Boudreau, 1991, 1998; Rose, Gottfried & Bridger, 1981a,b; Ruff, 1989; Streri, 1993). Moreover, the developmental timetable of haptic perception of various object properties in infancy delineated by Bushnell and Boudreau (1991) indicates a relationship between infants' abilities to haptically perceive specific object properties (e.g., shape, texture, hardness, and weight) and the development of specific motor abilities considered to be prerequisites for the perception of each property.

There is evidence indicating that infant haptic behaviour, even in its earliest form of oral exploration is an active process of seeking information. Mouthing appears to drive and organize early exploratory behaviour and is a primary means by which infants explore and discriminate among objects and detect what they afford for action (Rochat & Senders, 1991). Rochat (1983) reported that the perceptual-exploratory functioning of the mouth is evident at birth. He recorded the oral activity of neonates and young infants following successive presentations of nonnutritive rubber nipples varying in shape and texture. Even among neonates only a few hours old, variations in oral responses corresponded to variations in the physical characteristics of the nipples. Infants responded with significantly more mouthing and less sucking of the experimental nipples relative to a control pacifier that was comparable to a natural nipple. Furthermore, the ratio of sucking to mouthing varied according to the age of the infant and the features of the nipple. Newborns displayed a sensitivity to changes in texture, whereas one-month-olds displayed a sensitivity to changes in texture and shape of the nipple. These findings suggest that early in development, the nutritive function of sucking changes in relative importance as the young infant actively develops the perceptual-exploratory potential of the mouth (Rochat & Senders, 1991).

The coordination of oral and manual activities, or hand to mouth behaviour, from birth also supports the differentiation view of haptics as an organized and active system geared towards exploration. The mouth and the hands do not function independently, but appear to be functionally linked from birth (Rochat & Senders, 1991). Hand-mouth contact is frequent in the neonate and is one of the earliest demonstrations of the integration of two separate systems. Butterworth and Hopkins (1988) analyzed hand-mouth contact among newborns and reported that the infant's mouth is often open in anticipation of the arrival of the hand, and that this contact is independent of the Babkin or rooting reflex. A further series of studies (Blass, Fillion, Rochat, Hoffmeyer & Metzger, 1989; Rochat, Blass & Hoffmeyer, 1988) illustrated that gustatory stimulation with sucrose appears to play a primary role in determining coordinated hand-mouth behaviour in neonates. That is, sucrose significantly increased the likelihood of hand to mouth behaviour, relative to water, olfactory stimulation, as well as tactile stimulation to the hand (Rochat & Senders, 1991). Moreover, hand-mouth behaviour decreased when a rubber pacifier was placed inside the infant's mouth following sucrose delivery. According to the investigators, sucrose appeared to engage the neonates' feeding system which recruits hand-mouth coordination. This coordinated action may be oriented toward providing the infant with an object on which to suck. They concluded that these rudimentary oral-explorative behaviours appear to be an integral part of the feeding/sucking system, which once engaged orients the newborns towards objects affording sucking. These observations suggest that the hand transport to the mouth is perhaps the earliest expression of goal directed action (Rochat & Senders, 1991). Hand-mouth contact is viewed as heralding later developments in object exploration.

The hand-mouth coordination observed among neonates rapidly evolves to become more object-oriented. The coordination between the hands and the mouth becomes reoriented by 2 months of age toward exploration, as opposed to feeding. This is illustrated by the transport of objects, introduced to the hand, to the mouth for oral contact and haptic exploration. The root of this action is not the engagement of the sucking/feeding system via oral stimulation but rather manual/haptic contact with the object as an integral part of the infants' exploratory action system (Rochat & Senders, 1991). By 5 months, this behavioural pattern is the main feature of the infant's spontaneous exploration of objects and culminates in visually guided reaching. Thus, the research on hand-mouth contact at birth, and its development within the first few months after birth, are consistent with the conceptualization of haptics as a perceptual system innately oriented towards "action" or active exploration of the environment. This research also challenges Piaget's view of hand-mount contact in the neonate as accidental and fortuitus and hand-mouth coordination as a combination of originally independent schema (i.e., sucking and grasping; Rochat & Senders, 1991).

Haptics, according to the differentiation perspective, also serves to provide information regarding the affordances of stimuli. Grasping behaviour is observed in the neonate, and like mouthing, manual grasping is a means for the young infant to haptically perceive the affordances of objects. Rochat and Gibson (1985) and Rochat (1987) have demonstrated, in studies with newborns and 2- to 3-month-olds, that from birth, infants show differential haptic responding with mouth and hands towards various qualities of an object. In particular, infants sucked at a soft object and impressed the hard one with protracted bites. The reverse was found when infants acted manually on the object; infants made repeated grasping motions on the hard object, and clutched the soft one. The finding suggests that soft or hard objects present the infant with different affordances for oral and manual action. The hand and the mouth are differentially oriented in their haptic response. The manual-haptic response appears oriented toward the object's affordance for clutching, (e.g., with the hand tightly closed as afforded by the soft object). The oral-haptic response, including exploration, is oriented toward objects' affordance for sucking (i.e., as afforded by the soft object) and biting (as afforded by the hard object). These findings are consistent with the differentiation view that haptics is an active perceptual system from birth geared towards the detection of affordances. They also challenge Piaget's more passive view of early haptic behaviours as reflexes and providing and being repeated only for the sensory stimulation they provide.

Summary Implications of Integration and Differentiation Theories

In summary, the haptic modality, as understood within both differentiation and integration theory, is an important source of perceptual learning. While these theories may understand haptic perception differently, in terms of the abilities and functions of haptics as a function of developmental stage, and in terms of the units/contents of haptic perception, they both strongly implicate haptics in cognitive development during the first 6 months of life. However, there are sufficient data presently to support earlier and greater contributions of the haptic modality to cognitive development than suggested by Piaget's theory. The available research suggests that haptics is an active perceptual system that provides not only sensory information but allows learning of the affordances of objects. Moreover, the cross-modal abilities between haptics and vision strongly support a role for haptics in the organization of intersensory relationships. However, as stated earlier, the present knowledge on infants' haptic abilities is limited since it is based largely on cross-modal perception studies which have been conducted primarily with infants during the second half-year of life (Bushnell & Boudreau, 1991). There is a lack of empirical research directly assessing haptic perception during the first half-year of life. Such research is warranted given the importance both integration and differentiation theories hold for haptics, and given the cross-modal findings that have been obtained to date. Further understanding of the haptic modality's contributions to cognitive development would entail research into the issues of what information or object properties are processed through haptics, the efficiency of haptic processing (e.g., the facility, speed or rate with which information is processed haptically), and how infants use the haptic modality to acquire information about the world during their first half-year of life.

Further research is warranted on the basis of the limitations of Piagetian and Gibsonian theories in predicting cognitive ability from infancy. While their emphasis on perceptual-action relations in cognitive development have had a substantial impact on advancing developmental theory and research, these ideas have been limited in their ability to predict cognitive ability based on infant perception-action abilities. Standardized scales of mental development such as the Griffiths, Bayley, Cattell, and Gesell, which measure perceptual and motor development during infancy and early childhood have not fared well, in what Bornstein, Slater, Brown, Roberts and Barrett (1997) have termed the "first wave" of prediction research, in predicting children's later performance on more traditional psychometric assessments of intelligence. It was argued that the lack of predictive validity was due to the fact that the infant "mental scales" measured perceptual and motor development, which are different from the cognitive and intellectual abilities measured in childhood. Accordingly, the search began in a "second wave" of prediction research for cognitive measures of infant performance that might display stability into childhood, and correlate better with abilities measured by childhood intelligence tests. This "second wave" of research also holds implications for the haptic modality.

Information Processing Theory

The "second wave" of prediction research was based on the information processing framework whose basic assumption is that thinking is information processing

(Snow, 1998; Siegler, 1991). Cognitive development and functioning are understood within this framework as the process by which information is entered into the brain through the sense organs and how it is perceived and processed by the infant. While the input and output (i.e., infant response) features of information processing can be observed, the internal processing remains unseen. The internal processing or inner mechanisms that produce cognitive growth are the focus in this framework (Siegler, 1991). Two proposed mechanisms consist of the acquisition of cognitive skills that improve the way information is processed (e.g., strategies for remembering information improve with age) and changes in the rate of acquiring and processing information. Theoretically, these abilities improve with age and experience. The research aimed at predicting, from infancy, cognitive abilities in later childhood implicates perceptual-cognitive abilities as likely analogs for childhood information processing skills. The visual and auditory modalities have been the primary foci of research on infants' information processing abilities.

The perceptual-cognitive analogs for information processing skills consist of habituation, response to novelty (or dishabituation), and recognition memory. Paradigms testing these abilities permit the study of different aspects of perceptual and cognitive development in infancy such as encoding, memory, retrieval, and comparison of new and familiar stimulation (Bornstein, 1981; Lamb & Bornstein, 1987; McCall, 1994). Habituation is the decrement in attention infants pay to a continuously available or repeated stimulus, which cannot be accounted for by change in state, response fatigue, or sensory adaptation (Bornstein et al., 1997). Infants' habituation to a repeatedly presented stimulus has been conceptualized as a build-up of an internal representation or mental trace of the stimulus, and as involving the creation of a mental schema or mental representation of the stimulus (Bornstein & Tamis-LeMonda, 1994; Cohen & Gelber, 1975; Columbo, 1993; Lhote & Streri, 1998). In addition, the waning of attention is thought to reflect internal comparisons of mental representations, or the comparison of an internal memory representation or trace of a stimulus to that of a subsequently presented stimulus (Bornstein & Sigman, 1986; Bornstein & Tamis-LeMonda, 1994; Colombo, Mitchell, O'Brien & Degen-Horowitz, 1987; Rose & Tamis-LeMonda, 1999; Zelazo, Kearsley & Stack, 1995). When a match between the stimulus and the representation occurs, infants are less likely to look at the recognized stimulus (Lhote & Streri, 1998) and the subsequent waning of attention is thought to indicate cognitive familiarity with the stimulus. In addition, habituation, or the duration of attention towards a stimulus, is thought to reflect the rapidity or efficiency with which infants acquire or process information about the stimulus (Columbo, 1993). Greater decrements, quicker declines, or relatively lesser amounts of cumulative looking are generally inferred to indicate more efficient styles of information processing (Bornstein & Sigman, 1986; Columbo, 1993). The research on infant visual attention has supported the view of habituation as reflecting infants' speed of processing or rate of acquisition and encoding of information about a stimulus (Bornstein & Sigman, 1986; Columbo, 1993).

Response to novelty and recognition memory are related processes that also index information processing abilities (Rose & Tamis-LeMonda, 1999). Response to novelty, or dishabituation, is the recovery in attention infants show to a new stimulus. It is measured by the relative amounts of looking infants pay to novel over familiar stimuli. Recovery of attention to novel stimulation suggests that infants discriminate between familiar and novel stimuli (Lhote & Streri, 1998) and that the decline in attention during habituation was not simply due to receptor adaptation or fatigue (Columbo, 1993). Discrimination abilities are also thought to involve comparisons of mental representations of familiar and novel stimuli. That is, discrimination abilities suggest that infants have formed a memory of the familiar stimulus to which they compare the novel stimulus (Bornstein et al., 1997) and that the comparison has not led to a match between these two mental representations (Cohen & Gerber, 1975). In turn, infants attend to, or continue to explore novel stimuli. Relatively greater amounts of looking at novel stimuli are interpreted as more efficient information processing (Bornstein & Sigman, 1986).

Recognition memory, or memory for the familiar, habituation, stimulus involves similar comparisons of mental representations and is inferred based on the response to novelty (Columbo, 1993). Recognition memory is inferred when following renewed attention to a novel stimulus, the infant's response declines when the old stimulus is reintroduced. Alternatively, recognition memory is also inferred when the infant shows a greater preference for novel relative to familiar stimuli when these are presented simultaneously following habituation. These responses to the novel relative to the familiar stimulus are based on the learning or acquisition of information about a stimulus that has been previously viewed, and on the retention of this information in memory. A systematic response to the novel stimulus cannot occur if the infant cannot remember which of the two he or she has previously seen (Columbo, 1993). Habituation, response to novelty, and recognition memory have been widely interpreted in terms of speed and rate, or accuracy, efficiency, and completeness of information processing (Bornstein & Sigman, 1986; Bornstein et al., 1997, McCall & Carriger, 1993; D.H. Rose, Slater & Perry, 1986; Sigman, Cohen, Beckwith, Asarnow, & Parmelee, 1991; Sigman, Cohen, Beckwith & Parmelee, 1986).

Three avenues of research have provided substantial evidence that information processing measures indeed tap into and assess the mental capacities of infants (Rose & Tamis-LeMonda, 1999). First, developmental studies within the first year of life have identified age related changes in information processing abilities (Rose & Tamis-Lemonda, 1999). Across age, infants habituate faster, and display shorter accumulated looking times to habituation (Bornstein, Pêcheux & Lécuyer, 1988; Columbo, 1993; Colombo & Mitchell, 1990; Slater & Morison, 1985), and more reliable and faster responses to novelty (Fagan, 1974; Rose, 1983; Rose et al., 1982; Richards, 1997). Second, studies on the discriminant validity of information processing measures have been found to reliably distinguish risk groups (e.g., Down's Syndrome infants, cocaine-, alcohol- and polychlorinated biphenyis- (PCB) exposed babies, and full-term infants with health problems or nutritional deficiencies) from age-matched low-risk controls (Rose & Tamis-LeMonda, 1999; Zelazo, Weiss, Papageorgiou & LaPlante, 1989). Infants "at risk" for cognitive delay or handicap have been shown to habituate less efficiently than low risk controls, to exhibit novelty preferences at older ages, and to continue displaying difficulties in processing speed well into childhood (Cohen, 1981; Friedman, 1975; Jacobson, Fein, Jacobson, Schwartz, & Dowler, 1985; Jacobson, Jacobson, Sokol, Martier & Ager, 1993; Lester, 1975; Rose, 1980, 1983, 1994a; Rose, Feldman, McCarton & Wolfston, 1988; Rose, Gottfried & Bridger, 1978). Finally, studies of visual and auditory information processing in infancy have shown continuity with performance in childhood (Bornstein et al., 1997; McCall, 1994; Rose & Tamis-LeMonda, 1999). Predictive validity research has documented moderate to strong relations between infant information processing measures, and measures of intellectual functioning, vocabulary, and language comprehension in toddlerhood and childhood for both full-term (Bornstein & Sigman, 1986; Bornstein et al., 1997; Fagan & Singer, 1983; Lewis & Brooks-Gunn, 1981; McCall & Carringer, 1993; Miller et al., 1979; D.H. Rose, et al, 1986; Ruddy & Bornstein, 1982; Tamis-LeMonda & Bornstein, 1989, 1993) and pre-term infants (O'Connor, Cohen and Parmelee, 1984; Rose & Feldman, 1995; Rose, Feldman, & Wallace, 1988, 1992; Rose, Feldman, Wallace, & Cohen, 1991, Rose, Feldman, Wallace & McCarton, 1989, 1991; Sigman et al., 1986, 1991).

The clinical utility of both visual and auditory infant information processing measures for detecting mental retardation has also been supported. In a longitudinal study, Rose, Feldman and Wallace (1988) found that a cutoff of 54% novelty preference at 7 months correctly identified 8 of 11 children who had IQ scores in the mentally retarded range and 42 of 45 children with IQ scores above this range (see also Fagan & Vasen, 1997). Zelazo and Kearsley (1984) and Zelazo (1988) also discriminated developmentally delayed infants (i.e., presenting with a delay of at least 4 months on the Bayley Scales of Infant Development) with intact mental ability from those with impaired mental ability. They used a Standard-Transformation-Return paradigm in two visual and three auditory tasks. A standard stimulus event (either visual or auditory) was repeatedly presented for a fixed number of trials, followed by a novel transformation in the event. Finally, a return to the standard was represented in order to assess recognition memory. A "cluster" of behavioural measures (i.e., visual fixation, smiling, vocalizing, pointing, and clapping) as well as heart rate were used as indices of information processing. The information processing procedures identified 75% of the sample of children as having age appropriate information processing ability, despite delays. The children then received treatment for the delays. The "intact" group improved following treatment, while the "impaired" information processing group did not. This pattern of results held up as children entered school. The ability of information processing procedures to identify children with intact mental ability suggests that conventional tests may be misleading. Moreover, the ability to distinguish between children with intact and impaired mental ability on the basis of information processing measures and to predict future functioning supports the contention that these measures tap central processing ability (Zelazo et al., 1995).

The information processing perspective has also contributed to extending the knowledge of infants' haptic perception and processing abilities, and ultimately to understanding the contributions of haptics to development. The indices of habituation, response to novelty, and recognition memory have also been applied towards understanding the nature of the information encoded, processed, and retained through haptics, the efficiency, or speed, with which information is processed haptically, as well as infants' haptic sensitivity and discrimination abilities. Most of the present knowledge of infants' haptic perception and information processing abilities has been derived from studies of shape perception, and to a smaller extent, studies of texture perception. The methodology of haptic perception research consists, in large part, of information processing paradigms, procedures, and measures. The methodology is reviewed below since it is critical to understanding the research on haptic perception and processing of shape and texture which follows.

Methodology of Haptic Perception Studies

The present knowledge about infants' haptic information processing has been obtained largely within the context of intramodal equivalence, cross-modal transfer and matching, and violation of expectancy paradigms. All of these paradigms rest on measures of habituation, response to novelty and recognition memory (Rose & Ruff, 1987). Intramodal equivalence refers to the recognition of an object in the modality in which it was originally presented. Infants are familiarized with an object in one modality, either visual or haptic, and then tested in the same modality. Cross-modal transfer refers to the recognition of an object in a modality other than that in which it was initially experienced: e.g., visually recognizing an object that has only been felt but never seen before (Rose, Gottfried, & Bridger, 1981a,b). Infants are habituated in one modality and tested for dishabituation or recognition in another modality (Rose & Tamis-LeMonda, 1999).

Novelty preferences are indexed in the visual and haptic modalities by greater visual attention, or active manipulation, respectively of the novel object. The novelty response on the test suggests that infants form a representation in one perceptual system (e.g., haptic) and successfully access it either in the same system (e.g., haptic) or in another (e.g., visual; Rose & Tamis-LeMonda, 1999). Negative findings, particularly in the crossmodal studies, may, however, be due to the memory demands placed on infants because of the sequential presentation of familiarization and test objects. Thus, a matching paradigm, where infants continue to explore the familiarization object in one modality during testing in the other, is sometimes preferred in crossmodal studies (Rose & Ruff, 1987). For example, two objects may be visible while the infant simultaneously handles an object identical to one of the two visible ones, but which is shielded from view. Successful transfer is indicated by a visual preference for the novel of the two visible objects.

Finally, in the violation of expectancy paradigm infants are visually presented with an object but when allowed to tactually explore it, it does not feel like the visible object (Rose & Ruff, 1987). Such experiments are believed to assess the highest level of transfer because of the formation of expectancies for the second sensory system. However, an important issue complicating the interpretation and usefulness of the findings is the choice of the behaviour that is used as an index of surprise or puzzlement.

The procedures employed within these paradigms consist of the fixed trials and infant-controlled habituation procedures which have been typically and reliably employed to study visual and auditory perception (Streri, 1993). While both procedures use the same two behavioural measures of decrement and recovery of attention from which to infer information processing (e.g., Bornstein & Sigman, 1986; Kisilevsky & Muir, 1984; Stack & Bennett, 1990), they differ on a number of variables which directly influence the findings. In the fixed trials procedure, the number, duration and interval between stimulus exposures is predetermined (Bornstein & Benasich, 1986). Thus, infant behaviour 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. That is, when infants are given time limits within which to become familiar with a particular shape during familiarization and a predetermined amount of time within which to display novelty responses, their responses may not reflect their true capacities for processing. In turn, the findings which indicate lack of discrimination may be attributed to limitations in the modality being tested when they may actually be a result of the limitations of the procedure employed. Furthermore, infants may not be equally exposed to a stimulus during the preset trials for reasons that also have little to do with processing (Bornstein & Sigman, 1986). The fixed time of familiarization and test trials does not take individual differences in haptic exploration into account (Streri, 1993). The majority of studies of haptic perception of shape, and all studies of haptic perception of texture have employed this procedure.

Infant-controlled procedures correct for the limitations of fixed trials procedures in that they permit tracking of individual courses of habituation and equate infants on degree of habituation. This procedure better reflects infants' sensitivities in that it ensures that every infant during visual habituation is looking in the spatial location of the stimulus at the time of stimulus onset, or in haptic habituation that every infant is handling the stimulus. Stimulus offset is set at the termination of infant looking or infant touching. This procedure permits infants to vary on the speed or rate of their habituation and on their pattern of fixations, or manipulations, before habituation. Thus, it yields assessment of individual differences (Bornstein & Benasich, 1986; Colombo et al., 1987). For these reasons, the infant-controlled procedure has gained popularity in the study of visual and auditory perception and it may also be more informative of processing rates and abilities within the haptic modality. However, it has been used in only a small minority of studies of haptic perception among infants under 5 months of age, and most of these have focused on perception of shape (e.g., Pineau & Streri, 1990; Streri, 1987; Streri & Pêcheux, 1986a,b; Streri, Pêcheux & Vurpillot, 1984).

Haptic Perception of Shape

Studies employing infant-controlled procedures have revealed that very young infants are capable of haptic (H-H) and visual (V-V) intramodal transfer of shape information, but V-V transfer becomes easier, requiring less familiarization time, at approximately 4 months of age (Streri, 1987; Streri & Pêcheux, 1986a). Streri (1987) found haptic-haptic and visual-visual intramodal transfer with shapes that differed topologically (e.g., a solid disk from a disk with a hole in the middle) among 2- to 3-month-old infants following similar amounts of exploration (i.e., 91 and 105 seconds of haptic and visual exploration, respectively). Streri and Pêcheux (1986a) found that, following 90 seconds of haptic exploration, 5-month-olds can haptically distinguish between shapes differing along the rectilinear/curvilinear dimension (e.g., a six-pointed star from a six-petal flower-like object), as well as, between shapes that differ on a topological characteristic (e.g., a solid square from a square with a hole in the middle). However, visual discrimination occurred following only 33 seconds of visual exploration at this age. That is, there was a 2/3 decrease in visual exploration time to habituation for shape but no corresponding decrease in tactile exploration time between the ages of 2- to 3-months and 4- to 5-months (Streri, 1987; Streri & Pêcheux, 1986b). These studies were the first and only, to date, that were conducted using an infant-controlled habituation procedure in the haptic modality. The findings demonstrate that infants exhibit haptic habituation to the objects presented to them and react to novelty by holding an unfamiliar, relative to a familiar, object longer. These studies also illustrate that infant-controlled procedures, typically employed to study the visual modality, can be adapted to the study of the tactile modality (Streri, 1993).

Using fixed trial habituation procedures, studies of intramodal transfer of shape during the second half-year of life have shown that H-H transfer continues to be relatively slower (occurring after 30 sec of haptic familiarization) than V-V transfer (occurring after 15 sec of visual familiarization; Rose et al., 1981a,b; Rose & Orlian, 1991). At one year of age, infants are capable of haptically distinguishing a star from a circle, an octagon from an hour-glass shape, and a sphere with a protruding nipple from a sphere with a rectangular notch or missing segment (Rose et al., 1981a).

The results from studies of cross-modal transfer of shape have also yielded pertinent information regarding haptic perception and processing. Streri (1987) and Streri and Milhet (1988) found that 2- to 3-month-old infants were capable of H-V transfer but did not demonstrate V-H transfer abilities even when allowed to continue viewing the familiarization shape while they tactually explored an identical or different shape. Failure of V-H transfer in these studies was not due to the inability of the two systems to pick up information or to the lack of discrimination abilities in either modality. The two systems did not differ in familiarization time required to reach habituation and in the ability to transfer information intramodally (Streri, 1987). Interestingly, this asymmetry is reversed in infants between 4 and 6 months of age. Streri et al. (1984) and Streri and Pêcheux (1986b) found that 4- to 5-month-old infants ceased to exhibit any prior ability to transfer shape information from haptics to vision. Only V-H transfer was observed with a number of different shapes. Failure to find H-V transfer among 4- to 5-month-olds was not attributable to intramodal transfer difficulties since, like the 2- to 3-month-olds, these infants were capable of H-H and V-V intramodal transfer (Streri & Pêcheux, 1986b).

Streri and Molina (1994) proposed, given the developmental changes in sensory-motor abilities, that different factors account for the asymmetry in transfer at each age. They suggested that failure to observe V-H transfer in 2- to 3-month-olds may be due to infants' motor limitations. That is, infants at this age are limited in their ability to follow the contours of an object, a haptic exploratory procedure which is necessary for capturing information about object shape. Hence, following visual familiarity with a shape, they cannot haptically recognize the previously seen object. However, in a series of studies with this age group (Streri & Molina, 1993), they were able to observe V-H transfer when the visual display consisted of a flat drawing of an object rather than the real 3-dimensional object. Thus, the authors proposed that each modality may lead to a different representation of stimuli and that the different representations may account for the asymmetry in transfer at this age. Streri and Molina (1993, 1994) suggested that when infants are visually familiarized with 3-dimensional (3-D) objects, they construct a holistic, 3-D representation. In contrast, they suggested that haptic exploration with a 3-D object leads to an analytic level representation, or a representation of the object parts, but not to a full representation of its 3-D structure. Thus, following visual familiarization with a 3-D object, infants fail to haptically recognize a 3-D object following visual familiarization because recognition requires that they descend from their higher-level, holistic and 3-D representation to representation of lower dimensionality. Thus, V-H transfer of 3-D objects is not observed. However, when the visual presentation of the object is reduced from 3-D to 2-D, haptic recognition occurs by matching representations at a single level, and V-H transfer is observed. In contrast, infants are capable of H-V transfer of 3-D objects by moving upward from a lower-level to a higher-level representation. Their account of the asymmetry in transfer at this age also suggests that it is difficult to recognize analytic level properties of a stimulus (i.e., obtained haptically) once its holistic level has been perceived (i.e., visually). That is, visual exploration does not lead to a representation of information transferable to haptics, whereas haptic exploration leads to representations of object shape that are transferable to vision (Streri, 1987).

Streri and Molina (1994) argued that the asymmetry in transfer observed at 4- to 5-months needs to be accounted for differently given that infants at this age are in an important stage of sensory-motor development. The superiority of V-H transfer found at 4-5 months, and the absence of H-V transfer, were attributed to the development of visuo-prehensile coordination (i.e., the visual control of handling objects; Streri, 1987; Streri &

Pêcheux, 1986a). Streri and Pêcheux (1986a) and Streri and Molina (1994) suggested that during the development of visuo-prehensile coordination at 4- to 5-months, the motor activity and functions of the hand predominate over its perceptual functions. That is, the infant's newly acquired ability to transport objects, to bring objects to the field of vision, to move his/her arms and to coordinate both hands predominate over the perceptual, fine-motor abilities and the manipulatory activity that are necessary for the recognition of the object. They concluded that when 5-month-olds hold small and simple objects in their hands such as those in the Streri and Pecheux studies (1986a, 1986b), in the process of trying to transport the object to the mouth or the eyes, they detect little information. Although this information may be sufficient to discriminate the object intramodally, it is not sufficient to recognize it visually.

There is support for the view that movement is the predominant feature at this age. Four- to 5-month-olds who miss their target when reaching for objects do not correct their movement but rather start the reach over from the beginning (Bower, 1974). In addition, Streri and Pineau (1988) have demonstrated that infants' movement of the object could interfere with awareness of object properties. They conducted two experiments with haptic familiarization and test phases. In the first experiment they demonstrated that 5-month-olds could discriminate a sphere from a cube haptically. In the second experiment a sphere or a cube was placed on a turnable crank attached to a box. Infants were helped to turn the crank by holding the sphere or the cube for eight 10 second trials (i.e., the mean duration of habituation phase in the first experiment). The test phase was the same as in the first experiment, however, no evidence of discrimination was found. They concluded that infants could not simultaneously attend to the action on the device and to the properties of the object they were holding. This study illustrates the interference of motion on the perceptual capacities of the hand (Streri & Molina, 1994).

In addition, studies have shown that 4- to 5-month-old infants are capable of H-V transfer of properties such as object unity and boundaries when exploration is bimanual and when it involves considerable movement of the objects (Streri & Spelke, 1988, 1989; Streri, Spelke, & Rameix, 1993). For example, Streri and Spelke (1988) gave infants rings to hold (one in each hand, and out of view) that were rigidly connected and moved together or that could be moved independently. Infants who explored the independently moving rings perceived two distinct objects during a visual test with rings that were connected or separated. Infants who explored the rigidly connected rings perceived a single object. In another study, Streri et al. (1993) gave infants a device they could manipulate, but not see, that was made of two surfaces, one small and one large. In one condition the surfaces were rigidly connected. In another two conditions, the smaller surface could be moved either vertically along the edge of the large surface, or it could be moved in a horizontal manner away and towards the larger surface. In the final two conditions, the infant held the device but the experimenter performed the vertical and horizontal sliding motions. On the visual test the device was presented as a single connected object, and as two separate parts (or surfaces). Infants who had handled the rigidly connected device visually perceived it as a single unit. Infants in the movement conditions visually perceived it as two units. When the experimenter moved the display, the infants' responses were indeterminate. These studies point to the importance of arm movements at this age, and their importance in the perception of object unity which can be transferred unlike, shape, from haptics to vision. Since the infant's attention at this age is focused on the transport and manipulation of objects, H-V transfer of shape may be suppressed.

However, the absence of H-V transfer of shape is thought to be specific to 5-month-olds, since by 6 months the data show that infants consistently visually recognize felt objects. H-V transfer of shape reemerges and is consistently observed during the second half-year of life. Ruff and Kohler (1978) found that 6-month-old infants haptically familiarized with a cube could visually discriminate it from a sphere. Bryant, Jones, Claxton and Perkins (1972) found H-V transfer among 6.5- to 11-month-old infants using an ellipsoid paired with an ellipsoid with a rectangular notch or missing segment. Rose et al. (1981b), using two pairs of stimuli, a cylinder paired with a cylinder incised with curved indentations and a cross paired with a tapered ellipsoid, found H-V transfer among 6 month-olds after 60 seconds of haptic familiarization. In the same study (Rose et al., 1981b), when memory demands were reduced by permitting infants to keep the familiar object in their hands during the visual test, the 6-month-olds displayed H-V transfer after 45 seconds of familiarization, however, only with the cylinder pair. Twelve-month-olds performed the same H-V transfer tasks after only 30 seconds of haptic familiarization (Gottfried, Rose & Bridger, 1977). Rose et al. (1981b) concluded that younger infants are capable of H-V transfer but are hampered by a slower rate of acquiring information haptically. Moreover, H-V cross-modal transfer of shape seems to be dependent on sufficient familiarization time, the paradigm employed (matching or successive presentation), and the selection of stimulus shapes.

Interestingly, among 12-month-olds, cross-modal transfer from haptics to vision appears to be easier than transfer in the opposite direction despite, at this age, the faster speed of processing within the visual modality and the relative ease of V-V intramodal transfer as compared to H-H intramodal transfer (Gottfried et al., 1977; Rose, 1990b, 1994b; Rose et al., 1981a,b; Rose & Orlian, 1991). Gottfried et al. (1977) found 12-month-olds were capable of H-V transfer after 30 seconds of familiarization, however, in a later study using a variety of different shapes, Rose, Gottfried and Bridger (1981a) found evidence of V-H transfer after only 60 seconds of visual familiarization, but not after 30. These results suggest that at one year of age, like at 2 to 3 months of age, H-V transfer may again be superior to V-H transfer. At one year, cross-modal recognition of equivalences seems to be easier when haptic rather than visual information is the basis from which judgments are made. Rose (1990b, 1994b) has suggested that this asymmetry in the difficulty of cross-modal transfer at one year implies that the hand and the eye may be sampling different stimulus characteristics rather than directly processing or detecting the same invariants or the same amodal stimulus properties.

A number of studies using the violation of expectancy paradigm have shed additional light on the transfer of information between haptics and vision in infancy. Bushnell (1978, cf. Bushnell & Boudreau, 1991) and Bushnell and Weinberger (1987) using this paradigm allowed infants to see one object while simultaneously touching a second object, either identical or different than the one in view. Bushnell (1978) and Bushnell, Weinberger and Polan (1984) observed that for certain discrepancies 15- and 11-month-olds, respectively in each study, exhibited surprise and problem-solving behaviours such as manual search. Bushnell et al. (1984) found that 11-month-old infants' detection of discrepancies was dependent on the nature of the seen object, i.e., on the presence of "distinctive" visual features of the seen objects. Infants detected discrepancies in which they saw a) an egg and felt a cube and b) saw a fur covered cube and felt an egg and c) saw a cross and felt a fur-covered cube. Infants did not detect the discrepancies in which they saw: a) a cube and felt a cross or b) saw a cube and felt a fur-covered cube. The authors concluded that the detected discrepancies involved a "distinctive" feature of the seen object that could not be found manually. The discrepancies which involved a feature of the felt object which was absent from the seen object were not detected.

In a follow-up study, Bushnell and Weinberger (1987) confronted infants with discrepancies that were the converse of those which seemed to go unnoticed above. That is, they saw either a cross or a fur-covered cube and felt a plain cube. Both of these new discrepancies were detected. These data were again interpreted as evidence that visual information plays a directive, goal-setting role for infants' manual explorations. Bushnell and Weinberger (1987) also suggested that detection of V-H discrepancies appears easier when objects differed on more than one stimulus property relative to when they differed only on one, suggesting that additional cues are necessary for V-H transfer to occur. However, it also seems possible that visual information may interfere with tactile manipulations and in turn lead to failure to detect visual-tactile discrepancies.

Bushnell and Boudreau (1991) proposed that the research on haptic perception of shape can be sorted into three categories according to the nature of the stimuli employed. In some studies the stimuli differed topologically. That is, the differences between them would be preserved even under hypothetical bending and stretching, as with Streri's (1987) disk versus a disk with a hole in it. In some studies stimuli differed featurally, meaning that one contained abrupt angles, edges, and protrusions while the other contained only smooth curves, such as the cube versus the sphere or an octagon versus an hourglass. Finally, the third type of stimulus difference is configurational, meaning that both stimuli contained the same kind of features such as angles and edges but these were different in number or spatial arrangement for the two stimuli [e.g., cube and the cross-like solid pair employed by Bushnell (1978) and Bushnell and Weinberger (1987)].

Bushnell and Boudreau (1991) interpreted the results of the shape studies within this classification system. It seems that infants as young as 2, 3 and 4 months old can haptically perceive topological shape differences. Infants from 6 months on can haptically perceive featural shape differences. Even older infants (i.e., 6.5- to 11- and 15-month-olds), however, may have difficulty haptically perceiving configurational shape differences. Configurational shape perception by touch has been documented only among 18-month-old blind children to date (Landau, 1990, cf. Bushnell & Boudreau, 1991).

Although this post-hoc attempt at understanding the basis of infants' shape discriminations is valuable, more attention needs to be paid to systematic pre-selection of stimulus pairs with the aim of identifying the properties attended to by each modality (Rose, 1994b). When the objective, however, is to document the sensitivity and abilities of the haptic system, it may be more efficient to employ stimulus properties which are optimally salient to haptics, such as texture, rather than stimulus properties that are salient to vision (i.e., shape).

Haptic Perception of Texture

Arguments for the salience of texture to haptics are based on the functions and abilities of the hand, such as active or purposive touch (J.J. Gibson, 1962), and exploratory strategies that are best suited for its perception (Katz, cited in Krueger, 1982; Klatzky & Lederman, 1987). Among adults, haptic exploration has been found to be best suited and oriented for the perception of specific stimulus properties such as weight, hardness, and texture since these are generally available to haptics, while vision seems to be oriented towards the encoding of shape (e.g., Bushnell & Boudreau, 1991; Katz, cited in Krueger, 1982; Klatzky, Lederman & Reed, 1987; Lederman, Thorne & Jones, 1986). Moreover, when adults are permitted only haptic exploration they exhibit haptic exploratory procedures (EPs), or stereotyped hand movements that maximize the sensory input corresponding to a certain object property, permitting increased ease of encoding (Klatzky et al., 1987; Lederman & Klatzky, 1987). For example, when adults performed tasks involving the property of hardness they engaged in the "pressure" EP (i.e., squeezing or poking). For temperature tasks, they engaged in static contact or enclosure (i.e., enveloping as much of the object with the hand), and for weight, they engaged in "unsupported holding" (i.e., resting the object flat in the hand and lifting it away from any supported surface). For shape tasks, they engaged in "contour following" (i.e., moving the fingers smoothly and nonrepetitively over the edges of the object). Finally, when solving experimental tasks hinging on texture, adults exhibited "lateral motion" (i.e., rubbing the fingers back and forth) across the surface of an object. The lateral motion produces changes in local skin pressure, which varies according to an object's surface texture (e.g., roughness), permitting the encoding of texture.

The perception of a property such as texture offers an excellent opportunity to study the developing capabilities and limitations of the haptic system not only in adulthood (Lederman, 1982), but also in infancy. Recent evidence indicates that these haptic exploratory procedures emerge in human infants at approximately 6 months of age, and correspond with the emergence of texture perception (e.g., Bushnell & Boudreau, 1991). Texture perception has been postulated to emerge at this age because of simultaneous gains in differential arm and shoulder muscle accommodations, and substantial gains in fine motor control, although fine motor abilities are still relatively immature (Bushnell & Boudreau, 1991, 1993). Infants at this age can accurately reach for, grasp and manipulate objects. Many studies support the correspondence between texture perception and fine motor abilities. For example, 6- to 12-month-olds have been found to finger bumpy and rough objects more than smooth ones (Lockman & McHale, 1989; Ruff, 1982a, 1984; Steele & Pederson, 1977). Palmer (1989) found that 6-, 9-, and 12-month-olds picked up, released, and squeezed furry objects more than smooth plastic ones. However, the results of these studies are difficult to interpret in terms of haptic perception of texture since the objects' texture was also visible. Thus, infants' responses to different textures may have been motivated by visual discrimination and cues rather than haptic discrimination.

A number of other studies conducted with infants during the second half-year of life have demonstrated that infants respond to haptic texture information. Ruff (1982a) found that 12-month-old-infants, who looked at and handled objects, attended to the texture rather than to the colour of objects since they failed to detect novelty in colour during test trials. Bushnell (1982), employing a violation of expectancy paradigm, assessed 8-, 9 ½-, and 11-month-olds' texture discrimination abilities. Only 9 ½- and 11-

month-olds responded differently on trick (seen and felt object were different) and control trials (seen and felt object were identical). That is, they detected a V-H discrepancy between a fur covered cylinder and a knobby object made of smooth plastic. Similarly, Bushnell and Weinberger (1987) found that texture as well as shape can serve as a basis for cross-modal matching for infants. Using the violation of expectancy paradigm, 11-month-olds detected the discrepancy between a fur-covered cube they saw and a smooth wooden cube that they touched. In a subsequent study, Bushnell, Weinberger and Sasseville (1989, in Bushnell & Boudreau, 1991) presented wooden dowels to infants. Along the back of some dowels and out of view there was a strip of fur, sandpaper, or bumps while other dowels were plain. Twelve-month-olds, and to a lesser degree 9-month-olds, were more likely to lean forward in order to look at the back of the dowel after gripping a textured dowel than after gripping a plain one. Bushnell et al. (1989) suggested that haptic sensitivity to texture led to such exploratory behaviour. While these studies more convincingly suggest that infants were responding according to the haptic information, infants were nonetheless permitted to simultaneously see the objects. Thus, it is unclear which component, visual or haptic, contributed to the exploratory behaviour.

Although sparse, studies designed to eliminate the visual component of stimulation have also indicated that infants are capable of texture discrimination. Bushnell, Boudreau, Weinberger and Roder (1992) presented surfaces that were textured on one side (e.g., soft bristles or several short cylinders) and plain on the other to 7- to 8-month-olds seated in the dark. Infants touched the textured surfaces longer than the plain surfaces, indicating that they discriminated the two. In addition, they found that while infants touched and explored both a shallow well of water and a patch of brush bristles equally, they used two hands when exploration occurred in the light and only one hand when they explored in the dark. Infants' exploratory strategies also varied as a function of the nature of the stimulus. Infants scrumbled (i.e., alternately flexed and extended their fingers) on the brush more than on the water, and they banged the water more than the brush. These results appear to indicate that infants can discriminate object properties through touch and, like adults, use distinct hand movements or exploratory procedures to evaluate specific object properties. Finally, infants' exploratory procedures were more pronounced in the dark. This may be due to the lack of vision in general, or because vision may not be integral to the adaptations infants make with their hands to different stimuli (Bushnell et al., 1992).

While, in some of the aforementioned studies, attempts were made to eliminate some or all visual cues, the results remain confounded by the lack of systematic control over the stimulus properties being examined. Stimuli in the reviewed studies simultaneously varied along a number of dimensions including shape, size, weight, and temperature. For example, texture is confounded with shape when bumpy surfaces or brush bristles are paired with smooth surfaces.

Recently Stack and Tsonis (1999) conducted a study designed to clarify findings on infants' haptic perception abilities by isolating texture and exercising stringent control over confounding stimulus properties and eliminating visual cues. Seven-month-old infants participated in either a Touch-no-Vision (T) condition where textures were occluded by an opaque plastic cover or a Touch-plus-Vision (T+V) condition where a transparent plastic cover was employed. The texture stimuli consisted of smooth cotton flannel and rough carpet lining. The smooth and rough textures were visually identical in size, shape, colour and weight. Following the Familiarization phase, during which 30 sec of tactile contact with one of the two textures was acquired, infants participated in two sequential test phases, each 30 sec in duration. Infants in the experimental group received a novel texture during the Novelty phase and the original texture in the Return-to-Familiar phase. Infants in the control group received the same texture in all three phases.

Both experimental and control infants displayed similarly high and sustained levels of haptic manipulation during the Novelty phase in both the Touch-no-Vision and Touch-plus-Vision conditions. The high levels of responding among control infants during this phase suggested that the familiarization time employed was insufficient for complete processing of the original texture. Consequently, it was not possible to isolate whether the high levels of responding demonstrated by experimental infants during the Novelty phase reflected a true response to the novelty in texture. However, infants' responses during the Return-to-Familiar phase were indicative of recognition memory for the original Familiarization texture. The experimental group's manipulation levels were significantly higher than the control group's levels on the initial Return-to-Familiar trials, however, then decreased by the last Return-to-Familiar trial to the meet the lower levels of the control group. This suggests that the experimental infants discriminated between the two textures and that they may have formed and retained in memory a representation of the original texture. Haptic sensitivity to changes in texture were also reflected in infants' visual attention. Specifically, experimental infants exposed to changes in texture, looked towards the stimuli more, relative to control infants, regardless of whether the textures were visible or not. This group difference suggests that experimental infants perceived the changes in texture and reflected their perception through direction of their visual fixation.

Consistent with past research findings that finer exploratory strategies are enhanced in the dark (Bushnell et al., 1992), experimental infants in the Stack and Tsonis (1999) study scrumbled more than control infants when the textures were not visible, relative to when they were visible. Vision may have interfered with tactile exploration because of the lack of visually detectable discriminations between the smooth and rough textures. This interpretation is compatible with findings from Bushnell and Weinberger (1987), who had infants view one object while, simultaneously and out of view, touch a different one. Infants' haptic manipulations corresponded to the visual distinctive features rather than to the haptic cues. For example, infants displayed greater poking, gripping, and digging when they felt a smooth wooden cube but saw a furry cube than when they (a) saw the smooth wooden cube but felt the distinctive furry one or (b) saw and felt the same object. Taken within the context of the Stack and Tsonis (1999) study, infants faced with conflicting visual and haptic information seemed to rely primarily on vision which provided no cues. Hence, they did not exhibit any exploratory procedures. These findings support the contention that vision may not be necessary for, or even distract attention from, the adaptations infants make with their hands to haptic stimuli (Bushnell et al., 1992).

Visibility of the textures did, however, lead to higher levels of total attention, visual fixation, bimanual exploration, and simultaneous fixation and manipulation relative to the Touch-No-Vision condition (Stack & Tsonis, 1999). This is compatible with the results of Bushnell et al. (1992) in which infants employed both hands significantly more when tested in light as compared to dark, and it is consistent with a number of studies demonstrating that infants' manipulation of objects is accompanied by visual fixation (Rubenstein, 1974; Ruff, 1976, 1986, 1989). However, the additional haptic exploration acquired in the Touch-Plus-Vision condition (i.e., through greater amounts of bimanual contact) and the simultaneous visual and haptic manipulation did not appear to facilitate texture discrimination.

Collectively, these results provide some insight into haptic perception of texture. First, there was evidence, reflected in both haptic and visual behavioural measures, that 7-month-old infants are sensitive to changes in texture. Second, vision does seem to increase infants' total attention and fixation, direct both hands towards the stimuli and lead to greater amounts of simultaneous visual and haptic exploration. However, these effects of the visibility of the textures did not seem to aid infants in the Touch-plus-Vision condition in haptically discriminating the textures. Rather, it appeared to hinder their exploratory procedures. It is also likely that the perceptual discrimination task in the Stack and Tsonis (1999) study was more difficult relative to those of past studies because stimulus cues other than texture were not available even when infants could see the textures. More importantly, the findings highlight a limitation of the fixed-trials procedure in that they indicated that infants required more familiarization time in order to fully process texture than was expected, and allotted, on the basis of past studies on haptic discrimination of shape. Given the fixed familiarization time, the quality of contact with the stimulus during familiarization may not have been equivalent across all infants. It is likely that the findings, and the understanding of infants' haptic processing of texture, were limited due to the paradigm selected.

Interestingly, there have been no attempts to directly investigate texture perception, either by haptics alone or even in conjunction with vision, among infants during the first half-year of life. The majority of research on haptic perception in infancy has involved infants in the second half-year of life or older. These infants are already skilled at visually guided reaching and object exploration (Bushnell, Rosenblatt, Gill, & Striano, 1996). A few texture perception studies have been conducted with infants in the second half-year of life, while the majority of research on haptic perception with younger infants has focused on the property of shape (e.g., Streri and Pêcheux, 1986a,b; Streri, 1987). The lack of studies on texture perception in infants younger than 6 months of age may be due to the hypothesis that haptic perception is directly linked to manual motor control and that young infants may have difficulty perceiving an object's texture because they cannot yet engage in the specific hand movement patterns optimal for exploring texture (Bushnell & Boudreau, 1991; Bushnell et al., 1996). In addition, Bushnell and Boudreau (1991) have proposed that if the studies of featural shape differences are considered as studies of texture perception then these would suggest that infants younger than 6 months of age cannot readily perceive texture.

This analysis raises, however, a critical issue in the area of haptic perception: the definition of texture and shape. According to Bushnell and Boudreau (1991) texture is considered to be akin to featural shape and thus defined by the presence or absence of features such as angles, edges and protrusions. These features distinguish object pairs such as cubes and spheres, octagons and hourglasses, cylinders and pyramids. However, the property of texture also denotes the feel of an object such as its degree of softness or roughness as was exhibited by some of the stimuli employed in studies of texture perception such as fur, bristle or sandpaper covered surfaces. Moreover, in the adult haptic literature texture is primarily defined as a substance related attribute (assuming homogeneous objects or regions), whereas shape is a global structural property (Klatzky et al., 1987).

The latter definitions of texture and shape have been supported in the adult haptic literature. Klatzky et al. (1987) investigated the cognitive representations of objects that are encoded through haptic exploration. Adults were asked to sort objects by similarity. Three groups of participants used only haptic exploration and were given different definitions of similarity. The haptically biased group was instructed to sort objects according to how similar objects feel, the haptics plus visual imagery group was instructed to sort objects according to similar visual images, and the unbiased haptics group was given no definition of similarity. A fourth group used vision, in addition to haptics, but similarly to the unbiased haptics group, they were not given a definition of similarity. The objects to be sorted differed factorially along the dimensions of texture (i.e., roughness), hardness, shape, and size.

Klatzky et al. (1987) predicted that haptic encoding without vision would most naturally focus on texture and hardness, whereas the addition of vision (either imaged or real) would lead to greater emphasis on shape and size. As predicted, the unbiased haptics and haptically biased groups were highly similar. Both groups found the substance dimensions of texture and hardness relatively salient, while the haptics plus visual imagery group found shape to be overwhelmingly salient. The haptics plus vision group showed salience to be more equally distributed over the dimensions. Thus, Klatzky et al. (1987) argued that the haptic and visual systems have distinct encoding pathways with haptics oriented towards the encoding of substance rather than shape. Moreover, they argued that this may reflect a direct influence of haptic exploratory procedures that are executed under unbiased haptic encoding. The procedures were those that are generally found to be rapid and accurate permitting high "ease of encoding".

If the haptic modality is oriented to the encoding of texture when considered as substance, rather than shape, then predictions of texture perception abilities in infants in the first half-year of life should not be based on their abilities to haptically perceive featural shape differences. Rather, texture defined as substance is more akin to topological shape differences. That is, they are preserved under hypothetical bending and stretching. When texture is defined in this manner it eliminates confounding properties of shape such as bumps and angles. Streri's (1987) findings of topological shape discriminations among 2- to 3-month-olds may thus suggest that texture is relatively salient to haptics even at such a young age and is worthy of further investigation.

In addition, exploration in the haptic modality may already be geared towards the encoding of texture. For instance, Streri (1987) noted that the 2- to 3-month-old infants engaged in precision handling of objects and in finger pression, opening and closing of the hand, and sliding the thumb or all fingers over the surface. These observations suggest that the limited fine motor and exploratory procedures that 2- to 3-month-old infants are motorically capable of include those that are most efficient for texture perception among adults (e.g., lateral motion) and that these may be sufficient for the perception of texture.

Thus, there seems to be ample reason to pursue the investigation of texture perception during the first half-year of life. However, only one such recent investigation exists. Bushnell et al. (1996) examined 3-month-olds' haptic perception of material properties. Infants were tested in the dark with a series of "dumbell" shaped stimuli with either a metal spring or a sponge curler as the shaft, and nerf balls on both ends. The spring and curler differed in texture, temperature, and compliance, but not perceivably in size, shape, or weight. Infants' fingers were placed around the shaft, and were permitted to hold and freely explore each stimulus until they dropped it, or for a maximum of 25 seconds. The results were interpreted cautiously since evidence of discrimination was indirect. That is, only the infants who were exposed alternatively to both stimuli displayed overall higher activity levels than infants exposed only to one stimulus repeatedly. These infants also preferred the curler stimulus, holding it longer and mouthing it more than the spring. The authors concluded that very young infants: 1) may be able to perceive material properties with their hands but do not manifest this ability in manual activity per se, possibly on account of their limited repertoire of manual exploratory behavior; and 2) may encode stimuli mainly in terms of how they feel to the mouth or in terms of hand posture required to hold them and since the stimuli were identical in this respect, they did not discriminate them more dramatically. In addition, they concluded that stimulation received through the hands seemed to primarily affect infants' overall arousal levels and perhaps their inclination to explore the stimuli orally. Their findings and conclusions unfortunately, are difficult to interpret vis à vis texture perception since the pair of stimuli employed also differed on the dimensions of temperature, compliance and shape (i.e., when the grooves between coils of the spring are considered).

Summary

As underscored by the literature review, touch and haptics serve important and vital functions in promoting adaptive infant development. Tactile stimulation serves to organize and foster biological, physical and intersensory perceptual functions. It also fosters adaptive attachment and social and sexual behavior. Integration and differentiation theories of development have acknowledged the importance of haptic stimulation and exploration in perceptual learning and cognitive development. Ensuing research has substantiated that infants, from birth, are sensitive and responsive to haptic stimulation, and engage in haptic exploration as a means of learning about the world and its physical properties. Haptic perception and information processing procedures and measures have documented that infants process a variety of stimulus properties through haptic exploration, form mental representations of haptically perceived information, and can transfer this information to vision. Haptics appears to be an "expert" system for the acquisition of specific information about the world, such as texture, temperature, substance and weight.

While there is a firm theoretical and empirical base that supports the importance of haptics in infant development, the knowledge of the functioning of this modality and of infants' haptic perception and information processing abilities is limited for many reasons. First, as indicated in the literature review, the current knowledge of infants' haptic processing abilities has arisen mainly out of research efforts to study infants' cross-modal abilities (i.e., between haptics and vision). In turn, since infants' motor-haptic abilities are thought to be limited, most of this research has been conducted with infants over 6 months of age. Thus, very little is known about infants' haptic perception and processing during the first half-year of life, despite the evidence supporting the importance of this modality, and the haptic abilities of infants during the early months of life. Second, even the few intramodal haptic studies conducted during the first half-year of life, and all those conducted with older infants have centred on the perception and processing of the stimulus feature of shape. While these studies have been informative regarding infants' abilities, studies of texture perception would provide a more precise assessment and documentation of the contributions of haptic processing to cognitive growth. Detection of texture is considered best achieved by touch, relative to other sensory modalities (Bushnell & Boudreau, 1991; Klatzky et al., 1987; Lederman et al., 1986). It therefore follows that the study of this, or any other, perceptual modality and its sensitivity, processing and development therein, would best be served by the use of the most appropriate and salient stimuli.

Third, the few efforts to study texture perception in infancy have been limited by the availability of concurrent visual information. Isolating the sense of touch from vision is a particularly difficult challenge with infants who are interested in exploring their world and are not likely to take kindly to blindfolds, or to the dark. However, the presence of visual information leads to difficulties in ascertaining the independent functioning, sensitivity and contributions of haptics, as well as the nature of the information attended to, detected and processed through haptics. Fourth, studies of texture perception, even the few that have controlled for simultaneous visual information, are confounded by a lack of systematic control over competing stimulus properties such as shape, size and temperature. Thus, it is unclear which stimulus properties infants are attending to and processing during haptic exploration. In turn, any interpretations regarding infants' perception of texture and haptic abilities, are limited. Finally, the majority of studies on haptic perception of shape and all studies of texture have employed methodology, such as fixed-trials habituation procedures, that impose experimental constraints on infants and, as a result, influence the experimental results obtained. Subsequently, interpretations regarding haptic perception and processing abilities are also constrained and equivocal. The end result of these limitations is inadequate understanding of infants' haptic information processing abilities.

The pervasive implications of touch and haptics for a vast range of developmental functions clearly validate and support the attention and research dedicated to haptics to date. However, the limitations in this domain of research highlight the need for further research. Specifically, research directed at assessing infants' haptic processing abilities, independent of vision, and during the first half-year of life is warranted. Moreover, research should take into consideration the methodological issues of stimulus properties and experimental paradigms in order to obtain a clearer picture of haptic sensitivity, acuity, and processing capacity early in infancy.

The Present Research: Rationale and General Objectives

Two studies were designed to contribute to the understanding of infants' haptic abilities during the first half-year of life by studying their texture perception abilities. Study 1 was designed to assess infants' intramodal haptic perception of texture. Study 2 was designed to assess the functioning of the haptic modality during bimodal, haptic and visual, exploration. The same infant-controlled habituation procedure was employed in both studies, as was a habituation (HAB)-novelty (NOV)-return-to-familiar (RFAM) paradigm. During the HAB phase a texture stimulus was repeatedly presented to infants until they reached a preset habituation criterion. The habituation criterion was based on past infant-controlled studies of visual habituation and of haptic shape perception. The NOV and RFAM test phases each consisted of 3 infant-controlled trials. A novel texture was presented in the NOV phase, and the original HAB phase texture was presented in the RFAM phase. The same set of two textures were used in both studies. In Study 1, infants were permitted only haptic exploration of the textures, and vision of the textures was occluded in all phases by a cover placed at upper chest level. The purpose was to assess whether infants could process and discriminate textures on the basis of haptic exploration alone. In Study 2, the cover was transparent during the HAB phase, permitting bimodal, haptic and visual exploration. This permitted an evaluation of infants' haptic habituation patterns during bimodal exploration. However, vision was occluded during the test phases in order to assess what information was processed by the haptic modality during the bimodal HAB phase.

Four general objectives set the basis for the design of the two studies. The first objective was to assess infants' haptic perception abilities, specifically their haptic processing speed, discrimination or response to novelty, as well as their recognition memory for haptic stimulation, during the first half-year of life. Given the salience of texture to haptics and to tap into the perceptual potential of the haptic modality, a texture discrimination task was employed. This objective was realized in Study 1 with the isolation of haptics from vision in order to obtain a clear understanding of the independent perceptual abilities of the haptic modality. The infant-controlled HAB-NOV-RFAM procedure permitted assessment of haptic: 1) speed of processing; 2) discrimination; and 3) recognition memory abilities. A no-change control group received the original HAB phase texture during the 6 trials corresponding to the NOV and RFAM trials. Infants were expected to discriminate texture solely on the basis of unimodal haptic exploration and habituation, and to display recognition memory for texture information. These abilities were expected to be observed on the haptic behavioural measures of total haptic manipulation and on the more specific forms of haptic manipulation, infants' exploratory procedures (i.e., stroking and scrumbling).

The second objective consisted of examining the influence of vision on infants' haptic abilities. The predominating notions that vision is the dominant sensory modality and that haptic perception is limited before the development of visual-motor coordination (since vision is integral to infants' haptic manipulations) formed the basis for this objective. Thus, the two studies were designed and conducted in a sequence that specifically addressed whether, and how, vision influences infants' haptic processing, discrimination, and recognition of texture, as well as how it affects their exploratory procedures. That is, in Study 1 haptics was isolated from vision during an infant-controlled texture habituation task. This permitted an assessment of infants' abilities to process texture information and to discriminate texture solely on the basis of haptic exploration. However, in Study 2, infants were permitted both haptic and visual exploration during the HAB phase. Thus, Study 2 permitted an examination of infants' haptic habituation and exploratory procedures during a bimodal condition that was similar to their opportunities for exploration in their natural environments. In addition, occluding vision during the test phases in Study 2 and testing for haptic discrimination and recognition memory abilities, served the purpose of examining the nature of the information processed during the bimodal HAB phase. Finally, since the same methodology was employed in both studies, statistical comparisons across the two studies were possible in order to document the impact of vision on haptic perception of texture. The systematic manipulation of vision uniquely contributes to the understanding of the relations between haptics and vision during the first half-year of life. Specifically, the questions addressed were whether and how vision alters: 1) the rate of haptic processing of texture information during habituation; 2) the nature of the sensory information attended to, and processed during habituation, and therefore infants' haptic discrimination of, and recognition memory for, texture information and 3) haptic exploratory procedures and bimanual manipulation.

It was hypothesized that the visibility of the textures would lead to faster habituation and less total duration of haptic manipulation to the habituation criterion in Study 2, relative to Study 1. However, infants were still expected to display texture discrimination and recognition abilities, following bimodal exploration during the HAB phase, in their levels of haptic manipulation. Thus, while the availability of visual information in Study 2 was expected to modify habituation patterns, it was not expected to interfere with infants' attention to, and processing of texture information during the HAB phase. This hypothesis was based on literature indicating very early haptic sensitivity and processing abilities (Rochat & Senders, 1991; Streri, 1987; Streri &

Milhet, 1988; Streri & Pêcheux, 1986a,b), and literature supportive of the Gibsonian idea that infants' exploration is geared towards the understanding of an object's affordance (Rochat, 1983; Rochat & Gibson, 1985; Rochat & Senders, 1991). Given that the stimuli in the present study were designed to be defined by texture, it was expected that even when the texture stimulus was visible during habituation, infants would attend to the haptically perceived property of texture, rather than, or in addition to, its visual properties. Moreover, the habituation criterion was based on infants' haptic manipulation levels. Habituating infants on the basis of haptic manipulation increases the likelihood that they are habituating to the haptic, texture properties of the stimulus, rather than the visible properties. Only if they attended to texture during bimodal habituation would they be able to detect the novel texture during the unimodal haptic test trials.

The visibility of the textures was, however, expected to influence the nature of infants' exploratory procedures and their bimanual manipulation. As observed in previous studies (Bushnell et al., 1992; Stack & Tsonis, 1999), the visibility of the textures was expected to dampen infants' exploratory procedures (i.e., result in lower levels of exploratory procedures) during the habituation phase of Study 2, relative to Study 1. As a result, discrimination and recognition memory abilities were not expected to be observed on the measure of exploratory procedures in Study 2, but only on the measure of haptic manipulation as stated above. The visibility of the textures was expected to direct both hands to the stimulus and to therefore lead to higher levels of bimanual manipulation during HAB in Study 2 relative to Study 1.

The third objective in the present set of studies was to examine developmental changes in: a) haptic habituation, discrimination, and recognition memory during unimodal haptic exploration (as reflected in age differences in Study 1) as well as during bimodal haptic and visual exploration (as reflected in age differences in Study 2); and b) haptic exploratory procedures, bimanual manipulation and visual attention responses during each of the unimodal (haptic) and bimodal (haptic and visual) texture tasks (in Studies 1 and 2, respectively). Infants at 3- and 6-months of age were included in each study. These ages were selected since there have been no studies on intramodal haptic texture perception conducted to date with infants during the first half-year of life, and these ages permit the assessment of haptic abilities just before and just after (3- and 6-months, respectively) the development of visual-motor coordination and fine-motor skills. The available literature suggests that the haptic system is the expert system for the perception of texture information, and that even very young infants may have sufficient haptic sensitivity and exploratory skills necessary for the perception of texture. However, the information processing literature suggests that there are developmental differences in information processing indices. Thus, infants at both ages, that is, before and after the development of visual-motor coordination, were expected to process texture information during, and to make texture discriminations following both unimodal (i.e., Study 1) and bimodal (i.e., Study 2) exploration. However, the older infants in both studies were expected to be more efficient processors and this efficiency was expected to be reflected in habituation measures.

Three- and 6-month-old infants were also expected to differ on other behavioural measures, including exploratory procedures, bimanual manipulation, and visual attention responses. In each study, older infants, as a result of more developed fine-motor abilities and visual-motor coordination were expected to display higher levels of exploratory procedures, bimanual manipulation, and visual fixation towards the stimuli.

The fourth objective of the present studies, implicitly incorporated in the design of the two studies was to address the methodological issues that have limited the interpretation of past research results vis à vis haptic perception during the first half-year of life. The primary methodological consideration was the choice and design of a habituation procedure that would be more promising in understanding haptic perception and processing patterns, including habituation patterns and novelty discriminations. An infant-controlled procedure was designed and adapted from such procedures employed in the study of visual and auditory processing. An infant-controlled, rather than fixed trials, habituation procedure eliminated experimental constraints imposed on infants and allowed them to haptically explore and process texture information at their own, natural pace. It allowed for the examination of the speed of haptic processing of texture information, the rate at which mental representations of haptically experienced stimuli are formed, the retention of these representations in memory and of subsequent comparisons to new haptic information.

Additional methodological considerations included the systematic selection of the optimal stimulus property for the study of haptics and controls for the presence of additional, confounding stimulus features. Texture was defined on the dimension of roughness, and the choice of textures was based on a preliminary study of adult ratings. The texture stimuli in the present studies were carefully designed in order to control for confounding stimulus properties such as temperature, hardness, size, compliance, weight, shape, and colour that have limited interpretations about infants' haptic perception in the past. Finally, the confound of visibility of stimuli which has limited interpretations of haptic abilities was addressed by systematically controlling for the visibility of the textures during haptic exploration. This control measure contributes substantially to understanding the independent functioning of haptics and to clarifying the influence of vision on haptics.

In summary, an experimental series of two studies was conducted and applied towards meeting the global objective of examining haptic perception in very young infants. Given the paucity of research on haptic perception during the first half-year of life, 3- and 6-month-old infants were tested. In addition, texture was the property isolated and investigated, the haptic modality was isolated systematically from the visual, and an infant-controlled habituation procedure was employed. Addressing the methodological issues was deemed invaluable in understanding: 1) haptic perception and processing of texture (including the speed at which information is processed haptically, and haptic discrimination and recognition memory abilities); 2) haptic exploratory procedures by which infants acquire information through haptics; 3) how vision influences infants' haptic information processing and haptic exploration; and 4) developmental changes in unimodal (i.e., haptic) and bimodal (i.e., haptic and visual) exploration.

CHAPTER 2: Study 1

The purpose of Study 1 was to contribute to the understanding of infants' haptic perception and processing abilities in a number of ways. First, haptic information processing, discrimination and recognition memory abilities, as well as exploratory procedures during the first half-year of life were examined. There is a paucity of research directed specifically at haptic intramodal abilities during the first 6 months, despite the evidence that haptic exploration is organized from birth (Rochat & Senders, 1991), that infants are sensitive and respond differentially to various forms of haptic stimulation (Rochat & Gibson, 1985; Rochat et al., 1988), and are capable of haptic-visual cross-modal transfer of information (Meltzoff & Borton, 1979; Steri, 1987; Streri & Milhet, 1988; Steri & Pêcheux, 1986a,b). The view that vision dominates and guides haptics in perceptual-cognitive development, the view that visual-prehensile coordination is necessary for infants' haptic exploratory behaviour, the faster development to maturity of the visual system, and the fine-motor limitations of the haptic system have all contributed to the lack of research on haptic perception during the first half-year of life.

Second, developmental changes in haptic processing and discrimination were assessed by studying infants at 3 and 6 months of age. The predominating notions are that infants' haptic perception and information processing are limited prior to visual-prehensile coordination, is dependent on the development of sufficient fine-motor exploratory procedures, and that vision is integral to the execution of these exploratory procedures (Bushnell & Boudreau, 1991, 1993, 1998; Hatwell, 1987, 1993; Heller, 1982). The selection of these two age groups permitted the examination of the impact of visual-prehensile coordination and fine-motor exploratory abilities on haptic perception and information processing. Moreover, the haptic intramodal design directly addressed the issue of whether vision is necessary for the execution of these fine-motor exploratory procedures.

Third, Study 1 contributed to clarifying the impact of methodological limitations in past studies on the interpretations and conclusions regarding infants' haptic abilities. A number of methodological issues were addressed in Study 1 since these may account for any observed, or interpreted, limitations in infants' haptic processing abilities. These limitations have typically, to date, been attributed to an immature, insensitive, or slow processing haptic system. In order to permit a clearer understanding of the early functioning of the haptic modality, the impact of the choice of habituation procedure employed, stimulus property presented, and the availability of confounding visual information were assessed. Study 1 was the first study of haptic intramodal perception of texture during the first half-year of life using an infant-controlled habituation procedure. Fixed-trials procedures employed in past studies impose time constraints on processing, and observed limitations in infants' haptic processing may be due to these constraints (Bornstein & Sigman, 1986). An infant-controlled procedure permitted a clearer evaluation of how information is processed through haptic exploration. That is, it permitted a view of haptic intramodal information processing patterns (e.g., accumulated haptic manipulation time to habituation and trials to habituation), and any changes therein as a function of age.

Past studies of haptic perception have also been confounded by the selection of nonoptimal stimulus parameters for haptics, by lack of control for confounding stimulus properties, and by the visual access to, or visibility of, stimuli. Study 1 was the first study to systematically select texture as the stimulus property to be employed in an intramodal haptic perception task with infants under 6 months of age. Texture was selected on the basis of its salience to haptics (Bushnell & Boudreau, 1998; Klatzky et al., 1987; Lederman, 1982; Lederman & Klatzky, 1987), making it more appropriate and amenable to the purpose of tapping into the perceptual and processing abilities of the haptic system. Furthermore, the textures were selected on the basis of an adult blindrating study, and the texture stimuli were then constructed to control for confounding features such as shape, size, colour, temperature, hardness, and weight. The study of less appropriate stimulus properties in past research may have also contributed to observed limitations in haptic perception and processing. Finally, Study 1 was the first study to systematically isolate vision from haptics during an infant-controlled texture habituation task during the first half-year of life. The occlusion of vision permitted an assessment of the nature of the stimulus information attended to and processed on the basis of only haptic exploration.

The design of Study 1 consisted of an infant-controlled HAB-NOV-RFAM haptic intramodal procedure. Vision was occluded in all phases by a large opaque cover. During the HAB phase, infants were required to meet a baseline criterion of 20 seconds of haptic contact with the HAB phase texture. They then had to meet the habituation criterion which consisted of two consecutive trials of haptic manipulation that were each at a decrement of 50% of the baseline mean. Infants were subsequently presented with three trials of a novel texture in the NOV phase, and then with a further three trials of the original HAB texture in the RFAM phase. In order to facilitate interpretation of infant responses during each of the test phases, a no-change control group was included. The control group was also habituated to a texture, but continued to receive the original HAB texture during six trials corresponding to the experimental NOV and RFAM test trials. Subsequently, control group infants obtained two to four additional dishabituation (DHAB) trials during which a novel texture was presented. The dishabituation trials served as a further control for decline in responsivity over control trials as being due to fatigue effects.

There were three primary objectives for Study 1, and each was tested with a subset of hypotheses. The first objective consisted of examining infants' haptic information processing patterns during habituation. A number of information processing measures, based on infants' haptic responses, were recorded during the HAB phase. These included the number of trials required to reach the baseline minimum criterion of 20 seconds of haptic contact with the HAB texture, the number of trials to reach the habituation criterion, the magnitude of the habituation response (i.e., an index of the magnitude of the relative decline of manipulation levels on the two final habituation criterion trials relative to the two longest baseline trials), and the total accumulated haptic manipulation to habituation. A number of hypotheses regarding infants' haptic information processing and discrimination abilities were tested. First, on the basis of past visual and auditory research indicating developmental differences in habituation patterns and information processing speed (Rose & Tamis-LeMonda, 1999), 6-month-olds were expected to be more adept than 3-month-olds at haptic exploration, and faster processors of the texture information. That is, they were expected to meet the baseline minimum criterion and the habituation criterion faster, within a shorter number of trials. They were also expected to display a sharper habituation response (i.e., greater magnitude of habituation), and less accumulated total haptic manipulation time to habituation.

The second objective consisted of examining infants' response to novelty, or discrimination of textures, as well as their recognition memory for textures. A number of haptic and visual attention responses were examined. Since infants were habituated haptically and not visually, infants' haptic responses were expected to be more reliable and valid indicators of discrimination and recognition memory abilities relative to their visual attention responses. Therefore, predictions of discrimination and recognition abilities were made for haptic dependent measures and interpretations regarding these abilities were based on the haptic measures. However, given the importance accorded to visual attention as an index of information processing, measures of infants' visual attention were also examined for any patterns indicative of discrimination and recognition memory, and guarded hypotheses were proposed.

A number of haptic behavioural measures were recorded in order to assess infants' haptic discrimination and recognition abilities. These included levels of haptic manipulation, exploratory procedures (i.e., stroking and scrumbling), and bimanual manipulation. In addition, similar to the index of the magnitude of habituation, an index of the magnitude of the dishabituation response upon presentation of the NOV texture was calculated on the basis of active manipulation levels. It was based on the levels of haptic manipulation on the NOV trials relative to the criterion trials. Infants at both ages were expected to display discrimination of the textures. That is, experimental group infants were expected to display higher levels of haptic manipulation and exploratory procedures and a greater magnitude of dishabituation, relative to the no-change control group infants during the NOV phase. However, the same pattern was not expected on the measure of bimanual manipulation since this was an intramodal haptic task, and vision has been documented to be necessary for infants to explore with both hands (Bushnell et al., 1992; Stack & Tsonis, 1999). A final haptic indicator of infants' discrimination abilities was obtained by looking at the control group's levels of haptic manipulation during their extra dishabituation trials, where they were finally presented with the novel texture, relative to the three trials of the RFAM phase. Higher levels of haptic manipulation during the DHAB phase were expected to indicate response to novelty, or discrimination of the textures. Behavioural indicators of response to novelty would indicate that infants had indeed processed the texture during the HAB phase, and had distinguished the novel texture on the basis of only haptic contact with each. Novelty responses would further imply the formation of memory representations and mental comparisons.

It was also expected that habituating infants to the same criterion level would result in both ages displaying recognition of the original texture during the RFAM phase. Since the RFAM trials for the experimental group consisted of a change in texture, their levels of haptic manipulation during the RFAM phase were expected to be greater than the control group levels during this phase. This would indicate detection of the discrepancy between the NOV trials and the RFAM trials. However, the experimental group infants were also expected to display significantly lower levels of haptic manipulation in the RFAM phase relative to the NOV phase. This would suggest that while the detection of the discrepancy between NOV and RFAM phases led to higher levels of manipulation relative to controls in the RFAM phase, recognition of the RFAM texture led to lower levels of haptic manipulation relative to the NOV phase. Higher levels of haptic manipulation by the control group on the DHAB trials would also serve as a control for fatigue effects being responsible for the lower levels of haptic manipulation among experimentals during the RFAM phase. Support for recognition memory would also imply that infants retained haptic information in memory, at least short-term, and engaged in comparison of mental representations.

Infants' visual attention responses were also examined for response to novelty and recognition memory. The objective in measuring visual attention during a haptic-intramodal task was to assess whether infants' haptic processing was coordinated with, and therefore reflected in their visual attention. The measures of visual attention included total attention (consisting of looking at the cover, at the experimenter, and in the direction of the texture stimulus under the cover), direct attention (i.e., looking at the experimenter and looking in the direction of the texture stimulus) and fixation (i.e., looking in the direction of the texture stimulus). The hypotheses about infants' discrimination and recognition abilities being reflected in visual attention measures were guarded since the habituation criterion was not based on visual attention, but rather on haptic manipulation. It was expected on the basis of the haptic and visual unity posited in differentiation theory, and evidence supportive of early haptic-visual cross-modal abilities, that the predicted haptic discrimination and recognition responses (during the NOV and RFAM phases, respectively) would be reflected as well in total visual attention and direct attention, for both age groups. However, only 6 month-olds were expected to display discrimination and recognition responses in their levels of fixation. The haptic task was expected to direct the visual attention of even 3-month-old experimental group infants, (and lead to higher levels of total attention and direct attention). However, given less developed visual-motor coordination at 3 months, the younger infants were not expected to be capable of directing their eyes towards an unseen, but manipulated, texture stimulus.

The third objective was to examine developmental differences in habituation patterns, discrimination, recognition memory, exploratory procedures and visual attention between 3 and 6 months of age. As discussed earlier, developmental differences were expected in habituation indices. However, since infants were permitted to habituate to the same criterion, developmental differences were not expected in haptic discrimination and recognition memory. Nonetheless, 3- and 6-month-old infants were expected to differ in their exploratory behaviour. That is, 6 month-olds were expected to display higher levels of exploratory procedures and of bimanual manipulation, as a result of gains in fine-motor abilities and visual-motor coordination, respectively. Evidence for haptic discrimination and recognition abilities among 3-month-olds, despite lower levels of exploratory procedures at this age, would imply: 1) an earlier timetable for the haptic perception of texture than suggested by existing literature; and 2) an important role for the perceptual functions of the hand, relative to the motor functions, during haptic perception. Finally, developmental hypotheses were made pertaining to visual attention. In general, given the development of attentional resources with age, 6-month-olds were expected to display higher levels of total attention, direct attention, and fixation relative to 3-month-olds. In addition, as stated earlier, due to the development of visual-prehensile coordination, discrimination and recognition abilities on the measure of fixation were expected only for the 6-month-olds.

Method

Participants

The names of potential participants were obtained from the birth records of a community teaching hospital in the Montreal area. Criteria for inclusion included full-term birth and uncomplicated medical and developmental histories. Parents were contacted by telephone and informed of the general purposes of the study and asked for their voluntary participation. Thirty-eight 3-month-old infants were tested. Of these, 9 were excluded from the final sample because of fussiness, 2 for not making the baseline criterion, 2 because the caregiver spoke during the testing, and 1 because of experimenter error. Thirty-eight 6-month-olds were also tested. Seven were excluded from the final sample due to fussiness, and 5 due to lack of obtaining the baseline criterion. In addition, 2 were excluded when interviews with the parents revealed that the children's medical and developmental histories did not meet the inclusion criteria for the present study. The final sample consisted of 48 infants: 24 3-month-olds (12 of each sex) with a mean age of 3 months, 4.5 days ($\underline{sd}$ = 3.82 days), and 24 6-month-olds (12 of each sex) with a mean age of 6 months, 5.7 days ($\underline{sd}$ = 6.45 days). The majority of the families in the final sample were Non-Hispanic White (68%). The remaining families were Hispanic (15%), African American (13%), and bi-racial (4%). In terms of education, families were classified as 13% with high school education, 24% had some college education or trade school training, and 63% had college degrees from programs requiring 4 years of college or more. In terms of occupational status, the families were classified in the domains of Professional Specialty (33%), Administration/, Managerial (13%), Sales (13%), Clerical (11%), Craft/Trade Specialty (11%), Operatives (9%), Service workers not in private households (2%), and Farm Labourers (2%). The remainder of the families were unemployed (4%) and students (2%).

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 to eliminate any sources of visual distraction in the testing room. Infants were seated on their caregivers' laps facing a neutral-faced (i.e., expressionless) experimenter (E1) who was seated on a stool approximately 70 cm away. A large rectangular opaque 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. All testing sessions were videotaped on 8mm Sony video cassettes by a Hitachi VK-C350 camera mounted to the front and slightly 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 so that a time code was placed on each video record in minutes, seconds, and milliseconds. The time code permitted precise frame-by-frame coding of video records. A variable speed remote control with shuttle function was used in subsequent coding of the video records.

A button on a computer mouse connected to a computer in the testing room was used by the experimenter to signal whenever infants actively manipulated the objects. A custom designed computer program calculated infants' active haptic manipulation. At the onset of each new trial and at each change of phase, tones were transmitted to the experimenter via earphones she wore.

Experimental Stimuli

The selection of the texture stimuli employed in Study 1 was based on the results of a pilot study, where twenty adults (10 of each sex) were asked to rank 10 textures while blindfolded in each of two sessions. In one session the textures were placed on a square flat surface, and in the other on a cylindrical surface. Surface order was counterbalanced across participants and each received the textures in a different random order. In each session they were asked to rank order the 10 textures on the dimension of roughness (i.e., from least to most rough). They were presented with each texture sequentially until they had all 10 sorted from least rough to most rough on the table in front of them. The mean rank order position values (ranging from 1st to 10th) are presented in Appendix A, Table A1 for each surface. Kendall's coefficients of concordance on the rank ordering of textures on the dimension of roughness were calculated to be 0.84 and 0.80 for each of the square and cylindrical surfaces respectively. These values indicated a significant degree of agreement among subjects on the rank order positions attributed to the textures (χ^2=151.2, $p \leq .001$ and χ^2=144, $p \leq .001$ for the square and cylindrical surface concordance values).

Mixed Analyses of Variance (ANOVA) on the mean rank order values were conducted for each surface separately, with the between variables of Sex (male, female) and Order of surface presentation (square-cylinder, cylinder-square) and the within variable of Texture (10 levels). The ANOVA results indicated only a Texture main effect, $F(9,171) = 101.39$, $p<.001$, and $F(9,171) = 75.27$, $p<.001$ for the square and cylinder surface, respectively. Tukey's HSD pairwise comparisons were then performed on the mean ranking for each texture (range from 1 to 10, indicating most rough to least rough respectively) and for each surface. The two textures which yielded the greatest significant difference in mean ranking on roughness were selected for the infant study. The same two textures, cotton fleece and carpet lining, were ranked as the least and most rough, respectively, with each of the two surfaces. The square surface was selected for use in the infant studies since the surface area was large enough for an infant's hand to be fully extended on it, and since it permitted a greater surface area for the execution of exploratory procedures necessary for the perception of texture. In addition, it reduced infants' reflex to grasp and simply hold the stimulus. The ANOVA summary and Tukey HSD analyses tables for the square surface mean ranks are presented in Appendix A, Tables A2 and A3.

The smooth, cotton fleece, and rough, carpet lining, texture stimuli selected were identical in color (i.e., white). The textures were presented on a flat masonite surface with two components; a flat square surface and a flat rectangular handle that the experimenter held in order to present the stimuli to the infants. The two textures were wrapped around each component of the stimulus (i.e., the square surface and the rectangular handle) such that it was completely covered. The square flat surface was 13 cm in length and height, and 1.5 cm in width. The handle was 25.5 cm in height and 3.5 cm in length and 1.5 cm in width. Both texture stimuli were, thus, identical in color, shape, size, and hardness. In addition, since the experimenter held the stimuli by the handle when presenting them to the infants, the experimenter bore the weight of the stimuli. Thus, the stimuli differed only in texture.

Design

The design of the study, represented in Table 1, was a 2 (Age) x 2 (Group) x 2 (Order) x 2 (Sex) x 4 (Phase) mixed model. The 4 between factors were Age (3- and 6-months), Group (experimental, control), Order [order 1: smooth-rough-smooth and smooth-smooth-smooth (SRS/SSS), for experimental and control groups respectively; and order 2: rough-smooth-rough, and rough-rough-rough (RSR/RRR), for experimental and control groups, respectively], and Sex (male, female). The within factor was Phase with 4 levels [Before Habituation (BHAB), Criterion (CRIT), Novelty (NOV), and Return-to-Familiar (RFAM) phases]. The BHAB and CRIT phases comprised the habituation phase (HAB). The BHAB phase consisted of all but the two criterion trials during the HAB phase. The CRIT phase consisted of the last two trials of the HAB phase which were the two criterion trials. Each of the NOV and RFAM phases consisted of

Table 1

Design Table for Study 1

Age	Group	Order	Sex	Phase: HAB — BHAB (≥2 trials)	HAB — CRIT (2 trials)	NOV (3 trials)	RFAM (3 trials)	DHAB (2 to 4 trials)
3 months	Experimental	SRS	Male / Female	S		R	S	
		RSR	Male / Female	R		S	R	
	Control	SSS-R	Male / Female	S		S	S	R
		RRR-S	Male / Female	R		R	R	S
6 months	Experimental	SRS	Male / Female	S		R	S	
		RSR	Male / Female	R		S	R	
	Control	SSS-R	Male / Female	S		S	S	R
		RRR-S	Male / Female	R		R	R	S

Note. HAB = habituation. BHAB = before habituation. CRIT = criterion. NOV = novel. RFAM = return to familiar. DHAB = dishabituation. S = smooth. R = rough.

three trials. There were 24 infants within each age group and they were randomly assigned to each of the experimental (n=12) and control (n=12) groups.

Both experimental and control groups were required to meet a baseline level of haptic contact with the texture, and then to meet the habituation criterion before the test phases began. Experimental group infants then received three trials with the novel texture (NOV) and three trials with the original texture in the RFAM phase. Control group infants received the same texture in each of the three trials of the corresponding NOV and RFAM phases. Presenting the same texture to control infants during these phases permitted the attribution of dishabituation among experimental group infants to discrimination of the novel from the original texture (Colombo et al., 1987). The control group infants then received an additional two to four trials with the novel texture in a fourth Dishabituation (DHAB) phase in order to control for fatigue effects (Dannemiller & Banks, 1983; Zelazo et al., 1989). Initially two DHAB trials were administered but this was extended to four trials, since these infants exhibited disinterest in touching and boredom following habituation and test trials with the familiar stimulus. It was argued that four trials may have given these control infants a greater opportunity to recover their interest and attention. Eleven of the 24 control infants obtained two DHAB trials and the remaining 13 control infants received four DHAB trials.

The order of presentation of the textures within each group was counterbalanced. That is, half the infants in the experimental group received the smooth stimulus during habituation (BHAB and CRIT trials), the rough stimulus in NOV, and the smooth stimulus again in RFAM (Order 1; SRS), while the remaining half of the experimental group were habituated to the rough stimulus, received the smooth stimulus in NOV, and the rough stimulus again in RFAM (Order 2; RSR). Similarly, half the infants in the control group received the smooth stimulus in the three first phases, and the rough stimulus in DHAB (Order 1: SSS-R) while the other half obtained the rough stimulus in the first three phases and the smooth stimulus in DHAB (Order 2: RRR-S). There were an equal number of males and females in each order.

Procedure

Caregivers and infants were greeted and escorted into a waiting room. The experimenter 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 seated on their caregiver's lap. The experimenter then attached the opaque cover around the infant's neck. The experimenter remained neutral, that is still-faced and silent, and made no eye contact with the infant throughout the testing. The habituation stimulus was initially presented to the infant's right hand underneath the cover since many studies suggest a very early right hand dominance (McDonnell, 1979; Streri, 1987). Throughout each phase the experimenter alternated presentation of the stimulus to the other hand only if the infant's right hand was out of reach under the cover.

An infant-controlled procedure was employed. A trial began when the infant manipulated the stimulus for at least 1 second and ended when the infant released the stimulus for more than 1.5 seconds or when a maximum trial length of 60 seconds of manipulation was met. The experimenter pressed the mouse button every time the infant manipulated the texture and for the entire duration of each manipulation. If the infant released the stimulus the experimenter held the stimulus in the same position until the infant returned to it or until 1.5 seconds had passed at which time the computer signalled, via a single tone, the beginning of the next trial, whichever came first. When the computer signalled the beginning of the next trial, the experimenter re-presented the stimulus to the infant's hand. The computer monitored the trials and also signalled the beginning of each new phase to the experimenter via a double tone.

Baseline. The baseline criterion was modelled on criteria employed in infant-controlled visual and haptic habituation procedures (Columbo & Mitchell, 1990;

Columbo, Mitchell, Coldren & Freeseman, 1991; Streri, 1987; Streri & Pêcheux, 1986a,b). During the HAB phase, the baseline was calculated as the mean of the longest two initial trials provided that the infant had manipulated the texture for a minimum of 20 seconds over the two trials. If this minimum manipulation criterion was not met over the first two trials, a floating point accommodated into the program then calculated the baseline on the basis of the next two longest consecutive trials that met the 20 second criterion (e.g., the mean of trials 2, and 3, provided that the sum of haptic manipulation over these two trials was equal or greater than 20 seconds). If a baseline was not obtained within 16 trials, testing was terminated to allow for a short break and one more attempt was made to resume testing. All infants in the final sample met the baseline criterion with the first attempt.

Habituation Criterion. The habituation criterion was based on infant-controlled visual and haptic habituation procedures (Columbo & Mitchell, 1990; Columbo et al., 1991; Streri, 1987; Streri & Pêcheux, 1986a,b). The criterion for habituation consisted of two consecutive trials that were each at a decrement of 50% of the baseline mean. The maximum number of trials for habituation was also 16. Testing then proceeded into the next phase even if the habituation criterion was not met within 16 trials. However, these infants were considered as nonhabituators and their data were excluded from the analyses. All infants in the final sample met the habituation criterion. A double tone to the experimenter's ear indicated that the habituation criterion was met, or that the 16 habituation trials had elapsed.

Test Phases. The test phases began immediately following the habituation phase. Each of the test phases, NOV and RFAM, consisted of three trials. The experimental group obtained the novel texture during the three NOV trials, and the original habituation texture during the three trials of the RFAM phase. The control group continued to receive the same habituation texture during these corresponding six trials, and then received the novel texture during either two or four DHAB trials. The NOV and RFAM test phase trials, as well as the DHAB trials, were also infant-controlled; a trial began when the infant manipulated the stimulus for at least 1 second and ended when the infant released the stimulus for more than 1.5 seconds. The end of the testing session, or the end of the RFAM phase for the experimental group and the end of the DHAB phase for control group, was indicated by a triple tone to the experimenter. Finally, in the event that any infant fretted for over 20 seconds at any point during the testing, or if parents requested to stop, a short break was taken before the procedure was attempted for a final time. None of the infants in the final sample required a break.

At the end of the testing session, caregivers and infants were escorted to the waiting room, and demographic information was collected (Appendix C). Caregivers were thanked for their participation and infants and their caregivers were given an Infant Scientist Award. All participants were informed that they would be mailed a report of the general findings of the study once it was completed.

Dependent Measures

1. Habituation Indices. A number of habituation measures are considered critical variables of interest in studies of visual habituation (Colombo et al., 1987). Each of these was adapted for the present haptic infant-controlled procedure. These measures are listed and defined below. They were calculated only for the measure of haptic manipulation, since this was the measure driving the infant-controlled procedure. Haptic manipulation was defined as all forms of manual contact with the stimuli.

a) Number of trials to baseline. This index was used to assess the number of trials infants required to meet the 20 second criterion of haptic manipulation of the first texture.

b) Number of trials to habituation. In studies of visual habituation, the number of looks to the stimulus during the habituation phase has been used as one index of the speed or rate of habituation (Colombo et al., 1987; McCall, Kennedy, & Dodds, 1977; Ritz, Woodruff, & Fagen, 1984). In the present study, the number of trials to habituation provided an index of processing patterns and speed within the haptic modality. It was defined as the number of trials to meet the habituation criterion of two consecutive trials each at 50% of the baseline mean.

c) Magnitude of habituation. This index was also adapted from studies of visual habituation (Colombo et al., 1987) and was calculated by the formula

$\frac{(M12 - MCRIT)}{NTRIALS}$ where M12 is the mean duration of the longest 2 first haptic manipulations (i.e., the baseline mean), MCRIT is the mean duration of the two criterion manipulations, and NTRIALS is the number of trials to reach the habituation criterion. A larger ratio indicates a greater magnitude of habituation. That is, it is a ratio of the discrepancy between the mean haptic manipulation on baseline relative to criterion trials, to the number of trials required to reach the habituation criterion. Given a certain discrepancy, the magnitude index would be larger when the denominator is small (in the case of a small number of trials to habituation), relative to when the denominator is large (in the case of a greater number of trials to habituation). Similarly if the number of trials is constant, the magnitude index is larger when the discrepancy is large, relative to when it is small. Thus, a greater magnitude of habituation represents a quicker and sharper decline from baseline levels to the habituation criterion.

2. Dishabituation Indices. Similar to the habituation indices, dishabituation measures are considered critical variables of interest in studies of visual habituation (Colombo et al., 1987). The Novelty Dishabituation index defined below was adapted for the present haptic infant-controlled procedure. In addition, the dishabituation of the controls during the DHAB trials was also assessed. These two measures of dishabituation were calculated only for the measure of haptic manipulation, since this was the measure driving the infant-controlled procedure.

a) Novelty Dishabituation Index. This dishabituation index was similarly adapted from studies of visual habituation (Colombo et al., 1987) and was used to evaluate the magnitude of the response to the novel texture following habituation. The following proportion was used to calculate the magnitude of dishabituation: $\frac{MNOV}{(MNOV + MCRIT)}$ where MNOV is the mean duration of haptic manipulation over the three novel trials, and MCRIT is the mean duration of haptic manipulation over the two criterion trials. This was calculated for both experimental and control infants. A ratio of 0.5 reflects no change between the mean haptic manipulation on the NOV phase and the mean on the CRIT phase. A ratio less than 0.5 reflects a decrease in the mean on NOV relative to the mean on CRIT. A ratio greater than 0.5 reflects an increase in the mean on NOV relative to the mean on CRIT.

b) Control Dishabituation. The mean haptic manipulation (in seconds) displayed by the control groups during their additional dishabituation trials (DHAB) was compared to their mean levels of haptic manipulation during the RFAM phase. This comparison permitted a control for fatigue effects, and also served as a further measure of haptic discrimination for the control group subjects.

3. Haptic and Visual Dependent Measures. The total duration, in seconds per trial, was coded and calculated for haptic manipulation, exploratory procedures, bimanual manipulation, and for visual attention. The start and end of each trial were determined by infants' haptic manipulation. Haptic manipulation was coded live, since this measure determined infants' habituation. The duration of haptic manipulation per trial was therefore obtained directly from the computer recordings of the testing. The onset and offset times of each trial, as determined by haptic manipulation, served as the trial onset and offset times during which all other measures were coded. The video records were viewed two times at slow speed for the coding of all other measures during each trial. The video records were viewed once to code exploratory procedures and bimanual manipulation, and once to code visual attention. A frame by frame analysis was used

whereby onset and offset of each infant behaviour was recorded to the precise frame. During coding, the volume on the video monitor was turned off in order to reduce context cues.

The haptic and visual dependent measures were based on behaviours that have been reliably and consistently employed in past studies of infant haptic perception (e.g., Bushnell et al., 1992; Ruff, 1989; Stack, St.Germain & Zelazo, 1992; Stack & Tsonis, 1999). Haptic manipulation was defined as all forms of tactile contact with the stimuli. The exploratory procedures consisted of the sum of stroking and scrumbling. Stroking was defined and coded as any lateral movement of one or more fingers over any part of the stimulus. Scrumbling was defined and coded as the alternate extension and flexing of one or more fingers on the stimulus. Bimanual manipulation was coded whenever infants manipulated with both hands simultaneously. Three measures of visual attention were analyzed: total attention, direct attention, and fixation. First, total attention consisted of the sum of attention to the cover, fixation towards the stimulus, and attention to the experimenter. Attention to cover was coded when infants were looking towards the cover (but not in the direction of the stimulus), regardless of whether they were holding the stimulus or not. Fixation toward stimulus (to be referred to as fixation) was coded when infants were looking directly at the stimulus that they were touching. Since the cover was opaque, attention to the cover and fixation were distinguished on the basis of whether the stimulus was in the infant's line of vision (should the cover have been transparent). If the stimulus was not in the infant's line of vision then attention to the cover was coded. However, if the stimulus was in the infant's line of vision and they were simultaneously holding the stimulus, fixation was coded. When the infant lost contact with the stimulus while fixating towards it, but continued to look in the same direction, then fixation was coded until the stimulus was again in contact with the infant's hand at another location underneath the cover. Attention to the experimenter was defined as looking at the experimenter's upper torso and face. Direct attention, a term used to reflect attention to the experimental situation, was defined as the sum of attention towards the experimenter and fixation towards the stimulus. All of the aforementioned haptic and visual behaviours have been shown to be reliable and valid indicators of exploration and processing (Bushnell et al., 1992; Bushnell & Weinberger, 1987; Stack & Tsonis, 1999; Streri, 1987; Streri & Spelke, 1988). Detailed descriptions of the dependent variables and how they were coded are found in Appendix D.

Inter-rater reliability was assessed by blind observers for 21% of the records upon completion of the coding. Since haptic manipulation determined the duration of each trial, reliability for haptic manipulation was obtained by assessing the correspondence between onset and offset times for each trial as indicated on the computer records of the live coding, with the onset and offset times for each trial as obtained on the video records. This permitted simultaneous assessment of the reliability of the live coding, as well as the reliability for haptic manipulation. The kappa coefficient for haptic manipulation was .90. The kappa coefficients for exploratory procedures and bimanual manipulation were .86, and 1, respectively. The kappa coefficients for the attention measures were also high (r_k =.89 for total attention; r_k = .92 for direct attention; r_k = .92 for attention to experimenter; r_k = .85 for attention to the cover; and r_k = .92 for fixation).

Results

Analyses were conducted on the data using the BMDP statistical package (Dixon, Brown, Engelman, & Jennings, 1990). Descriptive statistics were conducted on each dependent variable to screen the data for outliers and for significant non-normality. Where outliers were present, their influence was reduced by assigning the outlier a value that was one unit larger or smaller than the next most extreme score in the distribution (Tabachnick & Fidell, 1996). In the event of significant non-normality, that is significant skewness and kurtosis, the application of transformations was carefully considered before appropriate transformations were applied to normalize the data (Tabachnick & Fidell, 1996). First, the nature of the dependent measure was considered since some measures were not normally distributed by nature. Second, the efficiency with which each transformation corrected the level of skewness and kurtosis was considered. Third, the impact of transformations on the results from the analyses was assessed by comparing the results from the analyses conducted on transformed data with the results of analyses conducted without transformations. In general, the applied transformations corrected for non-normality in the present data set. However, they either did not change the results obtained without transformations, or they reduced the number of significant effects. Transformations did not lead to a greater number of effects. Thus, transformations were applied in appropriate situations to correct for non-normality, consistent with the guidelines provided by Tabachnick and Fidell (1996). When transformations were applied they are indicated in the text. For ease of comprehension, when data were transformed, raw means are presented in the text. However, when transformations were conducted, the F-scores and p-values cited in the text are taken from the analyses on the transformed data, as these were the values on which the effects were identified and on which interpretations were based.

Following descriptive analyses, statistical analyses were conducted on each measure. Each of the habituation indices (i.e., number of trials to baseline, number of trials to habituation and magnitude of habituation) and the Novelty dishabituation index were analyzed with between ANOVAs, as a function of Age, Group, Sex and Order. Interaction comparisons were conducted to isolate the source of any three-way or higher order interactions (Keppel, 1991). Simple effects were conducted to isolate the source of any two-way interactions (Keppel, 1991). The control dishabituation data were analyzed with a directional, one-tailed t-test. A critical alpha level of 0.05 was used as the criterion for statistical significance for these analyses.

Repeated measures ANOVAs were conducted on the behavioural dependent measures (i.e., haptic manipulation, exploratory procedures, bimanual manipulation, and each of the visual attention measures) since these were analyzed as a function of the four between variables and one within variable. The four between variables were: Age (3-, 6-months), Group (experimental, control), Order (SRS/SSS, RSR/RRR) and Sex (male, female). The within variable consisted of Phase (BHAB, CRIT, NOV, RFAM). Any potential Sex and Order effects or interactions were tested for each variable. If no Sex and Order main effects or interactions were found, these variables were collapsed and a 2 x 2 x 4 between-within ANOVA was conducted with the between factors of Age and Group and the within factor of Phase. However, in the event of any three-way or higher order interactions of the between group variables, analyses of the simple interactions of two factors at each level of the third were conducted. In turn, any significant simple two-way interactions were followed by simple effects analyses (Keppel, 1991). Significant interactions of between-within factors were followed by simple effects analyses (Keppel, 1991). Any Phase main effects were followed by Tukey Highly Significant Difference comparisons, since Phase was the only factor with more than 2 levels (Keppel, 1991; Tabachnick & Fidell, 1996). A critical alpha level of 0.05 was used as the criterion for statistical significance, and the more conservative Greenhouse-Geisser Adjusted F score and p value were used to assess significance for all within-subject effects.

The results of statistical analyses for the habituation indices are presented first, since they address the first goal of Study 1 to examine haptic habituation patterns. Subsequently, the results of the haptic measures (i.e., novelty dishabituation index, haptic manipulation, exploratory procedures, and bimanual manipulation), pertaining to the second objective and hypotheses regarding haptic measures of texture discrimination and recognition abilities, are presented. The results for the visual attention measures follow. For descriptive purposes, the raw data for all measures as a function of the primary factors (i.e., Age, Group, Order, and Phase) are also available at the end of each appendix containing the ANOVA and follow-up summary tables for each measure. The raw data are presented as a function of Sex of infant only if there was a significant main effect or interaction involving this factor. Similarly, the raw data are presented as a function of Phase only if the statistical analyses were conducted with this factor.

Trials to Baseline. An inverse transformation was applied to the measure of trials to baseline. A between ANOVA yielded a marginal main effect for Sex, $F(1,46) = 4.23$, $p=.05$ (Appendix E, Table E1), with males requiring a greater number of trials ($M = 3.33$) than females ($M = 2.38$ trials) to reach the baseline minimum of 20 seconds of haptic manipulation with the HAB texture.

Trials to Habituation. Infants took an average of 4.89 trials during the BHAB phase and a grand mean of 6.89 trials to reach the habituation criterion. A between ANOVA revealed main effects for Order, $F(1,40) = 13.65$, $p<.001$, and Sex, $F(1,40) = 6.43$, $p<.05$, and an Age x Order x Sex interaction $F(1,40) = 7.98$, $p \leq .01$ (Appendix E, Table E2). The Order main effect indicated that infants habituated faster, within fewer trials, to the rough texture ($M = 5.84$) relative to the smooth texture ($M = 7.96$). In order to assess the source of the three-way Age x Order x Sex interaction, the simple two-way interactions of the Age and Order variables were assessed at each level of the Sex variable (Keppel, 1991). The Age x Order interaction was significant for females, F(1,40) = 9.44, $p \leq .001$, but not for males (Table E3). Simple effects analyses indicated only an Order difference among males (Table E3). The males in the RSR/RRR order habituated faster (M = 6.17 trials) relative to males in the SRS/SSS order (M = 9.08 trials). Simple effects on the significant Age x Order interaction for females were conducted (Table E4). As indicated in Table 2, the 6-month-old females habituated faster (M = 5.00 trials) than the 3-month-old females (M = 8.66 trials) when habituating to the smooth texture (Order SRS/SSS) F(1,40) = 10.16, p<.001. However, the 3- and 6-month-old females habituated within a similar number of trials (Ms = 4.83 and 6.16, for each age respectively) to the rough texture (Order RSR/RRR). The 3- and 6-month-old males did not differ from each other when habituating to the smooth or the rough texture.

Magnitude of Habituation. A between ANOVA with a square root transformation indicated an Order main effect F(1,46) = 11.38, p<.001 (Appendix E, Table E5). Infants habituating to the rough texture (i.e., order RSR/RRR) displayed a greater magnitude of habituation (M = 3.51) relative to infants habituating to the smooth texture (i.e., order SRS/SSS; M =1.75).

Haptic Manipulation. A mixed ANOVA on the total duration (in seconds) of haptic manipulation indicated Group and Phase main effects, [F(1,46) = 17.14, p<.001, and F(3,138) = 176.16, p<.001, respectively]. These main effects were qualified by a Phase x Group interaction F(3,138) = 6.67, p<.001 (Appendix F, Table F1). Simple effects analyses revealed significant group differences at the NOV and RFAM phases, F(1,46) = 34.76, p<.001 and F(1,46) = 8.60, p=.01, respectively (Table F2). As indicated in Figure 1, experimental and control groups did not differ during the BHAB and CRIT phases. Infants accumulated a grand mean of 65.35 seconds of haptic manipulation during the BHAB phase, and an additional mean of 9.07 seconds during the CRIT phase, bringing the grand mean duration of haptic manipulation in the HAB phase to 74.42

Table 2

Mean Number of Trials to Habituation as a function of Age, Order and Sex, Study 1

Order		Age		
		3-month-olds	6-month-olds	
	Sex	M	M	Marginal Ms
SRS/SSS	Male	8.33 (0.92)	9.83 (1.35)	9.08 (1.14)
	Female	8.66 (0.88)	5.00 (0.26)	6.83 (0.57)
RSR/RRR	Male	6.17 (0.60)	6.16 (0.83)	6.17 (0.72)
	Female	4.83 (0.54)	6.16 (0.65)	5.50 (0.60)
Marginal Ms		6.99 (0.74)	6.79 (0.77)	6.89 (0.76)

Note. Values in parentheses represent standard errors.

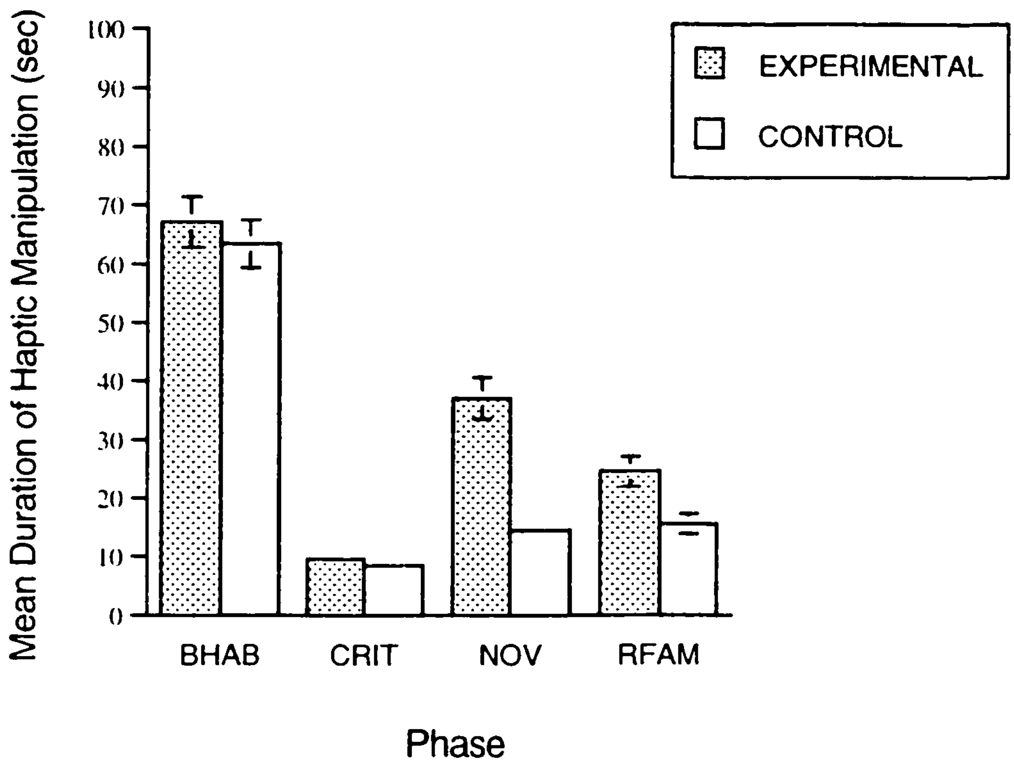

Figure 1. Mean duration of haptic manipulation as a function of Group and Phase. Standard errors are shown by vertical bars.

seconds. However, the experimental group infants displayed higher levels of haptic manipulation relative to control group infants in both the NOV (Ms = 37.11 and 14.50, respectively) and RFAM phase (Ms = 24.56 and 15.57, respectively). Simple comparison analyses were conducted to test whether the levels of haptic manipulation differed between the NOV and RFAM phases for each of the experimental and control groups (Table F3). The experimental group displayed significantly lower levels of haptic manipulation in the RFAM phase (M = 24.56) relative to the NOV phase [M = 37.11; $F(1,138) = 11.41$, $p < .01$], whereas the control group's levels of haptic manipulation did not differ between the NOV and RFAM phases (Ms = 14.50 and 15.57, respectively).

Novelty Dishabituation Index. A between ANOVA (Appendix F, Table F4) indicated a Group main effect $F(1,46) = 14.60$, $p < .001$, with the experimental group displaying a greater magnitude of dishabituation (M = 0.69) relative to the control group (M = 0.53).

Control Dishabituation. In order to control for fatigue effects as a possible factor for the declining levels of haptic manipulation among the control group infants, the mean duration of haptic manipulation across either the two or four DHAB trials was compared to the mean duration of haptic manipulation over the RFAM trials. A paired samples directional t-test (comparing the mean haptic manipulation on RFAM to the DHAB trials) indicated a significant difference $t_{(23)} = -3.918$, $p < .001$. Control group infants displayed a significantly higher mean level of haptic manipulation during the DHAB trials (M = 9.64) relative to during the three RFAM trials (M = 5.19).

Exploratory Procedures. A mixed ANOVA (Appendix F, Table F5) with a square root transformation revealed significant Group and Phase main effects [$F(1,40) = 5.11$, $p < .05$, and $F(3,120) = 19.05$, $p < .001$, respectively]. These main effects were qualified by an Age x Group x Order interaction $F(1,40) = 6.23$, $p < .05$, a marginal Phase x Group interaction $F(3,120) = 2.76$, $p = .05$, and a Phase x Age x Order interaction $F(1,120) =$

3.94, $p<.05$.

The Age x Group x Order interaction was pursued with the simple interactions of Age x Group were tested at each level of the third variable, Order (Table F6). There was a significant Age x Group interaction at Order RSR/RRR, $F(1,40) = 5.65$, $p < .05$, but not at Order SRS/SSS. Simple effects on the significant Age x Group interaction at Order RSR/RRR yielded no significant effects (Table F7), suggesting that the simple Age x Group interaction at Order RSR/RRR was spurious. However, in the process of conducting the simple interactions of Age x Group at each level of Order, a significant Group main effect at order SRS/SSS was identified $F(1,40) = 7.80$, $p < .05$, but not at Order RSR/RRR (Table F6). As depicted in Table 3, experimental group infants receiving the textures in the order of SRS (in the HAB, NOV, and RFAM phases, respectively), displayed higher levels of exploratory procedures ($M = 2.30$) relative to the corresponding control group receiving the textures in the order of SSS ($M = 1.09$). Since the difference between these two groups consisted of the texture obtained in the NOV phase, it can be inferred that the novelty of the rough texture during NOV for the experimental group elicited higher levels of exploratory procedures. The novelty of the smooth texture, for the experimental group in the order of RSR, did not lead to higher levels of exploratory procedures relative to the corresponding RRR control group. However, the experimental groups in Order SRS and Order RSR displayed similar levels of exploratory procedures, as did the control groups in Order SSS and RRR (Table 3 & Table F8 in Appendix F, for means and statistical analyses, respectively).

Given the Group main effect at Order SRS/SSS, the original three-way Age x Group x Order interaction was pursued in an alternative manner by looking at the two-way interactions of Group x Order at each level of Age (Table F9). A significant Group x Order interaction was revealed at the Age of 6-months, $F(1,40) = 8.69$, $p = .01$, but not at 3 months. There was only a Group main effect, $F(1,40) = 4.93$, $p < .05$, at Age of 3

Table 3

Mean Duration of Exploratory Procedures (in sec) as a Function of Group and Order, Study 1

	Group		
Order	Experimental	Control	Marginal Ms
SRS/SSS	2.30 (0.83)	1.09 (0.36)	1.70 (0.60)
RSR/RRR	1.84 (0.76)	1.51 (0.69)	1.68 (0.73)
Marginal Ms	2.07 (0.80)	1.30 (0.53)	1.69 (0.67)

Note. Values in parentheses represent standard errors.

months (Table F9). The Group effect at 3 months is represented in Table 4. The 3-month-old experimental group displayed significantly higher levels of exploratory procedures (M = 2.11) relative to the 3-month-old control group (M = 0.98). Given this Group difference as a function of Age, the simple effects of Age at Group were also assessed (Table F11). As seen in Table 4, 3- and 6-month-old experimental group infants did not differ in their levels of exploratory procedures (Ms = 2.11 & 2.02, for each age respectively; $F(1,40) = 0.15$, $p = .70$). Similarly, the 3- and 6-month-old control groups did not differ in levels of exploratory procedures (Ms = 0.98 and 1.63, for each age respectively; $F(1,40) = 0.70$, $p = .41$). These results suggest that the 3-month-olds responded to changes, or novelties, in texture over the phases with higher levels of exploratory procedures relative to when they did not experience any changes, and that their levels of exploratory procedures were similar to those of the 6-month-olds.

A Group difference was also identified at Age of six months, but it was qualified by Order. Follow-up simple effects were conducted on the Group x Order interaction at the Age of 6 months (Table F10). This effect is represented in Table 5, and suggests that 6-month-olds, like 3-month-olds responded to changes, or novelties, in texture with higher levels of exploratory procedures, but that their responses were more specific to the particular novelties in texture. Six-month-old experimental group infants in the order SRS engaged in higher levels of exploratory procedures (M = 2.75), relative to: 1) control group infants obtaining the textures in the corresponding order SSS (M = 0.97), $F(1,40) = 7.78$, $p \leq .01$; and 2) experimental group infants in the RSR order (M = 1.29) $F(1,40) = 5.78$, $p < .05$. These findings suggest that only the novelty of the rough texture led to higher levels of exploratory procedures among 6-month-olds. The 6-month-old experimentals in the order RSR did not differ from the 6-month-old controls in the corresponding order of RRR. In addition, the 6-month-old control groups in each order displayed similar levels of exploratory procedures.

Table 4

Mean Duration of Exploratory Procedures (in sec) as a Function of Age and Group.

Study 1

	Group	
Age	Experimental	Control
3-months	2.11 (0.74)	0.98 (0.28)
6-months	2.02 (0.87)	1.63 (0.78)

Note. Values in parentheses represent standard errors.

Table 5

Mean Duration of Exploratory Procedures (in sec) as a function of Age, Group, and Order, Study 1

Age	Group	Order SRS/SSS M	Order RSR/RRR M	Marginal Ms
3 months	Experimental	1.84 (0.68)	2.38 (0.79)	2.11 (0.74)
	Control	1.22 (0.24)	0.74 (0.31)	0.98 (0.28)
6 months	Experimental	2.75 (0.98)	1.29 (0.76)	2.02 (0.87)
	Control	0.97 (0.49)	2.28 (1.07)	1.63 (0.78)
	Marginal Ms	1.70 (0.60)	1.67 (0.73)	1.69 (0.67)

Note. Values in parentheses represent standard errors.

Although the Phase x Group interaction from the original ANOVA (Table F5) was marginally significant, simple effects analyses (Table F12) were nonetheless conducted given the importance of exploratory procedures to the perception of texture. Simple effects analyses revealed significantly higher levels of exploratory procedures during the NOV phase, $\underline{F}(1,46) = 9.03$, $\underline{p}<.001$, among the experimental group infants ($\underline{M}$=3.11) relative to control group infants ($\underline{M}$ = 1.09). This effect is illustrated in Figure 2. Simple comparison analyses were conducted to test whether the levels of exploratory procedures differed between the NOV and RFAM phases for each of the experimental and control groups (Table F13). The experimental group displayed significantly lower levels of exploratory procedures in the RFAM phase ($\underline{M}$ = 1.77) relative to the NOV phase [$\underline{M}$ = 3.11; $F(1,120) = 7.545$, $\underline{p} <.01$], whereas the control group's levels of exploratory procedures did not differ between these two phases ($\underline{M}$s =1.09 and 0.79 for the NOV and RFAM phases, respectively).

Follow-up analyses on the final interaction of Phase x Age x Order were conducted; the simple two-way Age x Order interaction was evaluated at each level of Phase. The results indicated that this interaction was not significant at any level of Phase (Table F14), suggesting that the three-way Phase x Age x Order interaction was spurious.

Bimanual Manipulation. A mixed ANOVA with a square root transformation was conducted and results indicated a Phase main effect $\underline{F}(3,141) = 4.31$, $\underline{p} =.01$ (Appendix F, Table F15). Overall, infants displayed low levels of bimanual contact, however, Tukey HSD analyses (Table F16) revealed that they engaged in significantly higher levels of bimanual exploration during the BHAB phase ($\underline{M}$ = 0.90) relative to the CRIT ($\underline{M}$ = 0.41) and RFAM ($\underline{M}$ = 0.02) phases. However, levels of bimanual manipulation did not differ between the BHAB and the NOV phase ($\underline{M}$ = 0.77), the latter being the only phase in which one group, the experimental group, received a novel texture.

Total Attention. A mixed ANOVA resulted in Group $\underline{F}(1,46) = 13.40$, $\underline{p} <.001$,

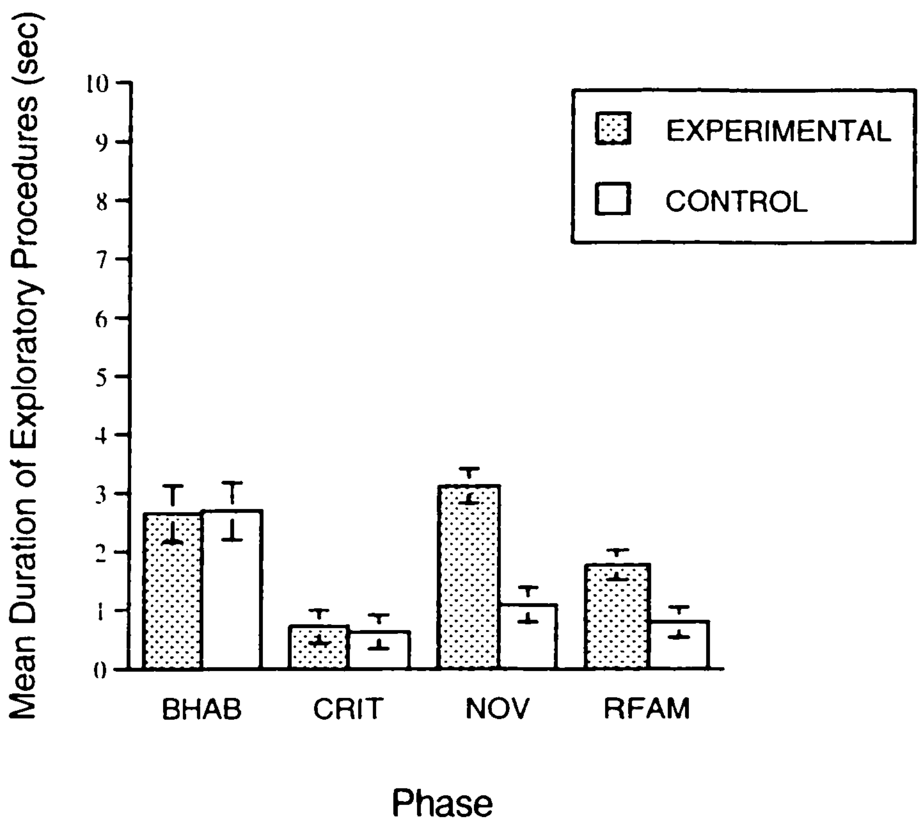

Figure 2. Mean duration of exploratory procedures as a function of Group and Phase. Standard errors are shown by vertical bars.

and Phase F(3,138) = 161.47, p<.001 main effects. These were qualified by a Phase x Group interaction F(3,138) = 5.15, p =.01 (Appendix G, Table G1). Simple effects (Table G2) revealed higher levels of total attention among experimental group infants relative to control group infants during the NOV (Ms = 30.82 and 12.68, respectively; F(1,46) = 21.53, p<.001) and RFAM phases (Ms = 18.35 and 10.83, respectively; F(1,46) = 9.40, p<.001). This effect is illustrated in Figure 3. Simple comparison analyses were conducted to test whether the levels of total attention differed between the NOV and RFAM phases for each of the experimental and control groups (Table G3). The experimental group infants displayed significantly lower levels of total attention in the RFAM phase (M = 18.35) relative to the NOV phase [M = 30.82; F(1,138) = 15.87, p <.01], whereas the control group's levels of total attention did not differ between these two phases (Ms =12.68 and 10.83 for the NOV and RFAM phases, respectively).

Direct Attention. A mixed ANOVA on the summed duration of fixation and search experimenter indicated a Phase main effect F(3,141) = 73.65, p <.001 (Appendix G, Table G4). Tukey HSD comparisons (Table G5) revealed that infants engaged in significantly higher levels of direct attention during the BHAB phase (M = 33.80) relative to all other phases [CRIT M = 4.42; NOV M = 12.16; and RFAM M = 8.98]. In addition, infants displayed higher levels of direct attention in the NOV phase relative to the CRIT phase.

Fixation. In contrast to the other measures, the total duration of fixation during only the two baseline trials of the BHAB phase was included in the analysis rather than the total duration of fixation over all the BHAB trials. The low frequency of fixations toward the stimulus, and the low duration of fixations led to high variability across infants during the BHAB trials; since infants varied in the number of BHAB trials (i.e., the number of trials before the two CRIT trials), the sum duration of fixation over all the BHAB trials varied extensively across infants. Thus, for the analyses of the measure of

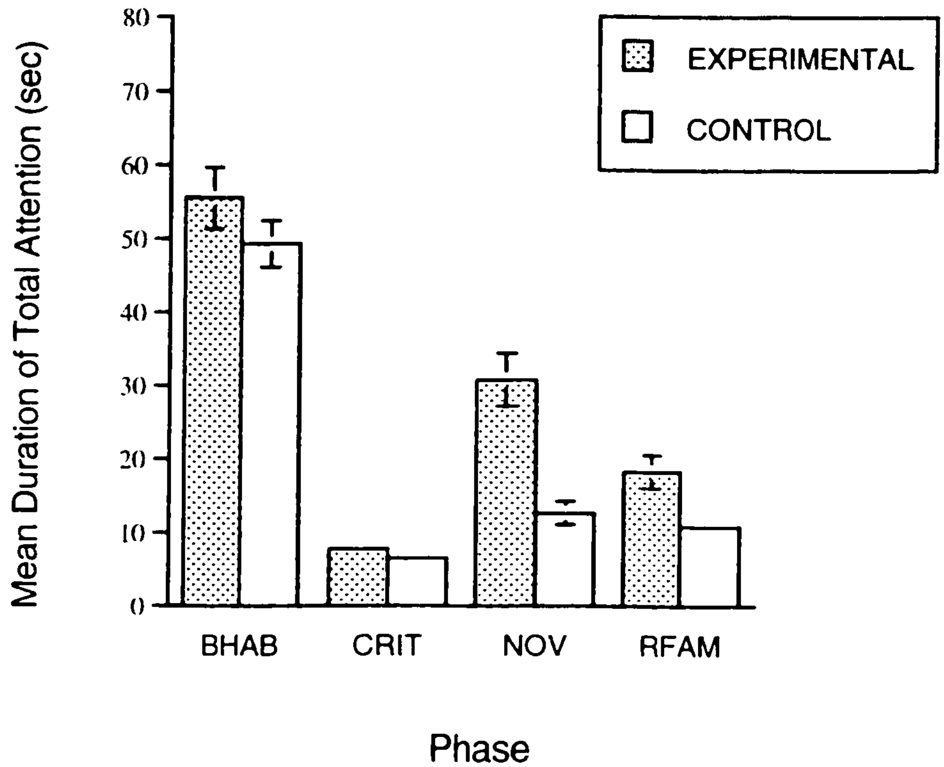

Figure 3. Mean duration of total attention as a function of Group and Phase. Standard errors are shown by vertical bars.

fixation, the total duration of fixation during the two baseline trials of the BHAB phase were considered rather than the total duration of fixation over all the BHAB trials. This equated the infants in terms of the opportunities (i.e., the two baseline trials) they had to display fixation during the BHAB phase. This also served to provide a better comparison of fixation levels during this phase to the subsequent phases, i.e., NOV and RFAM,during which infants were already equated for opportunity for fixation since all infants received three trials within each of these two test phases.

A mixed ANOVA with a square root transformation was conducted. Significant Group $F(1,46) = 6.20$, $p<.05$ and Phase $F(3,138) = 4.14$, $p = .01$ main effects were obtained that were qualified by a Phase x Group interaction $F(3,138) = 3.87$, $p <.05$ (Appendix G, Table G6). Simple effects (Table G7) revealed higher levels of fixation among experimental group infants relative to control group infants during the NOV phase (Ms = 1.77 and 0.05, respectively; $F(1,46) = 28.09$, $p<.001$). This effect is represented in Figure 4. While the experimental group appears to have responded to the novelty in texture with higher levels of fixation, relative to controls, in the NOV phase, the levels of fixation among both groups were low. Simple comparison analyses were conducted to test whether the levels of fixation differed between the NOV and RFAM phases for each of the experimental and control groups (Table G8). Experimental group infants maintained the level of fixation observed in the NOV phase in the RFAM phase (M = 1.77 in each phase). The control group's levels of fixation also did not differ between the NOV and RFAM phases (Ms = 0.05 and 0.60, for each phase respectively). The slight, nonsignificant, increase in the control group's levels of fixation in the RFAM phase relative to the NOV phase, and the overall low levels of fixation may have contributed to the lack of a group difference in the RFAM phase.

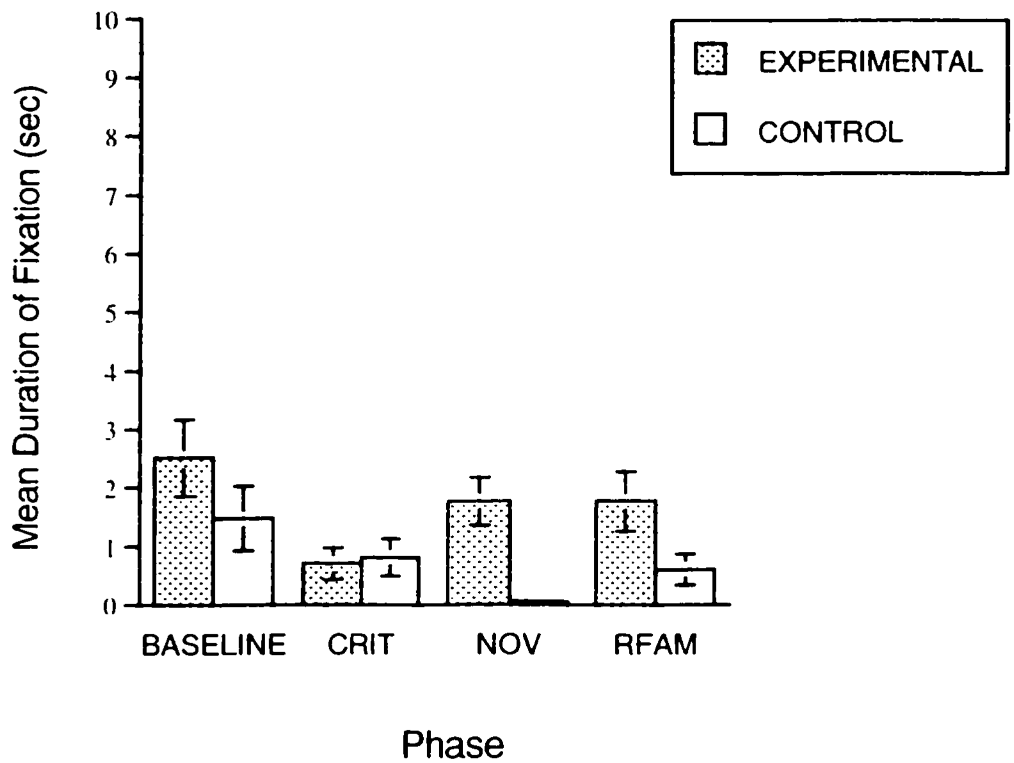

Figure 4. Mean duration of fixation as a function of Group and Phase. Standard errors are shown by vertical bars.

Discussion

The main purpose of Study 1 was to contribute to the understanding of infants' haptic processing of texture during the first half-year of life. An infant-controlled HAB-NOV-RFAM procedure was employed to assess 3- and 6-month-old infants' processing and discrimination of texture. There were three objectives specific to Study 1. The first objective was to examine infants' information processing patterns during haptic habituation to texture. The second objective was to examine infants' haptic discrimination and recognition of texture. The third objective was to assess developmental differences in habituation, discrimination, recognition memory, exploratory procedures, as well as in visual attention during a haptic task. The results from Study 1 are discussed with reference to each of these objectives and the hypotheses proposed within each.

The first objective was to examine infants' haptic perception and processing of texture information. The infant-controlled habituation procedure proved to be a rich observational window into infants' patterns of responding and information processing speed during haptic habituation to texture stimuli. An examination of the results for the measures of trials to baseline, trials to habituation, and levels of active manipulation during the HAB phase suggests that infants were responsive to the nonvisible texture stimuli. Infants did not require the 16 trials to meet the baseline criterion nor the additional 16 trials to reach the habituation criterion. Instead they met the baseline criterion in approximately 3 trials, and then met the habituation criterion within the subsequent 4 trials, which resulted in a mean of 6.89 trials to habituation. The absolute time spent haptically manipulating the textures during the BHAB and CRIT phases also provided information regarding the rate of haptic information processing of texture stimuli. Infants accumulated a mean of 74.42 seconds of haptic manipulation over the entire HAB phase. These results point to infants' responsivity to nonvisible haptic stimuli over trials, and suggest that infants need on average over one minute of haptic manipulation before habituating to texture information during the first half-year of life. The required total manipulation time prior to habituation observed in the present infant-controlled procedure was slightly longer than the fixed 30 or 60 seconds typically allotted to infants at 6 months to 12 months of age, in past studies of haptic perception of shape (Gottfried et al. 1977; Rose et al., 1981a,b) and of texture (Stack & Tsonis, 1999). It is also longer than the 25 seconds of familiarization permitted in one study assessing texture perception among 3-month-olds (Bushnell et al., 1996). Studies of shape perception which have employed infant-controlled procedures with infants during the first half-year of life have also documented that infants haptically explore for more than 60 seconds before meeting habituation criteria. Streri's studies of shape perception with infants from 2- to 3-months to 5 months documented that infants accumulated 88 to 91 seconds of haptic exploration to habituation criterion (Streri, 1987; Streri & Pêcheux, 1986a,b). The present findings provide support for the contention that the use of fixed trials procedures pose methodological limitations towards the understanding of infants' processing of texture among infants both under and over 6 months of age, and underscore the value of the infant-controlled habituation procedure in understanding haptic processing.

Furthermore, the present findings suggest that infants during the first half-year of life may process texture information faster (i.e., in approximately 74 seconds) than shape information (i.e., closer to 90 seconds as observed in Steri's studies). This comparison supports the notion that haptics is tailored for the perception and processing of specific stimulus properties and that such specificity may be evident very early in life. Furthermore, this qualitatively observed difference across studies of haptic texture and shape perception supports the contention that the choice of stimulus property for investigation may influence interpretations regarding haptic speed of processing. However, studies employing infant-controlled habituation procedures and directly comparing haptic processing speed, or time to habituation, for texture relative to shape stimuli are necessary in order for any firm conclusions to be made regarding faster haptic speed of processing of texture relative to shape.

The habituation indices were also valuable in assessing haptic habituation patterns and processing speed, but the hypotheses regarding the habituation indices were only partially supported. The literature on visual and auditory information processing has documented a positive correlation between age and more efficient speed of processing (Rose & Tamis-LeMonda, 1999). It was expected that this relationship would also hold true for haptics: six month-olds were expected to be more efficient processors of texture information relative to 3-month-olds. This efficiency was expected to be observed in the habituation measures that served as haptic analogues of visual and auditory measures of speed of processing. That is, 6-month-olds, relative to 3-month-olds, were expected to meet the baseline and habituation criteria within fewer trials, to display a greater magnitude of habituation, and require less accumulated haptic manipulation before reaching habituation.

The hypothesis of more efficient processing among 6-month-olds was supported only on the measure of trials to habituation, and only partially. That is, the 6-month-old females habituated faster, within significantly fewer trials, than the 3-month-old females but only when habituated with the smooth texture. This suggests an increase in the speed of processing among females but not males. However, conclusions regarding such sex differences in development are guarded for two reasons. First, only one other marginal sex difference was observed in Study 1; female infants met the baseline criterion within somewhat fewer trials relative to the males. Thus, replication of sex effects are required for any firm conclusions to be drawn. Second, the data indicate that the nature of the texture, either rough or smooth, played a greater role, relative to sex, in influencing infants' trials to habituation. An age difference was not observed among females habituated to the rough texture. In fact, the results indicated that among infants habituated to the rough texture, 3-month-old males and females were just as fast processors (i.e., habituated within a similar number of trials) as their 6-month-old counterparts. Moreover, the order main effect suggests that, overall, infants habituated significantly faster, within fewer trials, to the rough relative to the smooth texture.

The number of trials to habituation is one of many indices in visual attention research that is thought to reflect the rate at which infants habituate; the fewer number of looks needed to reach the criterion, the faster the rate of habituation (Columbo, 1993). In the present study, infants presented with the rough texture reached the habituation criterion faster, within fewer trials of haptic manipulation. While this might suggest faster processing of the rough texture, the results of the measure of duration of haptic manipulation suggested that infants manipulated both textures for the same amount of time to habituation. Thus, one possible explanation for fewer trials to habituation to the rough texture is that infants' prior experiences and knowledge may have influenced their habituation patterns. That is, since infants are generally more familiar with smooth textures in their everyday experiences, their inexperience with rough textures made the rough texture more salient to them. In turn, they reached the habituation criterion faster, within fewer trials. This explanation implies that the rough texture was especially salient for infants, even the 3-month-olds. The results also point to the 3-month-olds' haptic sensitivity to the rough texture, in that they did not differ from 6-month-olds in the number of trials to habituation, nor in total haptic manipulation to habituation. However, in response to the familiar texture, the 6-month-old females may have been be a little faster than the 3-month-olds. Overall, the data from the trials to habituation measure indicate a sensitivity, at both ages, to the nature of the texture stimulus being haptically explored. That is, while infants haptically manipulated both textures equally, they accumulated this haptic manipulation within a different amount of trials depending on the texture to which they were being habituated. These findings highlight the importance of using multiple measures of habituation in understanding how infants haptically perceive and process information.

The results from the measure of magnitude of habituation also support a different sensitivity and response to the two textures during the HAB phase. All infants habituated to the rough texture displayed a greater magnitude of habituation, or a sharper decline in levels of manipulation on criterion trials relative to baseline trials, compared to infants habituated to the smooth texture. Thus, the pattern of infants' haptic manipulation over trials to habituation appears to be have been driven more by the nature of the texture (i.e., rough and relatively more novel, or smooth and relatively more familiar) than by sex or age. The results for magnitude of habituation in conjunction with the trials to habituation support two patterns of habituation as a function of texture. In response to the rough texture, infants appeared to habituate within fewer trials, but also displayed a greater discrepancy in haptic manipulation levels between baseline and criterion trials. Thus, the first pattern, observed among infants familiarized with the rough texture, appears to consist of high levels of contact on baseline trials, followed by a sharp decrease in levels of manipulation on the two CRIT trials. This sharp decrease to habituation criterion when exposed to the rough texture also occurred relatively more quickly, (i.e., in fewer trials), relative to the smooth texture. The second pattern, observed among infants familiarized with the smooth texture, appears to consist of relatively lower levels of manipulation on the baseline trials, followed by a less sharp decrease on the two CRIT trials, and a slower progression, (i.e., more trials), to habituation criterion. Furthermore, the lack of an age difference on this measure suggests that both 3-and 6-month-olds responded similarly to each texture. These findings are consistent with the theory and research supporting that haptic exploration differs according to the nature of the haptic stimulus, and that infants' haptic exploration is guided by features salient to haptics

(Bushnell et al., 1992; Bushnell & Weinberger, 1987; Rochat & Senders, 1991; Ruff, 1989).

Interestingly, while the magnitude of habituation and the number of trials to habituation differed as a function of texture, the total amount of time spent haptically manipulating the textures until habituation did not. That is, infants haptically manipulated the smooth and rough textures for an equal amount of time over the HAB phase (all of the BHAB and the CRIT trials). It appears that while infants engaged in different patterns of exploration depending on whether they were exploring the smooth or the rough texture, they nonetheless required and acquired the same amount of experience with each texture before habituating. Moreover, there were no age differences in the total amount of haptic manipulation required to reach habituation. These findings are consistent with the intramodal, infant-controlled habituation, studies of shape perception indicating that, unlike with visual exploration, there was no decrease in haptic exploration time over the first half-year of life (Streri, 1987; Steri & Pêcheux, 1986a,b). These findings are also consistent with Streri and Spelke's (1988) findings that while 4-month-old infants accumulated similar amounts of contact with both rigidly and independently movable rings, they manipulated each differently (i.e., both hands moved at once when exploring the rigid rings, while the hands tended to move in alternation when exploring the rings that moved independently). Such findings are consistent with the notion that haptic exploration may vary in accordance with the properties or information afforded by objects (E.J. Gibson, 1969; E.J. Gibson & Spelke, 1983; J.J. Gibson, 1962; 1966).

While the habituation indices were informative regarding haptic information processing patterns, and speed of processing of texture stimuli, the test for response to novelty yielded a more direct assessment of the quality, or the nature of the information processed, during the haptic HAB phase. This was the second objective of Study 1. It was hypothesized that both 3- and 6-month-old infants would haptically process the nonvisible texture information during HAB and, since they were familiarized to the point of habituation, both age groups would detect the discrepancy during the NOV phase, and recognize the RFAM texture as being the original HAB texture. It was expected that discrimination and recognition memory would be displayed in the haptic measures of haptic manipulation and exploratory procedures. In addition, response to novelty and recognition memory were also expected to be observed in the visual attention measures. The results for the haptic measures are presented first, followed by the results for visual attention.

The discrimination and recognition hypotheses were both supported by the results for haptic manipulation. Following similar responding between the experimental and control groups in the BHAB and CRIT phases, the experimental group infants displayed significantly higher levels of manipulation upon receiving a novel texture during the NOV phase, relative to the control group infants who continued to be presented with the same habituated-to texture. The haptic discrimination findings were also reflected in the index of dishabituation, which measured the magnitude of the response during the NOV phase relative to the criterion trials. The experimental group displayed a significantly greater magnitude of dishabituation relative to the control group. This index substantiates the marked change in haptic responding between the NOV and CRIT trials for the experimental group infants. The response to novelty suggests that the experimental group infants discriminated between the HAB and the NOV phase textures and implies that infants processed the texture information sufficiently through haptic manipulation alone during the HAB phase. Moreover, the response to novelty suggests the creation of some representation or memory trace for the familiar texture and the mental comparison of the representation of the familiar texture to the representation of the NOV texture. The same processes of the formation of mental representations for texture information, and mental comparisons may account for the control group's significantly lower levels of haptic manipulation during the NOV phase. The lower responsivity of the controls suggests that they recognized the texture during the first test phase (corresponding to the experimental group NOV phase) as being the same texture as the HAB phase texture.

This difference in responding between experimental and control groups was also observed in the RFAM phase, further supporting discrimination abilities, but also recognition memory abilities. Experimental group infants continued to display significantly higher levels of haptic manipulation during the RFAM phase (when re-presented with the original HAB texture) relative to control group infants. This suggests again that the experimental group detected the discrepancy in texture between the NOV and the RFAM phases. However, the predicted significant decline in their levels of haptic manipulation from the NOV to the RFAM phase suggests that they also recognized the RFAM texture as being the original HAB texture. Following detection of the change in texture in the RFAM phase, infants may have recognized, (through the comparison of mental representations), the RFAM texture as being the original HAB texture. This recognition or memory for the original HAB texture may have resulted in lower levels of haptic manipulation by experimental group infants on the RFAM phase, relative to the NOV phase. In contrast, the control group displayed similarly low levels of haptic manipulation during the NOV and RFAM phases. The evidence for recognition memory abilities suggests that infants formed a memory trace for the original texture and that this memory trace remained in, and was accessed from, short-term memory even following experience with a novel texture (Bornstein et al., 1997; Zelazo, Kearsley & Stack, 1995).

A final piece of supporting evidence for the interpretation of discrimination and recognition memory for texture information stems from the control group DHAB phase. In order to control for fatigue effects as a possible factor accounting for the declining levels of active manipulation among the control group infants, these infants were finally presented with a novel texture, either the rough or the smooth, during the extra dishabituation (DHAB) trials which followed the RFAM phase. Their mean haptic manipulation was significantly higher, nearly double, in the DHAB phase, relative to the RFAM phase. This difference represents a response to novelty and as such provides additional support for haptic discrimination of textures (Bornstein et al. 1997; Zelazo et al., 1995). In addition, the higher levels of responding among controls during the DHAB phase suggests that their earlier lower manipulation levels during the NOV and RFAM test trials were not due to fatigue. Finally, the responsivity of infants in the control group during the DHAB trials also provides additional support that the experimental group's lower levels of haptic manipulation in the RFAM phase, relative to the NOV phase, were not due to fatigue, but rather to the recognition of the original texture.

Overall, the results for haptic manipulation suggest that texture information was processed haptically, and that there are many parallels between haptic information processing and information processing in the visual and auditory modalities. The findings support the hypothesis that at both 3- and 6-months of age, infants process texture information, and are capable of discriminating textures and storing texture information in short-term memory. The lack of age differences suggests that the haptic abilities of 3-month-olds may be quite well developed, at least for the perception of stimulus properties salient to the haptic system. The use of an infant-controlled habituation procedure may have permitted observation of texture discrimination abilities among both 3- and 6-month-olds. This is supported by a comparison of the present findings to those of the Stack and Tsonis (1999) study in which 7-month-olds were presented with a very similar texture discrimination task following a fixed familiarization time of 30 seconds. The textures employed were selected in the same manner, and were very similar to those used in Study 1. Although these infants were older than the ones in the present study, experimental and control group differences were not observed during the novelty test phase. Control group infants continued to show high levels of haptic manipulation of the familiar texture, suggesting that 30 seconds of familiarization was insufficient for processing of the texture stimulus. In contrast, clear differences between infants in the experimental and control groups were observed in Study 1, with younger infants, following the infant-controlled habituation phase. The comparison of the Stack and Tsonis (1999) study with Study 1 suggests that discrimination abilities can be attributed to the perception and processing of the texture during HAB, and not to the texture discrimination task being relatively easy (since the textures were selected from the extreme ends of the roughness ratings). The present findings also suggest that indices of information processing, such as habituation patterns and speed, response to novelty, and recognition memory, typically used with the visual and auditory modalities can also be employed to understand information processing within the haptic modality (Streri, 1993).

Response to novelty, or haptic discrimination of the textures, and recognition memory abilities were also expected to be reflected in infants' exploratory procedures. A novelty response was obtained during the NOV phase; experimental group infants engaged in higher levels of exploratory procedures during the NOV phase, relative to control group infants. The response to novelty of experimental group infants substantiated the hypothesis that infants, in response to haptic novelty, engaged in more exploratory procedures. It is important to note however, that infants displayed overall very low levels of exploratory procedures. For this reason, this and all other effects obtained for exploratory procedures must be interpreted with caution but it is nonetheless noteworthy that this effect emerged despite the low levels. Furthermore, it is also possible that higher levels of exploratory procedures during the NOV phase among infants in the experimental group may have been due to longer NOV trials. That is, since each trial was determined by infants' haptic manipulation, and experimental group infants haptically manipulated for longer durations during the NOV phase they may have had, as a result, a greater opportunity to engage in more exploratory procedures. However, the experimental and control groups did not differ in levels of exploratory procedures during the RFAM phase, despite the difference in haptic manipulation. There was a significant decline between the NOV and RFAM phase in levels of exploratory procedures by the experimental group. While it is possible that the decline was due to recognition memory for the original texture, this interpretation is precluded by the overall low levels of exploratory procedures.

There was additional support that infants' haptic perception and discrimination abilities were reflected in exploratory procedures, for both 3- and 6-month-olds. First, among 3-month-olds, the experimental group infants displayed higher levels of exploratory procedures relative to the no-change control group. This difference suggests that even 3-month-olds responded to changes in texture with higher levels of exploratory procedures. Second, greater specificity between exploratory procedures and texture novelty was observed among the 6-month-old infants. Six-month-old experimental infants displayed higher levels of exploratory procedures relative to controls, however, higher levels of exploratory procedures were observed among the 6-month-old experimental group infants receiving the textures in the order of SRS (in the HAB, NOV and RFAM phases, respectively) relative to the 6-month-olds receiving the textures in the order of RSR in the same phases. Since infants were habituated to the same criterion to either the rough or smooth texture in the HAB phase, and differed in the texture experienced during the NOV phase, it is possible that higher levels of exploratory procedures in the SRS order relative to the RSR were due to the experience of the rough texture as the novel stimulus.

Further support for this interpretation is provided by a number of other significant findings. First, the SRS experimental group also displayed significantly higher levels of exploratory procedures, relative to their SSS control group. These two groups differed only in their experience of the rough texture during the NOV phase. In contrast, experimental and control group infants receiving the textures in the orders of RSR and RRR, respectively, did not differ from each other, suggesting that the rough texture elicited higher levels of exploratory procedures. Second, the overall response to novelty observed on the measure of exploratory procedures discussed above (i.e., more exploratory procedures among experimental infants during the NOV phase relative to control groups) also supports the interpretation that the novelty of the rough texture may have led to higher levels of exploratory procedures among the 6-month-old experimental SRS group relative to the experimental RSR group. Finally, these data are consistent with the different patterns of responding during habituation indicating a greater salience of the rough texture (i.e., habituation within fewer trials, and a greater magnitude of habituation to the rough texture) for both 3- and 6-month-old infants. The question that immediately follows the interpretation that the novelty of the rough texture led to higher levels of exploratory procedures is why the Group x Order interaction effect for the 6-month-olds was not observed to occur as a function of phase in the original ANOVA. It is possible that the low levels of exploratory procedures precluded the observation of such a significant four-way interaction (Age x Group x Order x Phase).

The results indicating haptic texture discrimination abilities on the measures of haptic manipulation and exploratory procedures are consistent with the theory and past research supporting the early developing and organized perceptual abilities of the haptic modality (E.J. Gibson & Spelke, 1983; Rochat & Senders, 1991). While levels of exploratory procedures were low, compared to the substantially higher levels of haptic manipulation, they appear to have been sufficient for the perception and processing of texture; haptic discrimination abilities were reflected in infants' exploratory procedures as they were on their total levels of haptic manipulation. In addition, an increase in exploratory procedures, in response to changes in textures over the phases, were observed both among 3- and 6-month-old infants, despite the limited motor skills and lack of visual-prehensile coordination of the 3-month-olds. Moreover, the increase in exploratory procedures was also observed to be even more specific to salient haptic stimulation (i.e., the rough texture) among the 6-month-olds. These effects were observed within a unimodal context of haptic exploration, and out of the field of vision. Thus, the present findings challenge the long-standing view that visual control, or guidance, is necessary (Hatwell, 1987; Heller, 1982) for the development of manual exploration and haptic perception, at least in the case when the stimulus information is salient for haptics (i.e., texture). In fact, the present findings are consistent with Streri's (1987) observations of 2- to 3-month-old infants' manipulations during an infant-controlled haptic study documenting discrimination of shape; she reported that infants' exploration was limited to handling the objects and they did not display any real degree of motor movement. Infants' handling was observed to be quite precise and consisted of finger pressure, opening and closing of the hand, and sliding the thumb or all the fingers over the surface. In the present study only stroking and scrumbling were coded as exploratory procedures, since this type of handling has been proposed to be necessary for the perception of texture. However, the high levels of haptic manipulation suggest that infants were engaging in handling of the textures that provided sufficient information for the perception and processing of texture despite, as in Streri's (1987) study, limited motor skills, limited visual-prehensile coordination, and the absence of visual guidance.

The final haptic measure analyzed consisted of bimanual exploration, which revealed that infants displayed higher levels of bimanual exploration during the BHAB phase relative to the CRIT and RFAM phases. Since the BHAB phase consisted of more trials and lasted longer in absolute time, relative to the other phases, this finding suggests that with greater opportunity, infants are more likely to engage in bimanual exploration. However, the amount of time spent in bimanual exploration during the BHAB phase did not differ from the amount of time spent in bimanual exploration during the NOV phase, despite the fewer number of trials in the NOV phase. This suggests that the novelty in textures, in addition to eliciting more haptic manipulation and exploratory procedures, may have also elicited greater amounts of bimanual exploration. This interpretation is guarded, however, since the levels of bimanual exploration across the phases were not qualified by a group difference, which would be necessary to confirm that the novelty experienced by infants in the experimental group contributed to the higher levels of bimanual exploration during the NOV phase. It is possible that the very low levels of bimanual exploration displayed during the haptic intramodal texture discrimination task precluded the observation of a direct influence of novelty (as in a Phase x Group effect) on bimanual exploration.

Interestingly, while the infant-controlled procedure was driven by infants' haptic responses to the textures, their discrimination abilities were also reflected on the visual attention measures of total attention and fixation. The measure of total attention reflected attention to all components of the experimental situation (i.e., looking towards the experimenter, towards the cover, and in the direction of the texture being manipulated). Experimental group infants displayed higher levels of total attention during the NOV and RFAM phases, relative to control group infants. However, the experimental group also displayed lower levels of total attention during the RFAM phase relative to the NOV phase, while the control group did not differ during these two phases. These findings parallel the results obtained for total haptic manipulation suggesting discrimination during the NOV phase and recognition of the original texture during the RFAM phase. These findings suggest that haptic discrimination and recognition of textures that were only available to touch were reflected in infants' total visual attention. The low duration and frequency of fixations observed in the present study suggests that indeed visual-motor coordination may be difficult even for the 6-month-old infants when haptic stimuli, and their hands, are not visible.

However, discrimination abilities were also reflected in infants' fixations; infants in the experimental group displayed higher levels of fixation during the NOV phase relative to the control group. Remarkably, it appears that even when the textures were not visible, the haptically perceived novelty in texture elicited higher levels of fixation. That is, haptic novelty led to greater eye-hand coordination. Moreover, this effect did not differ as a function of age, highlighting the influence of haptically perceived information on visual-motor coordination among infants as young as 3 months old. This is interesting since very young infants, such as the 2- to 3-month-olds in Streri's (1987) study, have not been observed to bring a nonvisible object into view, nor display any attempts at prehension when the object is visible. However, the present study suggests that when infants are already handling an object, a perceived haptic novelty may elicit orienting the eyes towards the hand. This effect resembles neonates' classic head orienting response to auditory stimulation (Muir & Field, 1979).

Infants' total attention and fixation in response to the haptic novelty in texture suggest a guiding role for haptics on visual exploration. These findings are consistent with past studies suggesting that haptic information directs visual attention (Bushnell et al., 1989 in Bushnell & Boudreau, 1991; Bushnell et al., 1985), but document this effect during the first half-year of life. However, a guiding role of haptic stimulation on visual behaviour (or exploration) is contrary to the prevalent view that vision guides haptic perception. This effect also implies that haptic perception may actually have a role in the development of eye-hand coordination, and supports a greater role for haptics than that held by the Piagetian view that only the motoric component of haptic activity contributes to perceptual learning.

When a more direct measure of attention was considered the results differed slightly. The time spent looking at the cover was excluded in this measure. While looking at the cover could represent an immature attempt at fixation towards the object infants were touching underneath the opaque cover, the significance of looking towards the cover is unclear. When only direct attention to the experimental situation was considered, i.e., the looking towards the experimenter and fixation in the direction of the stimulus, only a phase main effect was obtained; infants displayed higher levels of direct attention during the BHAB phase relative to all other phases. This may simply reflect the longer duration, and greater number of trials, of the BHAB phase, and therefore a greater opportunity for direct attention relative to all other phases. While infants also spent more time in direct looking during the NOV phase relative to the CRIT phase, this cannot be attributed to the detection of any discrepancy in textures since this effect was collapsed over the groups.

The third and final objective of Study 1 was to assess developmental differences in haptic perception of texture. Developmental hypotheses were made for the following categories of abilities: a) habituation indices of haptic processing; b) discrimination and recognition memory abilities; c) exploratory procedures and bimanual exploration; and d) visual attention during haptic exploration. The hypothesis that more developed fine-motor and visual-prehension abilities among 6 month-olds would lead to faster and more efficient processing and discrimination abilities, relative to the 3 month-olds, was not supported. First, the results of the information processing habituation indices did not indicate developmental differences in information processing rates or patterns. As discussed, 3- and 6-month-olds met baseline and habituation criterion within a similar number of trials, displayed a similar magnitude of habituation, and accumulated the same amount of haptic manipulation until habituation. Moreover, the results indicated that even 3-month-olds were responsive to the salience of the rough texture, and that the rough texture elicited the same pattern of habituation (fewer number of trials to habituation, but greater magnitude of habituation) among both age groups. The habituation indices results suggest that the haptic modality is as adept and efficient at processing texture, and as responsive and sensitive to different textures, at 3-months as it is at 6-months of age. Second, as expected, haptic texture discrimination and recognition memory abilities were reflected in both 3- and 6- month-olds' levels of haptic manipulation. Similarly, both 3- and 6-month-olds displayed discrimination abilities, during the NOV phase, in their exploratory procedures.

Third, the hypothesis regarding higher levels of exploratory procedures among 6-month-olds was only partially supported. That is, while a main age difference was not found in levels of exploratory procedures, the results indicated a greater specificity of 6-month-olds' exploratory procedures for the rough, relative to the smooth texture, when it served as the novel stimulus. That is, 6-month-olds displayed higher levels of exploratory procedures when the rough texture served as the novel texture. However, 3-month-olds also displayed higher levels of exploratory procedures in response to any novelty or change in texture (i.e., when in either the SRS or the RSR experimental group), relative to when they did not experience any changes. The results suggest that 3-month-olds are responsive to novelty and engage in haptic exploratory procedures, but that they were equally responsive to the novelty of both the smooth and rough textures. Older infants may have acquired more experience and therefore were more discriminating in their exploratory procedures, engaging in more exploratory procedures only with the rough texture.

The lack of age differences in texture discriminations and recognition memory abilities on the measures of haptic manipulation and exploratory procedures have many implications. Novelty responses suggest that an adequate representation for haptically perceived texture information was formed, and was compared to the novel texture information, among 3-month-old infants (Bornstein & Tamis-LeMonda, 1994; Bornstein et al., 1997; Zelazo et al., 1995). While 3-month-olds' fine-motor exploratory abilities may be limited, the present findings suggest that they may be sufficient for the acquisition of texture information and for the perception of texture novelties. Contrary to Piaget (1952), the novelty responses observed in this study suggest that infants' haptic manipulation and exploratory procedures may be may be purposive rather than reflexive. In turn, the results imply that the haptic exploration, despite motoric limitations, is an important means of perceptual learning.

Finally, guarded hypotheses were proposed regarding infants' visual attention. As predicted, discrimination and recognition abilities were reflected on total attention responses at both ages, despite differences in attentional resources and visual-prehensile coordination, and despite the occlusion of vision. While it was hypothesized that discrimination abilities would be observed only in 6-month-olds' fixations, given their eye-hand coordination and visual-prehension abilities, this was also found to be true for 3-month-olds. Thus, even in infants as young as 3-months-old, whose eye-hand coordination and visual-prehension abilities are just beginning to emerge, haptically perceived novelties in texture were able to direct visual fixation towards the hands, even when the hands were not visible. The reflection of haptic discrimination and recognition memory abilities in 3- and 6-month-old infants' visual attention and fixation, during a task in which stimuli were not visible, suggests a certain level of integration and coordination of the senses by 3 months. It also suggests that haptic stimulation may orient, or prime, infants' visual attention for further information processing, and may serve a role in the development of eye-hand coordination.

In contrast to the findings for visual attention and fixation, and as predicted, haptic novelty responses were not observed on the measure of bimanual exploration. In fact, the results indicated that bimanual exploration occurred equally infrequently for 6-month-olds, as for 3-month-olds when stimuli were not visible, despite the more mature eye-hand coordination and visual-prehension abilities at 6 months. This is consistent with the present hypotheses and with past studies indicating very low levels of bimanual manipulation in the dark (Bushnell et al., 1992; Stack & Tsonis, 1999). The interesting question is why haptic novelty influenced both 3-and 6-month-olds' visual attention and fixation towards a non-visible stimulus, but did not direct the second hand towards the non-visible stimulus. As indicated in past developmental research and by the present findings, infants need to see an object in order to direct one or both hands towards it. However, the present findings suggest that even at 3-months, infants need only to feel an object in order to direct their eyes toward it. Thus, reaching to explore a visible object may depend on sufficient coordination between vision and the motor component of haptics. However, given the early functioning perceptual abilities of haptics, haptic stimulation may facilitate the coordination of the eyes to the hand, and in turn permit bimodal exploration, or the acquisition of visual information about the object in addition to haptic information. Thus, aside from serving the acquisition of sensory knowledge, haptic perception may also play a role in the coordination of the two sensory systems.

Taken together, the results from this study substantially contribute to the understanding of very young infants' haptic processing, discrimination, and recognition memory abilities. The findings suggest that: 1) infants as young as 3 months old perceive texture information, and can discriminate between textures on the sole basis of haptic information; 2) infants' perception and discrimination of texture information can be observed in more than one behavioural response system, namely in both their haptic behaviors (i.e., haptic manipulation and exploratory procedures) as well as in their total attention and visual fixations; 3) infants' haptic manipulation patterns during habituation vary according to the nature and salience of specific textures; 4) at 6-months of age infants' exploratory procedures may also be more specifically elicited by certain novelties or the salience of specific textures; 5) haptic detection of novel textures may prime or orient infants' visual attention, and play a role in eye-hand coordination by facilitating fixation towards the hand; and 6) the use of infant-controlled habituation procedures and the use of texture stimuli may facilitate access to, and understanding of, the functioning of the haptic modality during the first half-year of life.

Study 1 provided strong support for haptic processing and discrimination abilities even among the 3 month-old infants, and substantiated past evidence for an early and independent contribution of haptics to perceptual learning and cognitive development. Demonstrating that infants were capable of perceiving and discriminating texture on the sole basis of haptic exploration was a prerequisite for Study 2. The purpose of Study 2 was to expand the understanding of the haptic modality and its relative contributions to cognitive development by examining infants' haptic processing within a more naturalistic context permitting bimodal exploration. Specifically in Study 2, the influence of vision on infants' haptic information processing and discrimination abilities during the first half-year of life was examined. This was accomplished by permitting the visibility of the textures and infants' hands only during the habituation phase, and subsequently examining the consequences or influence of vision on infants' haptic processing of nonvisible textures, and their haptic discrimination and recognition abilities.

Chapter 3: Study 2

Study 2 was designed to enrich and extend our understanding of the contribution of haptics to cognitive growth by examining the relative role of haptic perception and processing during bimodal, i.e. haptic and visual (H+V), exploration of the world. Study 1 provided information regarding the efficiency of haptics at 3 and 6 months of age in obtaining information when operating in isolation, or independently from, vision. Intramodal studies such as Study 1 therefore address the question of what information infants can obtain from a system operating independently. Study 1 clearly documented that infants can obtain texture information, and make texture discriminations on the sole basis of haptic exploration. However, as Ruff (1989) pointed out, intramodal studies such as Study 1 do not address the more intricate question of how information is obtained when different systems are operating simultaneously. That is, they do not address the issue of what information infants actually do obtain when a greater, or full, range of perceptual activity is available (Ruff, 1989). Understanding how the haptic modality is actually used during naturalistic, bimodal and multimodal exploration, is critical to ultimately understanding its contribution to cognitive development. Thus, Study 2 was a logical progression from Study 1, extending our knowledge of the relative contributions of the haptic modality during naturalistic exploration. The emphasis in Study 2 was on examining the relative contribution of haptic exploration, and the relative salience of haptic information, during bimodal (i.e., haptic and visual) exploration. It permitted an understanding of the relative influence of the two modalities, haptics and vision, on infants' perception and discrimination of texture information.

There are methodological and interpretative obstacles in bimodal or multimodal studies that are not present in intramodal studies (Ruff, 1989). A primary difficulty is determining whether an infant recognizes an object because of the visual information obtained, the haptic information obtained, or both. The results from Study 1 indicated that when haptics is operating in isolation from vision, infants process and discriminate texture information through haptic exploration. However, in their natural and typical environments, when infants can both see and handle objects, do they attend to and process haptically perceived information (e.g., information about texture as in Study 1) or does the visibility of the texture stimuli affect their perception and processing of texture and how? Alternatively, if haptic perception and processing of texture is not influenced by the visible features of the stimuli, then what implications does this have for the haptic modality in perceptual learning? These questions directly address the relations between the visual and haptic modalities.

In a comprehensive paper devoted to the relations between vision and haptics, Ruff (1989) described three possible relationships between these modalities. These include cooperation, interference, and/or hierarchical arrangements between the modalities. In a cooperative arrangement, both systems contribute to providing valuable information about objects. The cooperative arrangement is based on evidence that the two systems are integrated in action such as when infants engage in the examination, or simultaneous looking and manipulation of objects (Ruff, 1989; Harris, 1972). The integration of the haptic and visual systems during exploration of objects may occur because each system operates more effectively with the cooperation of the other. More visual information may be acquired when the hands change the object's position and the hands may be more sensitive to haptic input when the actions are controlled and guided by vision (Heller, 1982).

There are two possible mechanisms for cooperative relations: detection of modality-specific information and detection of amodal properties. That is, each system may contribute to a better understanding of an object by detecting the modality-specific information available about the object. Studies demonstrating the salience of different stimulus properties for each modality (e.g., temperature and texture for haptics, and colour or shape for vision) support this mechanism of cooperation (Bushnell et al, 1985). Alternatively, the two systems may each be picking up the amodal properties or characteristics of objects, creating a redundancy in the information gathered by the two systems. This redundancy may lead to a better understanding of the object.

In a recent paper reviewing multimodal and unimodal perception research, Lickliter and Bahrick (2001) argued that when information is presented redundantly across two modalities the processing of amodal (redundant) stimulus properties is facilitated. They also argued that: 1) processing of amodal stimulus properties developmentally precedes the processing of arbitrary intermodal relations (relations between properties in two sense modalities that do not predictably occur together in nature or across contexts); and 2) processing of amodal properties takes precedence over the processing of modality-specific properties that may be available (Bahrick & Pickens, 1994; Hernandez-Reif & Bahrick, 2001; Lickliter & Bahrick, 2001). Studies on the perception of audio-visual events have reliably indicated that infants are capable perceivers of the redundancy across auditory and visual stimulation, and that there is a developmental lag between the perception of amodal relations and the perception of arbitrary relations (Hernadez-Reif & Bahrick, 2001; Lickliter & Bahrick, 2001). For example, Bahrick (1992, 1994) found that the amodal synchrony that united the visible and auditory impacts of an object hitting a surface was perceived by 3-month-old infants, but that the arbitrary relation between the colour and shape of the visual stimuli and the pitch of their sounds was not perceived until 7 months of age.

While more sparse, there is some evidence to suggest that sensory redundancy, or the presence of amodal information, across vision and haptics facilitates processing of objects, and that perception of amodal relations between vision and haptics also precedes that of arbitrary relations. Ruff (1982a) found that 12-month-olds were less likely to respond to a novel shape after familiarization with objects encased in transparent plastic boxes than after familiarization during which the objects could be handled directly. This suggests that haptic input was important to learning about the structural characteristics of the familiarization objects. Haptic input may be particularly useful when variations in visual characteristics, such as colour or pattern, compete with the detection of structural invariants.

Similarly, in a recent study, Hernandez-Reif and Bahrick (2001) haptically familiarized 4- and 6-month-old infants by letting them explore, under a bib and out of view, a 3-D object of a distinctive shape and size. Infants simultaneously also viewed the identical object presented with a distinctive colour pattern above the bib. Following familiarization, in the amodal test condition infants were visually presented with two objects while they handled one of the two. Thus, amodal information specifying the common shape was available to both modalities. Both 4- and 6-month-old infants were capable of visual-haptic matching; that is, they spent a significantly greater proportion of time looking at the object that matched the one in their hands. However, in the arbitrary test condition infants viewed 2-D posterboards depicting the distinctive colour patterns, rather than the actual objects, while they haptically explored the 3-D object. In this condition, only 6-month-olds perceived the arbitrary relation between an object's shape and colour. That is, infants looked more at the colour pattern that had previously been paired with the shape in their hands. The authors suggested that during familiarization, infants may have related the haptically experienced object properties (shape, size, and depth) with the visually experienced properties (shape, size, depth, and colour pattern), and that the visual and haptic information may have been perceived as related because they were experienced together. The perception of the arbitrary relation among only the 6-month-olds was interpreted as reflecting the developmental lag between detection of amodal and arbitrary relations that has similarly been observed in the auditory-visual perception research.

In a further experiment, Hernandez-Reif and Bahrick (2001) tested their hypothesis that the perception of the arbitrary relation between colour and shape was due to the detection of amodal information, available to both haptics and vision, during familiarization. In this experiment, amodal information was eliminated during familiarization. Six-month-old infants were haptically familiarized below the bib with an object of distinctive shape, but saw a distinctive colour pattern displayed on the flat posterboard above the bib, rather than the actual object. Thus, amodal properties of shape, size, and depth common to the visual and haptic stimulation were eliminated as a basis for intermodal learning. During the test phase, infants were visually presented with two posterboards while they manipulated one object under the bib. Infants did not look significantly more at the colour pattern previously paired with the object they had in their hands. The arbitrary relation between object shape and colour was not perceived in this experiment. These findings suggest that amodal haptic-visual information is perceived and can serve as the basis for learning about arbitrary relations.

There is also evidence supporting interference between the two modalities. Haptic manipulation can sometimes interfere with the detection of visual characteristics. For example, Ruff (1982b) permitted 12-month-olds to look at and handle several identically coloured objects that varied in texture. They were then presented with two objects of novel texture, one of the familiar colour and one of a novel colour. The infants failed to differentiate between the colour of the test objects. However, when the same objects were presented encased in clear plastic boxes during familiarization, infants were able to later discriminate between the colours of the test objects. For infants who handled the actual objects, the haptic information about the textures of the objects may have interfered with the detection of colour. Under quite different conditions, both Bushnell et al. (1985) and Casey (1979) have found similar failures to attend to colour changes.

Similarly, visual information or visual features may interfere with infants' attention to, perception and processing of haptic information. The Bushnell and Weinberger (1987) and the Bushnell et al. (1984) studies indicated a directive role for visual information using a violation of expectancy paradigm. Infants' detection of visual-tactile discrepancies was determined by the presence of salient visual information or features. In the absence of any such salient visual information (e.g., in the condition where infants saw a smooth wooden cube but felt the fur-covered cube), they did not detect the discrepancy. Thus, the visibility of the smooth wooden cube interfered with infants' attention to haptic information.

The final relationship between modalities is a hierarchical one in which one system is dominant. There are two possible ways this might occur. First, information from one system is attended to, while the consequences of exploratory activity in the other system are ignored because the infant may not be capable of picking up information from more than one modality. Such a limitation in attentional or processing abilities may be related to the sequential functional onset of the senses (Turkewitz & Kenny, 1982). Some limitations serve to prevent a young organism from being overwhelmed by input from different sources, and as reviewed in Chapter 1, permit adaptive organization of the senses, and the organism. The second and alternative way to avoid the potentially adverse interfering effects of input from different sources is for the hierarchy to consist of the domination of one system over another. Specifically, the dominance is in terms of determining what is attended to and explored and in turn, the information detected by the first system guides exploratory behaviour in the second system. It is this line of thinking that has led to the prevalent view that vision dominates haptics, and that haptic input is ignored during infancy (Hatwell, 1987), and/or the view that vision guides haptic exploration. However, there is also evidence for haptic dominance, or a guiding role for haptics, on visual exploration.

Many investigators who support the dominance of vision on haptics argue that the motor, or performatory, function of the hand dominates over its perceptual function in infants and young children and that haptic information is either not obtained or ignored in favour of visual information (Abravanel, 1972; Hatwell, 1987). They argue that, by moving objects, the hands function mainly to provide the visual system with visual information about the object. Hatwell (1987) argues that the "link established between the eyes and the hand after six months of age is so strong that it precludes the use of the 'perceptual hand' outside visual guidance" (p. 522). There is some empirical evidence to support this contention that vision is dominant and haptic perceptual input tends to be ignored. Diamond (1988; in Ruff, 1989) found that under 12 months of age, infants do not use tactual information about an opening in a transparent box to guide their actions in retrieving an object from under the box; they seem to need visual information about the opening. Behaviour on the visual cliff is another example; infants, even after patting the solid, though transparent, surface are reluctant to cross over the apparent drop-off (E.J. Gibson & Walk, 1960). These studies, however, are focused on the dominance that vision may have over haptic cues during the movement of the hands and body in space. However, visual dominance, to the point of complete inattention to haptic information, is not necessarily the case in all situations or for all object properties.

Bushnell and Weinberger proposed a more moderate view of the dominance of vision, based on infants' detections of visual-haptic discrepancies when seeing one object but feeling another (Bushnell, 1982; Bushnell & Weinberger, 1987). They suggested that vision has a directive role in infants' exploration of objects, and while haptic input may contribute during such exploration, it may be constrained. As reviewed in Chapter 1, visual information such as "distinctive" or more salient and complex visual features were deemed responsible for infants' detection of discrepancies between what they saw and what they touched. In the Bushnell and Weinberger (1987) study, 9 ½ - and 11-month-old infants shown a furry cube and manipulating a smooth cube detected the discrepancy, whereas infants in the reverse condition did not. The greater visual interest aroused by the furry cube relative to the smooth cube, when they each served as the viewed object, is thought to have instigated greater haptic exploration of the manipulated object. Thus, the view of the furry cube led to greater manipulation of the smooth cube and in turn facilitated the detection of the discrepancy. Detailed analyses of hand activity support this interpretation; infants exhibited longer durations of different manipulations (e.g., poking, digging, sweeping) in the visual furry/tactile smooth condition relative to the control condition of visual smooth/tactile smooth. Differences were not observed between the visual smooth/tactile furry and the control group of visual furry/tactile furry. This study illustrates how, to some extent, visual information controls or guides haptic manipulation, and in turn, the information that is picked up haptically.

Unfortunately, the interpretation of intriguing results from violation of expectancy paradigm studies have focused on the implications for the visual system. Yet these results raise important questions and have implications for the haptic system. The Bushnell and Weinberger (1987) study also illustrated the organized functioning within the haptic modality in response to salient visual information. Bushnell and Weinberger (1987) pointed out that visual information may also direct infants' manual activities in a more "cognitive" sense, by establishing a mental set regarding the object characteristics to which the hand will be sensitive. Thus they clarified that the visual dominance does not mean that what is seen is what is perceived, in which case none of the discrepancies would have been detected, but rather means that what is seen delimits what is to be attended to. While salient visual cues instigated the haptic activity that was necessary for the detection of the discrepancy, the haptic system appeared to respond to the visual objects that contained properties or features salient to haptics. For instance, when seeing a furry cube infants proceeded to manipulate more, even though they continued to touch a smooth cube. When seeing a smooth cube, infants engaged in less manipulation of the furry cube, and therefore, did not successfully perceive the discrepancy. Manipulation of the visible furry, but not the smooth, cube suggests that the importance of the salient visual features may lie in their significance for, and interpretation by the haptic system. Moreover, it suggests that haptics is responsive to visual cues that are salient for haptics, and to visual features that afford further understanding of the object through haptic manipulation. Thus, the textured, furry cube afforded further understanding of the object by haptic manipulation, whereas the smooth cube did not. Infants may or may not engage in haptic manipulation according to whether their understanding of an object is complete or incomplete on the basis of visual exploration. Such a feedback system between the two modalities permits greater understanding of the object than the independent exploration within one modality. This interpretation of the results of the Bushnell and Weinberger study suggests that the haptic modality is quite an organized functional system, responding in a meaningful and adaptive manner to visual information, and not necessarily subservient to vision or visual cues. As Bushnell and Weinberger (1987) concluded, multimodal functioning may be constrained by exploratory and attentional tendencies and the relation of these to the object properties involved. Thus, interpretations about hierarchical relationships in which dominance is usually attributed to vision, may ignore the role for, and functioning of, haptics in response to visually perceived information during multimodal exploration.

Studies that provide more naturalistic opportunities for exploration, relative to the experimentally contrived discrepancy tasks, support the view that haptics contributes uniquely during multimodal exploration, rather than being subservient to vision. This has been demonstrated particularly with infants during the second half-year of life. An increase in attention to haptic information has been documented between 5 and 12 months of age (Ruff, 1989), and by 12 months of age, infants have been shown to act in accordance with haptic information. The cross-modal literature supports the efficient functioning of haptics: 12-month-old infants are more likely than 6-month-olds to recognize a seen object after tactual familiarization, and to recognize a felt object after visual familiarization (Rose & Ruff, 1987). Haptic stimulus features have also been documented to predominate over visual features. Ruff (1982a) demonstrated that 12-month-old infants looking and handling objects attended to the texture rather than to the colour of objects; they failed to detect novelty in colour during test trials. Steele and Pederson (1977) found that 6-month-olds manipulated a novel object more if it were novel in texture or shape, but not if it were novel in colour.

Haptic input, even when not visible, has also been documented to direct visual examination. Bushnell et al. (1989; in Ruff, 1989) found that 12-month-old infants, but not 9-month-olds, looked at the back of a stationary cylinder when their hands encountered a texture not present on the front of the cylinder. Such effects have been documented among younger infants as well. Bushnell et al. (1985) found that 6-month-old infants handled objects that changed in temperature more than visually identical objects of a familiar temperature and looked longer at objects that had changed in temperature, but not when they changed in colour. These studies indicate that haptics may play a unique, and predominating role, particularly when tasks involve stimulus features that are salient for haptics, that haptic novelty may direct visual attention, and elicit longer looking even when there is no visual novelty to be detected.

These findings highlight the intricate ways that the haptic and visual systems may cooperate, interfere and potentially dominate each other. The research is just beginning to unravel the critical factors, contexts, and constraints that determine the nature of the relationship between the two systems. Structural or amodal properties may engage both systems in cooperating towards the understanding of objects, their properties and functions. If visual input is degraded, the infant may rely more heavily on the haptic system for information. In the case of learning about complex patterns, rather than structure, (e.g., a cube with pictures on each side) the visual system may predominate. If visual input is salient, and holds salient cues for haptics, or vice versa, then the impact of one system's direction or guidance on the other is observed. However, as Ruff (1989) pointed out, underlying determining factors in all these relationships include the speed and efficiency with which the different systems acquire information. That is, the faster and more efficient system is likely to guide the other, and the speed and efficiency of either system will vary with the object properties attended to and with development.

Since the goal of Study 2 was the assessment of the relative functioning of haptics during bimodal exploration, the properties of the stimuli to be employed were an important consideration. As in Study 1, the decision to select texture as the property of investigation was based on the salience of this property for haptics. The texture stimuli were identical to those employed in Study 1, however, in Study 2 infants were permitted to simultaneously view and handle the texture presented during the habituation phase. The textures were not visible during the unimodally haptic test phases. Therefore, since the HAB texture stimulus was visible, the stimuli were designed to differ only on texture, and they did not contain any distinctive visual features, or features salient to vision. This would provide an optimal context in which to access, and assess the unique contributions, and sensitivity, of haptics during bimodal exploration.

The purpose of Study 2 was to assess the influence that the visibility of textures during the habituation phase would have on infants' haptic processing patterns and texture discrimination and recognition abilities. In Study 2, infants were permitted to both see and touch the habituation texture, but not during the test phases which were, as in Study 1, unimodal and haptic. Study 1 established that infants can process, discriminate, and recognize texture on the basis of haptic exploration alone. The three objectives specific to Study 2 were to examine: 1) infants' haptic habituation patterns during bimodal exploration of a haptically salient property, that of texture; 2) whether bimodal exploration affects infants' attention to, perception, and processing of the relevant haptic input, i.e., the texture information, during the habituation phase, and their texture discrimination and recognition abilities during the test phases; and 3) whether the impact that bimodal exploration exerts on habituation patterns, discrimination and recognition abilities, exploratory procedures, bimanual manipulation, and visual attention is different for 3- and 6-month-olds. Thus, Study 2 permitted the examination of the functioning of the haptic modality in the presence of vision (i.e., during a bimodal context closely resembling infants' daily exploration experiences).

Predictions were made for the first objective of assessing the influence of bimodal exploration on infants' habituation to texture. The predominating view that vision dominates, or at least guides, haptic exploration suggests that among infants with visual-prehensile coordination, vision would facilitate information processing. Thus, it was expected that the 6-month-old infants would be more efficient at processing texture, relative to the 3-month-olds in Study 2. More efficient processing among 6-month-olds was expected to be observed in fewer trials to baseline and to habituation, a greater magnitude of habituation, and less accumulated haptic exploration to habituation.

The second objective was to assess infants' discrimination and recognition of texture following bimodal habituation. As stated earlier, developmental stage was a second important variable considered in influencing how the haptic and visual systems interact. While the visibility of the textures was expected to facilitate the acquisition of texture information by 6-month-olds during the HAB phase, it was expected that both 3- and 6-month-olds would display texture discrimination and recognition abilities as indexed by their overall levels of haptic manipulation. That is, experimental groups of both ages, were expected to display higher levels of haptic manipulation during the NOV and RFAM phases, relative to controls. This prediction was based on: 1) the literature reviewed highlighting the early importance of, and infants' sensitivity to, haptic stimulation; 2) the salience of texture to haptics and the isolation of this property in the present study; 3) the results of intramodal studies, including Study 1, indicating that very young infants are capable of haptic-haptic intramodal processing and on the results of cross-modal studies indicating that haptic-visual cross-modal transfer is superior to visual-haptic transfer; and 4) on the available literature supporting a haptic dominance during the second half-year of life. This dominance, the controls for texture, and the application of an infant-controlled procedure were expected to illustrate that the haptic system is extremely valuable in learning about specific object properties even when visual information is available, and that very young infants attend to this specific haptic information.

Predictions of texture discrimination and recognition abilities on the measure of haptic manipulation were also based on the fact that infants were habituated haptically, even though they were able to see the textures during the HAB phase. That is, as in Study 1, habituation was based and dependent on, haptic manipulation, and not visual attention. Moreover, the results of Study 1 did not indicate developmental differences in texture discrimination and recognition abilities. In order for infants to make the predicted texture discriminations in Study 2, they must have processed the relevant haptic information (i.e., texture) during HAB. Confirmation of discrimination and recognition hypotheses would imply that infants attended to and processed the haptic properties of the HAB stimulus (i.e., texture) even during bimodal exploration, or when the visual features of a stimulus were available. Moreover, vision was not expected to suppress the magnitude of the response to the novelty in texture; the same magnitude of dishabituation was expected in Study 2 as in Study 1. These expected results would be consistent with literature suggesting that infants attend to and process haptic stimulus information during bimodal exploration, and that the haptic modality plays a fundamental role in bimodal exploration and in obtaining specific information about the properties of objects. Thus, while Study 1 revealed that infants can process, discriminate, and recognize texture on the basis of haptic information alone, Study 2 was expected to illustrate that vision does not interfere with these abilities. That is, the results were expected to indicate that when exploring bimodally: 1) infants attend to, and presumably form a mental representation of, the haptic information obtained, and 2) the visibility of the textures does not interfere with the perceptual functioning of the hand.

While the visibility of the textures was not expected to interfere with infants' texture discrimination and recognition abilities as indexed by the measure of haptic manipulation, it was expected to influence infants' exploratory procedures. Past studies have reliably indicated that exploratory procedures are dampened when vision is available and are heightened and specific to the property under investigation in the dark or when vision is occluded (Bushnell et al., 1992; Stack & Tsonis, 1999). In addition, as observed in Study 1, infants displayed very low levels of exploratory procedures during the haptic intramodal texture task. Thus, the visibility of the textures during the bimodal HAB phase was expected to further interfere with the expression of exploratory procedures, and to continue to exert the same influence on exploratory procedures during the test phases. In Study 1, texture discrimination abilities were reflected in exploratory procedures in part because of the availability of only haptic input. However, in Study 2 both 3- and 6-month-old infants' texture discrimination and recognition memory abilities were not expected to be reflected in their exploratory procedures because of the earlier influence of the visual input.

Similarly, the visibility of the textures was not expected to lead to the observation of texture discrimination and recognition memory on the measure of bimanual manipulation. While vision has been shown to facilitate bimanual manipulation, or the orientation of both hands towards an object, the test phases were unimodally haptic. As observed in the haptic-intramodal design of Study 1, levels of bimanual exploration were very low and texture discrimination and recognition abilities were not observed on this measure. Similarly, experimental and control group differences indicative of discrimination and recognition memory were not expected to be observed during the test phases of Study 2.

As in Study 1, infants' visual attention responses were examined, but guarded predictions were made since infants were not habituated on visual attention. It was hypothesized, as for Study 1, that infants' haptic manipulation would be coordinated with their visual attention and as a result, visual attention responses would reflect discrimination and recognition memory abilities.

The third objective of Study 2 was to examine developmental differences between 3- and 6-month-olds, as a result of bimodal exploration. A number of developmental hypotheses were proposed. The first hypothesis was that the visibility of the textures in the HAB phase of Study 2 was expected to lead to faster processing among 6-month-olds, relative to 3-month-olds, given their visual control of their hands. Second, given more advanced visual-motor coordination abilities, 6-month-olds were also expected to display higher levels of bimanual manipulation, total attention, direct attention, and fixation during the bimodal HAB phase relative to 3-month-olds. Despite these predicted age differences during the HAB phase, both age groups were expected to display discrimination and recognition memory for the textures on the measure of haptic manipulation since they were both habituated haptically during bimodal exploration.

While the above objectives were specific to the purpose of Study 2 (i.e., to examine the functioning of the haptic modality during and following bimodal habituation), a number of comparisons between Study 1 and 2 were also made in order to directly assess haptic processing during unimodal and bimodal exploration. Since the design of Study 2 differed from that of Study 1 only with respect to the visibility of the textures during the HAB phase, direct assessment of the functioning of haptics during unimodal and bimodal exploration was possible. Thus, specific predictions were made for a number of haptic measures of texture processing as a function of unimodal or bimodal exploration. These predictions were tested within a subset of cross-study analyses.

Specifically, differences during the habituation phases between Study 1 and 2 were expected in habituation indices and bimanual exploration as a result of the unimodal or bimodal habituation. It was expected that the haptic habituation indices observed during bimodal, haptic and visual (H+V), and unimodal haptic (H) exploration would differ. According to the literature suggesting a directive role for vision (Bushnell & Weinberger, 1987; Ruff, 1989), infants in Study 2 were expected to habituate faster (i.e., fewer trials to habituation, and less accumulated haptic manipulation to habituation) and to display a greater magnitude of habituation following bimodal exploration. Infants were also expected to display significantly higher levels of bimanual manipulation during the HAB phase of Study 2 relative to the same phase in Study 1. However, the visibility of the textures was not expected to interfere with infants' ability to discriminate and recognize the textures. Differences between Studies 1 and 2 were not expected on magnitude of dishabituation, discrimination and recognition memory as indexed by levels of haptic manipulation. This hypothesis was based on: 1) the literature suggesting that infants attend to haptic information even when exploring visible stimuli; 2) the fact that the visibility of the textures during the HAB phase did not provide information (i.e., about texture) that was necessary to making texture discriminations; 3) infants were habituated haptically and expected to have processed the texture information during both unimodal, haptic, and bimodal, haptic and visual, habituation.

Method

Participants

Recruitment proceeded in the same manner as in Study 1, and the same criteria for inclusion were used. Thirty-five 3-month-olds were tested. Of these, 10 were excluded from the final sample because of fussiness and 1 as a result of equipment failure. Twenty-six 6-month-olds were also tested. Two were excluded from the final sample because of fussiness. The final sample consisted of 48 infants; 24 3-month-olds (12 of each sex) with a mean age of 3 months, 4.5 days (sd = 5.97 days), and 24 6-month-olds (12 of each sex) with a mean age of 6 months, 4.2 days (sd = 4.14 days). The majority of the families in the final sample were Non-Hispanic White (65%). The remaining families were Hispanic (15%), African American (12%), East Indian (2%), Asian (2%) and bi-racial (4%). In terms of education, families were classified as 8% with high school education, 29% had some college education or trade school training beyond high school, and 63% had college degrees from programs requiring 4 years of college or more. In terms of occupational status, the families were classified in the domains of Professional Specialty (46%), Administration/, Managerial (15%), Sales (13%), Service workers not in private households (8%) Clerical (6%), Operatives (6%), and Craft/Trade Specialty (2%). The remainder of the families were unemployed (2%) and students (2%).

Apparatus and Stimuli.

The apparatus employed in Study 2 was the same as in Study 1 with the exception of the cover employed to either permit or occlude visual exploration. The cover for Study 2 was constructed using 2 thin layers of plastic. The first layer employed during the haptic and visual HAB phase was transparent in order to permit infants to see the textures presented underneath the cover. The second layer was opaque and attached to the side of the first layer (on the infants' right side) with two snaps (one on each corner). During the HAB phase, the second, opaque, layer hung to the floor on the right side of the cover. At the end of the HAB phase, when the habituation criterion was met, the opaque layer was placed on top of the first transparent layer and secured into place with a snap on each left corner. Thus, visibility was occluded during the haptic test trials. The texture stimuli were identical to those employed in Study 1, and differed only on texture. It is important to note that since infants were only permitted to see the texture presented during the HAB phase, infants never had an opportunity to see both textures.

Design

The design of the study is illustrated in Table 6 and was a 2 (Age) x 2 (Group) x 2 (Order) x 2 (Sex) x 4 (Phase) mixed model. The 4 between factors were Age (3- and 6-months), Group (experimental, control), Order [order 1: smooth-rough-smooth and smooth-smooth-smooth (SRS/SSS), for experimental and control groups respectively; order 2: rough-smooth-rough, and rough-rough-rough (RSR/RRR), for experimental and control groups, respectively], and Sex (male, female). The within factor was Phase with 4 levels [Before Habituation (BHAB), Criterion (CRIT), Novelty (NOV), and Return-to-Familiar (RFAM) phases]. The BHAB phase comprised all trials of the habituation (HAB) phase prior to the two CRIT trials. The CRIT phase consisted of the two criterion trials. Each of the NOV and RFAM phases consisted of three trials. There were 24 infants within each age group, and half the infants within each age group were randomly assigned to each of the experimental and control groups.

As in Study 1, both experimental and control groups were required to meet a baseline level of 20 seconds of haptic contact with the texture, and then to meet the habituation criterion before the test phases began. Experimental group infants then received three trials with the novel texture (NOV) and three trials with the original texture in the RFAM phase. Control group infants received the same texture in each of the three trials of the corresponding NOV and RFAM phases. The control group infants then received an additional two to four trials with the novel texture in a fourth Dishabituation

Table 6

Design Table for Study 2

				Phase				
				HAB Haptic + Visual		NOV Haptic	RFAM Haptic	DHAB Haptic
				BHAB	CRIT			
Age	Group	Order	Sex	≥2 trials	2 trials	3 trials	3 trials	2 to 4 trials
3 months	Experimental	SRS	Male / Female	S		R	S	
		RSR	Male / Female	R		S	R	
	Control	SSS-R	Male / Female	S		S	S	R
		RRR-S	Male / Female	R		R	R	S
6 months	Experimental	SRS	Male / Female	S		R	S	
		RSR	Male / Female	R		S	R	
	Control	SSS-R	Male / Female	S		S	S	R
		RRR-S	Male / Female	R		R	R	S

Note. HAB = habituation. BHAB = before habituation. CRIT = criterion. NOV = novel. RFAM = return to familiar. DHAB = dishabituation. S = smooth. R = rough.

(DHAB) phase in order to control for fatigue effects (Dannemiller & Banks. 1983; Zelazo et al., 1989). Twenty-two of the 24 control group infants obtained DHAB trials. Of the two that did not get any DHAB trials, one refused to touch the texture, and the other one fussed for over 20 seconds and the procedure was stopped. Two of the remaining 22 control group infants received two trials; one infant fussed beyond 20 seconds on the third trial and the procedure was stopped, and the other stopped attending following the second trial and began to vigorously attempt to take the cover off. The remaining 20 of the 22 control group infants obtained four trials.

The order of presentation of the textures within each group was counterbalanced as in Study 1; as indicated in Table 6, half the infants in the experimental group received the stimuli in the order SRS and the other half in the order RSR. Similarly, half the infants in the control group received the stimuli in the order SSS-R while the other half obtained them in the order RRR-S.

Procedure

Caregivers and infants were greeted and escorted into a waiting room. The experimenter reviewed the procedure with the caregivers who were then asked to read and sign a consent form (Appendix H). Once in the testing room, the procedure was similar to Study 1. The infant was seated on the caregiver's lap and the cover was placed comfortably around the infant's neck. The infant-controlled procedure was identical to that employed in Study 1 and trials were defined in the same manner.

Baseline. As in Study 1, the baseline during the HAB phase consisted of the mean of the longest two initial trials provided that the infant had manipulated the texture for a minimum of 20 seconds over the two trials. If a baseline was not obtained within 16 trials, testing was terminated to allow for a short break and one more attempt was made to resume testing. All infants in the final sample of Study 2 met the baseline criterion on the first attempt.

Habituation Criterion. The habituation criterion was the same as in Study 1. The criterion for habituation consisted of two consecutive trials that were each at a decrement of 50% of the baseline mean. Testing then proceeded into the next phase even if the habituation criterion was not met within 16 trials. However, these infants were to be considered as nonhabituators and their data were analyzed separately. All infants in the final sample of Study 2 met the habituation criterion within the 16 allotted trials.

Test Phases. The test phases (NOV and RFAM) proceeded as in Study 1; each test phase consisted of three infant-controlled trials. The experimental group obtained the novel texture during the three NOV trials, and the original habituation texture during the three trials of the RFAM phase. The control group continued to receive the same habituation texture during these corresponding six trials, followed by the novel texture during four DHAB trials. In the event that any infant fussed for over 20 seconds at any point during the testing, a short break was taken before the procedure was attempted for a final time. None of the infants in the final sample fussed during the habituation or test trials. Two control group infants were not able to perform on any DHAB trials due to fussiness, and two others obtained only two DHAB trials rather than four due to fussiness. Since these infants had completed the test trials and it appeared that the fussiness was due to their group assignment and to the procedure, the testing was stopped and not reattempted.

At the end of the testing session, demographic information was collected (Appendix C), caregivers thanked, and infants were given an Infant Scientist Award.

Dependent Measures

1. Habituation Indices. The habituation indices were the same as for Study 1. These measures are listed and defined below. As in Study 1, they were calculated only for the measure of haptic manipulation, since this was the measure driving the infant-controlled procedure in Study 2 as well. Haptic manipulation was defined, as in Study 1, as all forms of manual contact with the stimuli.

a) Number of trials to baseline. This index was used to assess the number of trials infants required to meet the 20 second criterion of haptic contact with the first texture.

b) Number of trials to habituation. This was defined as the number of trials to meet the habituation criterion of two consecutive trials each at 50% of the baseline mean.

c) Magnitude of habituation. As in Study 1, the magnitude of habituation was calculated by the formula $\frac{(M12 - MCRIT)}{NTRIALS}$ where M12 is the mean duration of the longest two first haptic manipulations (i.e., the baseline mean), MCRIT is the mean duration of the two criterion manipulations, and NTRIALS is the number of trials to reach the habituation criterion. A larger ratio indicates a greater magnitude of habituation. That is, this index is a ratio of the discrepancy between the mean haptic manipulation on baseline relative to criterion trials, to the number of trials required to reach the habituation criterion. Given a certain discrepancy, the magnitude index would be larger when the denominator is small (in the case of a small number of trials to habituation), relative to when the denominator is large (in the case of a greater number of trials to habituation). Similarly if the number of trials is constant, the magnitude index is larger when the discrepancy is large, relative to when it is small. Thus, a greater magnitude of habituation represents a quicker and sharper decline from baseline levels to the habituation criterion.

2. Dishabituation Indices. The dishabituation indices were the same as those in Study 1, and calculated in the same manner. The two measures of dishabituation were calculated only for the measure of haptic manipulation, since this was the measure driving the infant-controlled procedure.

a) Novelty Dishabituation Index. As in Study 1, the novelty dishabituation index was used to evaluate the magnitude of the response to the novel texture following habituation. The following proportion was used to calculate the magnitude of dishabituation:

$\frac{MNOV}{(MNOV + MCRIT)}$ where MNOV is the mean duration of haptic manipulation over the three novel trials, and MCRIT is the mean duration of haptic manipulation over the two criterion trials. This was calculated for both experimental and control infants. A ratio of 0.5 reflects no change between the mean haptic manipulation on the NOV phase and the mean on the CRIT phase. A ratio less than 0.5 reflects a decrease in the mean on NOV relative to the mean on CRIT. A ratio greater than 0.5 reflects an increase in the mean on NOV relative to the mean on CRIT.

b) Control Dishabituation. The mean haptic manipulation (in seconds) displayed by the control groups during their additional dishabituation trials was compared to their mean levels of haptic manipulation during the RFAM phase. This comparison permitted a control for fatigue effects, and also served as a further measure of haptic discrimination for the control group subjects.

3. Haptic and Visual Dependent Measures.

The same behavioural measures were examined as in Study 1. The total duration, in seconds per trial, was coded and calculated for haptic manipulation, exploratory procedures, bimanual manipulation, and for visual attention. These measures were coded in the same manner and order as in Study 1. The start and end of each trial were determined by infants' haptic manipulation. The haptic measures (i.e., haptic manipulation, exploratory procedures and bimanual manipulation) were also defined as in Study 1 (see Appendix D for detailed descriptions and coding guidelines).

The same three measures of visual attention coded in Study 1 were also coded in Study 2: total attention, direct attention, and fixation. The definition of fixation changed slightly in Study 2 for the HAB phase to accommodate the visibility of the stimuli. Since fixation is incorporated in the definitions of total attention and direct attention, the change in definition of fixation also affected the definition of total attention and direct attention during the HAB phase. Fixation toward the stimulus was coded during the HAB phase as looking directly at any part of the stimulus, including the handle held by the experimenter. During the test phases, when the stimulus was not visible, fixation was defined and coded as in Study 1. That is, fixation during the test phases was coded as looking in the direction of the stimulus. Total attention consisted of the sum of attention to the cover, to the experimenter, and fixation. Attention to the cover was defined as looking towards the cover but not in the direction of the stimulus. Attention to the experimenter was defined as looking at the experimenter's upper torso and face. Direct attention was defined as the sum of attention towards the experimenter and fixation. Detailed descriptions of the dependent variables and coding guidelines are found in Appendix D.

Interrater reliability was assessed by blind observers for 21% of the records upon completion of the coding. Since haptic manipulation determined the duration of each trial, reliability for haptic manipulation was obtained by assessing the correspondence between onset and offset times for each trial as indicated on the computer records of the live coding, with the onset and offset times for each trial as obtained on the video records. This permitted simultaneous assessment of the reliability of the live coding, as well as the reliability for haptic manipulation. The kappa coefficient (r_k) for haptic manipulation was .95. The kappa coefficients for exploratory procedures and bimanual manipulation were also high, at .87 and .94, respectively. The kappa coefficients for the attention measures were also high (r_k = .91 for total attention; r_k = .92 for direct attention; r_k = .94 for attention to experimenter; r_k = .89 for attention to the cover; and r_k = .88 for fixation).

Results

Analyses were conducted on the data using the BMDP statistical package (Dixon et al., 1990). Descriptive data analyses were conducted on each dependent variable and outliers were corrected in the same manner as for Study 1. Transformations in Study 2 were applied, in the event of significant skewness and kurtosis, following the same considerations as outlined for Study 1. For ease of comprehension, when data were transformed raw means are presented in the text. However, the F-scores and p-values cited in the text were taken from the analyses on the transformed data, as these were the values on which the effects were identified and on which the interpretations were based.

Following descriptive analyses, statistical analyses were conducted on each measure. The habituation indices (i.e., number of trials to baseline and to habituation, and magnitude of habituation), as well as the novelty dishabituation index were analyzed with between ANOVAs, as a function of Age, Group, Order, and Sex. Interaction comparisons were conducted to isolate the source of any three-way or higher order interactions (Keppel, 1991). Simple effects were conducted to isolate the source of any two-way interactions (Keppel, 1991). The control dishabituation data were analyzed with a directional, one-tailed, t-test. A critical alpha level of 0.05 was used as the criterion for statistical significance for these analyses.

Repeated measures ANOVAs were conducted on the behavioural dependent measures (i.e., haptic manipulation, exploratory procedures, bimanual manipulation, and each of the attention measures) since these were analyzed as a function of the four between variables [Age (3-, 6-months), Group (experimental, control), Order (SRS/SSS, RSR/RRR) and Sex (male, female)] and one within variable [Phase (BHAB, CRIT, NOV, RFAM)]. As in Study 1, Sex and Order effects or interactions were tested for each variable and if none were found, these variables were collapsed and a 2 x 2 x 4 between-within ANOVA was conducted with the between factors of Age and Group and the within factor of Phase. However, in the event of significant three-way or higher order interactions of between group factors, the simple interactions of two factors at each level of the third were tested. In turn, any significant simple two-way interactions were followed by simple effects (Keppel, 1991). Significant interactions of between-within factors were followed by simple effects analyses (Keppel, 1991). Any Phase main effects were followed by Tukey Highly Significant Difference comparisons, since Phase was the only factor with more than 2 levels (Keppel, 1991; Tabachnick & Fidell, 1996). A critical alpha level of 0.05 was used as the criterion for statistical significance, and the more conservative Greenhouse-Geisser Adjusted F score and p value were used to assess significance for within-subject effects.

The results for all the Study 2 dependent variables are presented first followed by the results of cross-study statistical analyses, in a separate results subsection. For Study 2, the habituation indices are reported first, followed by the results for the haptic and visual attention measures. In addition, the raw data for Study 2 are also available as a function of the primary factors (i.e., Age, Group, Order, and Phase) at the end of each appendix containing the ANOVA and follow-up summary tables for each measure. The raw data are presented as a function of Sex only if there was a significant main effect or interaction involving this factor. Similarly, the raw data are presented as a function of Phase only if the statistical analyses were conducted with this factor.

Trials to Baseline. An inverse transformation was applied to the data for the number of trials to reach the baseline criterion of 20 seconds of haptic manipulation with the habituation phase texture. A between ANOVA yielded a main effect for Sex, $F(1,46) = 6.49$, $p<.05$ (Appendix I, Table I1). Males required a greater number of trials (M = 3.20), relative to females (M = 2.33 trials), to meet the baseline minimum of 20 seconds of haptic manipulation with the HAB phase texture.

Trials to Habituation. A between ANOVA on trials to habituation revealed no significant effects (Appendix I, Table I2). Infants required a mean of 6.23 trials to habituate.

Magnitude of Habituation. A between ANOVA on magnitude of habituation indicated an Order x Sex interaction $F(1,44) = 5.58$, $p<.05$ (Appendix I, Table I3). The simple effects of Order at Sex (Table I4) indicated a significant difference in magnitude of habituation only among females as a function of Order, $F(1,44) = 7.90$, $p \leq .01$. As seen in Table 7, female infants habituating to the smooth texture showed a greater magnitude of habituation ($M = 3.26$) relative to females habituating to the rough texture ($M = 1.91$). The simple effects of Sex at Order (Table I4) indicated a difference between males and females only in the SRS/SSS order $F(1,44) = 8.88$, $p < .001$. That is, female infants habituating to the smooth texture also showed a greater magnitude of habituation ($M = 3.26$) relative to male infants in this order ($M = 1.83$; Table 7). Male and female infants habituating to the rough texture (i.e., order RSR) displayed a similar magnitude of habituation (M's $= 2.08$ and 1.91; Table 7), respectively. The pattern of results for magnitude of habituation in Study 2 suggest that the visibility of the textures led to a greater magnitude of habituation among females habituated with the smooth texture.

Haptic Manipulation. A mixed ANOVA on the total duration (in seconds) of haptic manipulation indicated a Phase main effect $F(1,46) = 146.70$, $p<.001$, which was qualified by a Phase x Group interaction $F(3,138) = 5.38$, $p<.05$ (Appendix J, Table J1). Simple effects analyses revealed a significant group difference only at the NOV phase, $F(1,46) = 13.79$, $p<.001$ (Table J2). As indicated in Figure 5, experimental and control groups did not differ during the BHAB and CRIT phases. Infants accumulated a grand mean of 53.18 seconds of haptic manipulation during the BHAB phase, and an additional mean of 8.01 seconds during the CRIT phase, bringing the grand mean duration of haptic manipulation in the HAB phase to 61.19 seconds. However, the experimental group infants receiving a novel texture during NOV displayed higher levels of haptic

Table 7

Magnitude of Habituation as a function of Order and Sex, Study 2

	Order	
Sex	SRS/SSS	RSR/RRR
Male	1.83 (0.25)	2.08 (0.34)
Female	3.26 (0.42)	1.91 (0.32)

Note. Values in parentheses represent standard errors.

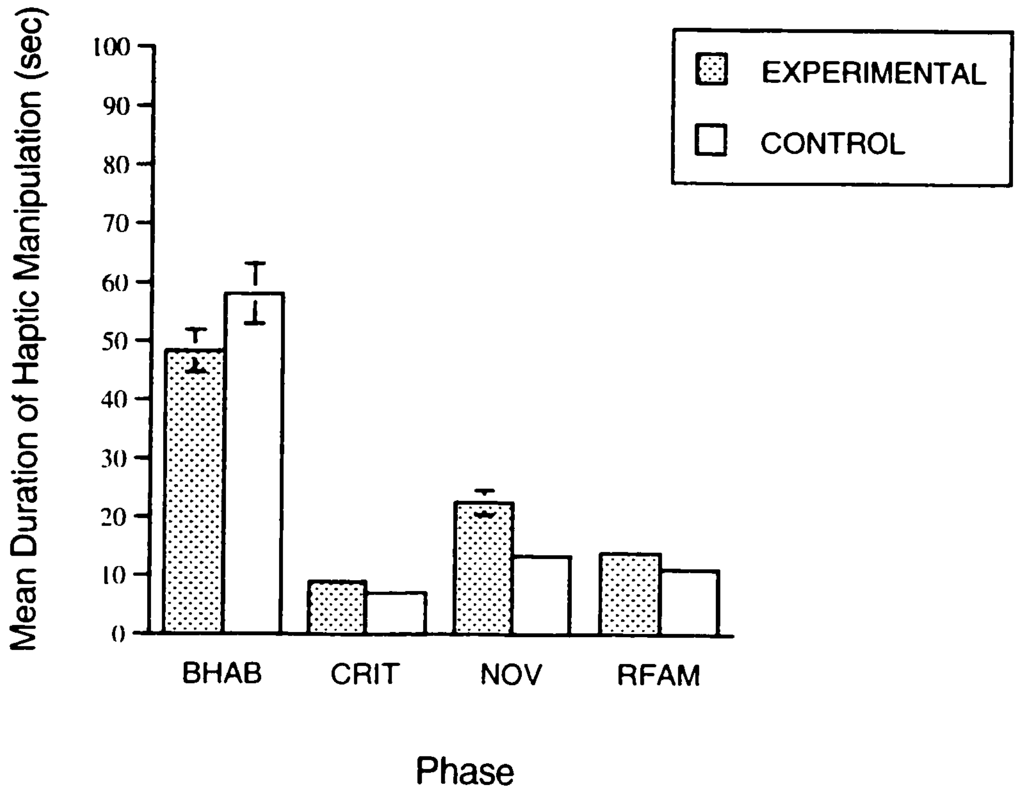

Figure 5. Mean duration of haptic manipulation as a function of Group and Phase. Standard errors are shown by vertical bars.

manipulation (M = 22.47) relative to control group infants who continued to receive the original habituated-to texture (M = 13.37). Simple pairwise comparisons were conducted to test whether the levels of haptic manipulation differed between the NOV and RFAM phases for each of the experimental and control groups (Table J3). The experimental group displayed significantly lower levels of haptic manipulation in the RFAM phase (M = 13.88) relative to the NOV phase [M = 22.47; $F(1,38) = 6.38$, $p<.05$], whereas the control group's levels of haptic manipulation did not differ between the NOV and RFAM phases (Ms = 13.37 & 11.06, respectively).

Novelty Dishabituation Index. A between ANOVA (Appendix J, Table J4) indicated a Group main effect $F(1,46) = 6.30$, $p<.05$, with the experimental group displaying a greater magnitude of dishabituation (M = 0.62) relative to the control group (M = 0.53).

Control Dishabituation. In order to control for fatigue effects as a possible factor in the declining levels of active manipulation among the control group infants, the mean duration of haptic manipulation across either the two or four DHAB trials was compared to the mean duration of haptic manipulation over the RFAM trials. A paired samples directional t-test revealed a significantly higher mean of haptic manipulation among control group infants in the DHAB phase (M = 7.86) relative to the RFAM phase (M = 3.84; $t_{(21)} = -4.31$, $p<.001$), reflecting a response to novelty and suggesting no fatigue effect.

Exploratory Procedures. A mixed ANOVA with a square root transformation revealed a significant Age x Order interaction $F(1,44) = 5.42$, $p<.05$, and a Phase main effect $F(3,132) = 38.19$, $p<.001$ (Appendix J, Table J5). Simple effects of Age at Order revealed a marginally significant difference between 3-and 6-month-olds in the SRS/SSS order $F(1,44) = 3.93$, $p=.05$, but not in the RSR/RRR order. As seen in Table 8, 6-month-old infants in the SRS/SSS order displayed marginally lower levels of exploratory

Table 8

Mean Duration of Exploratory Procedures (in sec) as a function of Age and Order.

Study 2

	Age	
Order	3 months	6 months
SRS/SSS	2.21 (0.42)	1.66 (0.61)
RSR/RRR	2.10 (0.62)	2.97 (0.69)

Note. Values in parentheses represent standard errors.

procedures (M = 1.66) relative to the 3-month-olds (M = 2.21) in this order. The simple effects of Order at Age (Table J6) indicated an Order difference among 6-month-olds only $F(1,44) = 7.45$, $p \leq .01$. As seen in Table 8, 6-month-olds in the order RSR/RRR engaged in significantly higher levels of exploratory procedures (M = 2.97), relative to 6-month-olds in the order SRS/SSS (M = 1.66). Three-month-olds displayed similar levels of exploratory procedures in the SRS/SSS and RSR/RRR orders (Ms = 2.21 and 2.09, respectively). Thus, in Study 2, it appears that the 6-month-olds engaged in higher levels of exploratory procedures when they had greater exposure, or more time with the rough, relative to the smooth texture. Unlike in Study 1, there were no experimental and control group differences, thus, the higher levels of exploratory procedures observed in Study 2 among the 6-month-olds in the RSR/RRR order cannot be attributed to changes, or novelties in texture.

Tukey's HSD analyses (Table J7) on the Phase main effect indicated that infants displayed higher levels of exploratory procedures during the BHAB phase (M = 5.13), which consisted of a greater number of trials, relative to each of the other phases, CRIT, NOV and RFAM (M's = 0.86, 1.60, 1.34, respectively). However, infants displayed significantly higher levels of exploratory procedures during the NOV trials relative to the CRIT trials. This difference was not qualified by Group. Consequently, higher levels of exploratory procedures during the NOV relative to the CRIT phase cannot be attributed to the perception of the change, or novelty in texture, by the experimental group as indicated on the measure of haptic manipulation. However, higher levels of exploratory procedures during the NOV relative to the CRIT phase may have occurred in response to the placement of the opaque cover which occluded the visibility of the texture available during the HAB phase.

Bimanual Manipulation. A mixed ANOVA with a square root transformation was conducted and results indicated a Phase main effect $F(3,141) = 22.82$, $p < .001$ (Appendix

J. Table J8). Tukey HSD analyses (Table J9) revealed that infants engaged in significantly higher levels of bimanual exploration during the BHAB phase (M = 6.62) relative to the CRIT (M = 0.55), NOV (M = 0.34) and RFAM (M = 0.27) phases.

Total Attention. A mixed ANOVA resulted in a Phase main effect $F(3,138) = 137.90$, $p<.001$, qualified by a marginal Phase x Group interaction $F(3,138) = 3.57$, $p = .05$ (Appendix K, Table K1). Simple effects (Table K2) revealed higher levels of total attention among experimental group infants relative to control group infants during the NOV phase (Ms = 17.22 and 11.06, respectively; $F(1,46) = 6.76$, $p<.01$). This effect is illustrated in Figure 6. Simple pairwise comparison analyses were conducted to test whether the levels of total attention differed between the NOV and RFAM phases for each of the experimental and control groups (Table K3). The experimental group displayed significantly lower levels of total attention in the RFAM phase (M = 10.08) relative to the NOV phase [M = 17.22; $F(1,138) = 4.07$, $p <.05$], whereas the control group's levels of total attention did not differ between the NOV and RFAM phases (Ms = 11.06 & 9.15, respectively).

Direct Attention. Mixed Anovas on the sum duration of fixation and search experimenter indicated Age $F(1,44) = 6.12$, $p <.05$, Order $F(1,44) = 6.81$, $p \leq .01$ and Phase main effects $F(3,132) = 88.06$, $p <.001$ (Appendix K, Table K4). Six-month-old infants displayed higher levels of direct attention (M = 17.23) relative to 3-month-olds (M = 13.34). Infants in the order RSR/RRR also displayed higher levels (M = 17.36) of direct attention relative to infants in the SRS/SSS order (M = 12.21). Tukey HSD comparisons on the Phase main effect (Table K5) revealed that infants engaged in significantly higher levels of direct attention during the BHAB phase (M = 41.06) relative to all other phases [CRIT M = 5.93; NOV M = 7.31, and RFAM M = 4.84].

Fixation. A mixed ANOVA with a square root transformation was conducted on this measure, however as in Study 1, the total duration of fixation during the two Baseline

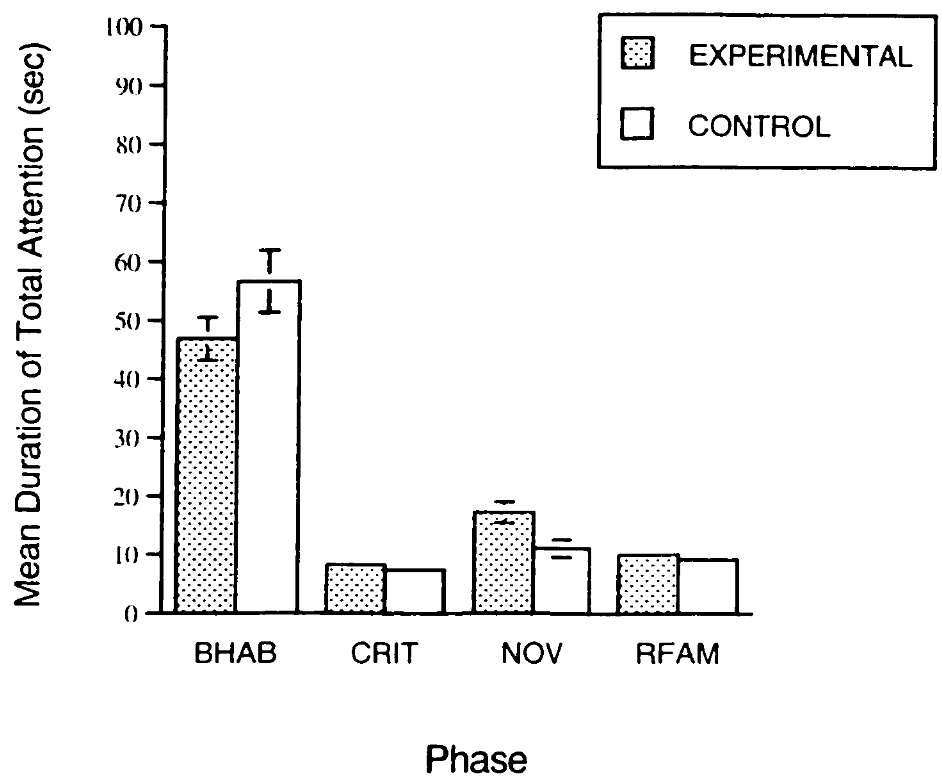

Figure 6. Mean duration of Total Attention as a function of Phase and Group. Standard errors are shown by vertical bars.

trials of the BHAB phase was included in the analysis rather than the total duration of fixation over all the BHAB trials. This was done to standardize levels of fixation over two specific trials (i.e., the baseline trials) due to the low frequency of fixations toward the stimulus and the low duration of fixations. Since infants varied in the number of BHAB trials, the sum duration of fixation over all BHAB trials created great variability. Only a significant Phase main effect was obtained $\underline{F}(1,141) = 73.55$, $\underline{p}<.001$ (Appendix K, Table K6). Tukey HSD comparisons on the Phase main effect (Table K7) revealed that infants engaged in significantly higher levels of fixation during the BHAB phase ($\underline{M} = 12.54$) relative to all other phases [CRIT $\underline{M} = 4.09$; NOV $\underline{M} = 1.26$, and RFAM $\underline{M} = 0.46$]. In addition, the level of fixation in the CRIT phase was also significantly higher than the NOV and RFAM levels of fixation.

Results: Cross-Study Analyses

Cross-study analyses were also conducted in order to statistically evaluate the influence of the absence or presence of vision, between Studies 1 and 2 respectively, on infants' haptic habituation patterns and haptic discrimination and recognition of texture. The cross-study analyses were therefore limited to the following haptic measures: trials to habituation, magnitude of habituation, dishabituation index, total haptic manipulation, and bimanual exploration. Between ANOVAs with five between factors of Study (Study 1, Study 2), Age (3-, 6-months), Group (experimental, control), Order (order 1: SRS/SSS, order 2: RSR/RRR) and Sex (male, female) were conducted on the measures of trials to habituation, magnitude of habituation, and the dishabituation index. Mixed ANOVAs on the measures of haptic manipulation and bimanual exploration were conducted with the same between variables in addition to the within variable of Phase (BHAB, CRIT, NOV, RFAM). Given that cross-study comparisons entailed analyses of measures that were previously analyzed within the context of each study (habituation indices and Novelty dishabituation index), a Bonferroni correction was applied to control for experiment-wise error (Keppel, 1991). Thus, a more stringent alpha level of .01 was used for the cross-study analyses. Simple effects analyses, followed by Tukey HSD comparisons were then conducted to isolate the source of effects contributing to any significant interactions or main effects, respectively (Keppel, 1991).

Trials to Habituation. A cross-study between ANOVA on trials to habituation yielded a Study x Order interaction $F(1,92) = 12.21$, $p < .001$ (Appendix L, Table L1). This interaction is represented in Table 9. The simple effects of Study at Order (Table L2) indicated that infants took longer to habituate to the smooth texture in Study 1 (M = 7.96) relative to Study 2 (M = 5.67; $F(1,92) = 12.14$, $p < .001$). However, infants habituated to the rough texture within a similar number of trials during unimodal (i.e., Study 1) and bimodal exploration (i.e., Study 2). The simple effects analyses (Table L2) of Order at Study indicated that in Study 1, infants took longer (i.e., a greater number of trials) to habituate to the smooth texture (M = 7.96) relative to the rough texture [M = 5.83; $F(1,92) = 10.44$, $p < .001$]. However, infants habituated to the smooth and rough textures within a similar number of trials during bimodal exploration (i.e., Study 2).

Magnitude of Habituation. A between ANOVA (Appendix L; Table L3) revealed a Study x Order interaction ($F(1,88) = 12.85$, $p < .001$), which is represented in Table 10. The simple effects of Study at Order (Table L4) indicated that infants' magnitude of habituation to the rough texture was also greater in Study 1 (M = 3.44) relative to infants habituated to the rough texture in Study 2 (M = 1.99). The simple effects of Order at Study (Table L4) indicated that during unimodal haptic habituation (i.e., in Study 1) infants displayed a greater magnitude of habituation to the rough (M = 3.44) relative to the smooth texture [M =1.75; $F(1,92) = 13.66$, $p < .001$], while infants habituated bimodally (i.e., in Study 2) displayed the same magnitude of habituation to both textures.

Haptic Manipulation. A mixed ANOVA conducted across studies (Appendix L; Table L5) indicated Study and Group main effects ($F(1,92)$ = 24.54 and 12.13,

Table 9

Mean Number of Trials to Habituation as a function of Study and Order

Order	Study 1 (Haptics)	Study 2 (Haptics & Vision)
SRS/SSS	7.96 (0.58)	5.67 (0.42)
RSR/RRR	5.83 (0.33)	6.79 (0.50)

Note. Values in parentheses represent standard errors.

Table 10

Mean Magnitude of Habituation as a function of Study and Order

	Study	
Order	Study 1 (Haptics)	Study 2 (Haptics & Vision)
SRS/SSS	1.75 (0.27)	2.54 (0.28)
RSR/RRR	3.44 (0.46)	1.99 (0.23)

Note. Values in parentheses represent standard errors.

respectively, and both at $p < .001$) which were qualified by a Study x Group interaction ($F(1,92) = 7.80$, $p = .01$). There was also a significant Phase main effect ($F(3,276) = 319.98$, $p < .001$) qualified by a significant Phase x Group interaction ($F(3,276) = 10.30$, $p < .001$), and a marginally significant Phase x Study interaction ($F(3,276) = 3.30$, $p = .05$).

Simple effects analyses (Table L6), holding the factor of Phase, isolated the source of the Phase x Group, and Phase x Study, interactions. Group differences were observed in the NOV and RFAM phases [$F(1,92) = 8.83$, $p < .001$, and $F(1,276) = 11.44$, $p < .001$, respectively]. These group differences suggest that when the total haptic manipulation levels are combined from both studies, the texture discrimination and recognition abilities are observed. As presented in Figure 7, experimental group infants manipulated for a significantly longer duration during the NOV and RFAM phases, relative to controls.

The Phase x Study interaction was marginally significant and did not meet the adjusted alpha level for the cross-study analyses. The simple effects (Table L6) were nonetheless pursued to explore the trend in the difference between the studies. Infants displayed slightly higher levels of haptic manipulation in Study 1, relative to Study 2, during the BHAB, NOV, and RFAM phases. The means for this effect are represented in Table L7. This effect was not qualified by a group difference, therefore suggesting that overall, all infants engaged in higher levels of haptic manipulation during unimodal haptic exploration, relative to bimodal exploration, during the BHAB, NOV, and RFAM phases. In turn, this implies that the visibility of the textures reduced levels of haptic manipulation during these phases.

While the overall ANOVA on haptic manipulation indicated a Study x Group interaction, the simple effects analyses (Table L6), conducted holding the factor of Phase, indicated that this interaction was significant only in the NOV phase ($F(1,92) = 8.83$, $p < .001$). Two simple pairwise comparisons were then conducted to assess: 1) whether the

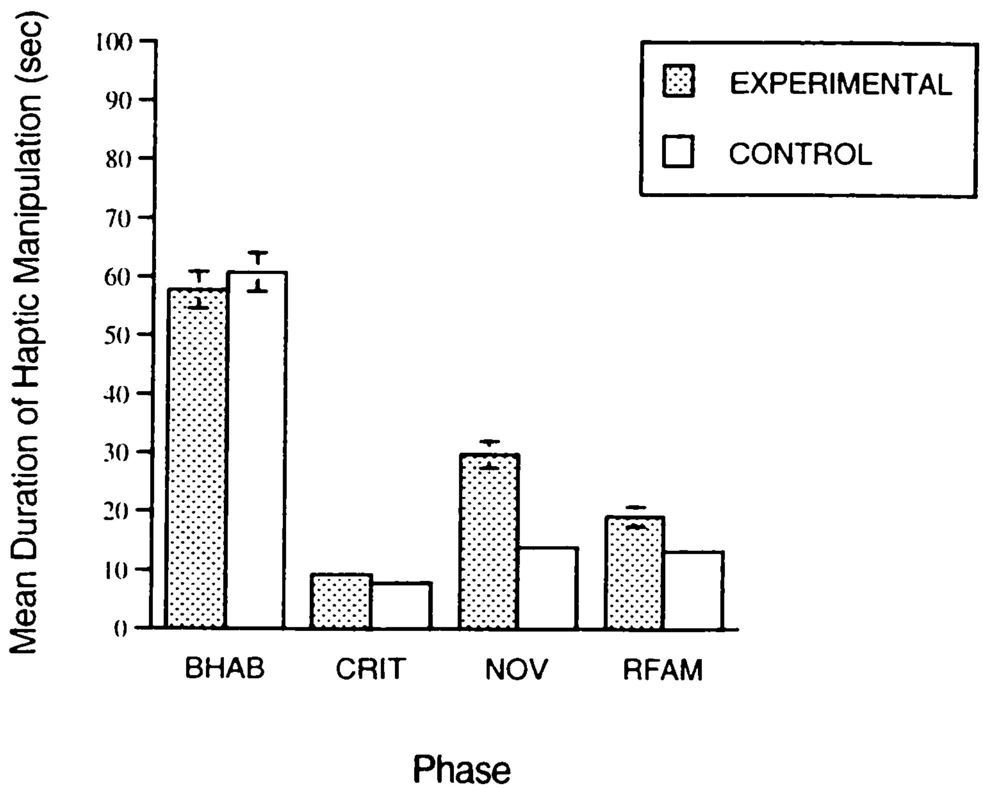

Figure 7. Mean Duration of haptic manipulation as a function of Group and Phase, Cross Study

experimental groups' levels of haptic manipulation differed during the NOV phase between the two studies; and 2) whether the control groups' levels of haptic manipulation differed during the NOV phase between the two studies. Only the first simple comparison was significant (Table L8); as seen in Table 11, the experimental group in Study 1 manipulated more ($\underline{M}$ = 37.12) during the NOV phase than the experimental group in Study 2 ($\underline{M}$ = 22.47) during the same phase. The difference may be attributed to the modality of exploration during the HAB phase. It appears that the visibility of the textures in Study 2, in addition to having lowered levels of haptic manipulation in all phases, may have also dampened infants' response to novelty. The control groups in each study did not differ from each other during this phase.

Novelty Dishabituation Index. A between ANOVA with the Study factor included revealed a Group main effect ($\underline{F}(1,94) = 20.17$, $\underline{p} < .001$; Appendix L, Table L9). The experimental group infants displayed a greater magnitude of dishabituation ($\underline{M}$ = 0.655) relative to control group infants ($\underline{M}$ = 0.53).

Bimanual Manipulation. A mixed ANOVA with a square root transformation on bimanual manipulation yielded Study and Phase main effects [$\underline{F}(1,92) = 9.24$, $\underline{p} < .001$, and $\underline{F}(3,276) = 25.80$, $\underline{p} < .001$, respectively]. These were qualified by a Phase x Study interaction ($\underline{F}(3,276) = 13.12$, $\underline{p} < .001$; Appendix L, Table L10), and a marginally significant Phase x Group interaction ($\underline{F}(3,276) = 3.25$, $\underline{p} = .05$). Simple effects analyses on the Phase x Study interaction (Table L11) indicated that infants in Study 2, relative to infants in Study 1, explored bimanually for a significantly longer time during the BHAB phase ($\underline{F}(1,92) = 16.04$, $\underline{p} < .001$) when the textures were visible (Table 12). Simple effects analyses on the Phase x Group interaction (Table L11) revealed that the experimental and control groups differed during the NOV phase ($\underline{F}(1,92) = 4.85$, $\underline{p} < .05$). As seen in Table L12, experimental group infants displayed higher levels of bimanual manipulation ($\underline{M}$ = 0.95) relative to control group infants ($\underline{M}$ = 0.15) during the NOV

Table 11

Mean Duration of Haptic Manipulation during NOV phase as a function of Study and Group

	Study	
Group	Study 1 (Haptics)	Study 2 (Haptics & Vision)
Experimental	37.12 (3.58)	22.47 (2.08)
Control	14.50 (1.38)	13.38 (1.30)

Note. Values in parentheses represent standard errors.

Table 12

Mean Duration of Bimanual Manipulation as a function of Study and Phase, Cross Study

	Phase			
Study	BHAB	CRIT	NOV	RET
Study 1 (Haptics)	0.90 (0.31)	0.41 (0.18)	0.77 (0.33)	0.03 (0.02)
Study 2 (Haptics and Vision)	6.62 (1.46)	0.05 (0.19)	0.34 (0.13)	0.27 (0.11)

Note. Values in parentheses represent standard errors.

phase. Phase x Group interactions were not obtained when bimanual manipulation was analyzed within the context of each study. The Phase x Group interaction obtained in the cross-study analyses was not qualified by the Study factor, indicating that: 1) haptic novelty may elicit higher levels of bimanual manipulation, regardless of whether habituation was unimodal or bimodal; and 2) that overall low levels of bimanual manipulation may have precluded detection of the novelty response on this measure when each study was analyzed separately.

Discussion

Study 2 was designed to examine haptic perception and processing during a more naturalistic, bimodal context of exploration. The predominant view has been that vision plays a dominant, or at least a directive role, on haptics during bimodal exploration, and only when sufficient motor development and visual-prehension abilities are developed (so that haptics can be guided by vision) can infants rely on haptics for its perceptual functions (Bushnell & Weinberger, 1987; Hatwell, 1987; Heller, 1982; Ruff, 1989; Streri, 1993). This view may account for the paucity of research on haptic perceptual abilities and on the relative contribution of haptics as a perceptual source during bimodal exploration during the first half-year of life when motor and visual-prehension skills are limited. The research that has been conducted has focused largely on stimulus properties more salient to vision than to haptics (e.g., shape). However, as demonstrated in Study 1, infants are capable of processing texture information on the basis of haptic exploration alone, even at a stage of immature haptic-motor development and visual-prehension.

Thus, the main objective of Study 2 was to assess the influence of vision on haptic perception and processing of texture in order to better understand the contributions of haptic perception during bimodal exploration. This objective was accomplished through a number of methodological considerations. First, the habituation phase of Study 2 was bimodal while the test phases were unimodal, haptic. This design permitted examination of haptic behaviour (e.g., habituation patterns, manipulation) during bimodal exploration. The unimodal haptic test phases made it possible to assess infants' haptic discrimination abilities following bimodal habituation and to ascertain whether infants had attended to and processed the haptically available texture information during the bimodal HAB phase. In addition, comparisons with Study 1 permitted an evaluation of the influence of vision on haptics, and of the relative contributions of haptics during unimodal relative to bimodal exploration. Second, Study 2 addressed the influence of visual-prehension abilities by assessing haptic processing during bimodal exploration just before and just after the emergence of visuo-prehensile coordination (i.e., at 3 months and 6 months, respectively). Third, texture stimuli, which are salient for haptics, were employed in the investigation of the perceptual contributions of haptics during bimodal exploration. Fourth, the visible stimulus features (e.g., colour, size, and shape) available during bimodal exploration did not contain any visually salient cues, nor did they provide the necessary haptic information (i.e., texture) required for the discrimination task. This made it possible to attribute discrimination abilities to infants' haptic processing of the stimulus property of texture even during bimodal exploration.

There were three objectives specific to Study 2. The first was to examine infants' haptic habituation patterns during bimodal exploration of texture. The second was to assess whether bimodal input affected infants' attention to, perception and processing of the relevant haptic input (i.e., the necessary texture information) during HAB, and in turn their haptic texture discrimination and recognition memory abilities. The third objective was to assess, in light of the view that vision may influence haptic exploration especially among infants with visual-prehension and more developed fine-motor exploratory abilities, whether the visual input during the bimodal HAB phase influenced 3- and 6-month-olds differently, given differences in their visual-prehension and fine-motor skills. The results pertaining to each objective, and the hypotheses proposed within each, are discussed below. Following the discussion of each objective, the relevant cross-study results that contributed to each, in terms of understanding haptic functioning under bimodal relative to unimodal conditions, are discussed.

The first objective of Study 2 was to assess infants' haptic habituation patterns during bimodal exploration. Although only one texture, either the smooth or the rough, was visible during HAB, infants were, as in Study 1, haptically, and not visually, habituated. The results for the habituation indices, which were the same as in Study 1 permitted assessment of the impact of the visibility of the HAB texture on haptic habituation patterns. The hypothesis that the visibility of the HAB texture would lead to faster habituation, or more efficient processing, among 6-month-olds, given more developed visual-motor prehension, eye-hand coordination, and fine-motor abilities relative to 3-month-olds was not supported. As in Study 1, there were no age differences on any habituation measure in Study 2. The lack of age differences in Study 2 suggests that the visibility of the textures did not affect 3- and 6-month-old infants' haptic habituation patterns differently and challenges the view that vision facilitates haptic perception, or increases sensitivity to haptic input by guiding haptic actions (Hatwell, 1987; Heller, 1982). One explanation for the lack of age differences on the habituation indices during bimodal exploration may be that the textures, while visible, did not contain any salient visual features (e.g., fur, bumps, or an interesting colour pattern). Both the smooth and the rough texture were uninteresting visually (e.g., relatively flat and uniform surface, and white in colour). They were also comparable in terms of the lack of visually salient features to the flat, smooth cube in the Bushnell and Weinberger (1987) study, which, in contrast to the furry cube, did not lead to the detection of visual-haptic discrepancies. Similarly, findings in the present study suggest that bimodal input alone was not sufficient to facilitate processing among 6- relative to 3-month-olds.

However, bimodal exploration did influence infants' trials to habituation relative to unimodal exploration, as indicated by the cross-study analyses. The prediction that visibility of the textures would lead to faster and more efficient habituation in Study 2, relative to Study 1, was supported but only for the smooth texture. Cross-study analyses indicated that infants habituated to the smooth texture faster in Study 2, relative to Study 1. There was no difference in trials to habituation to the rough texture between the two studies. However, in Study 1, infants required more trials to habituate to the smooth texture relative to the rough texture, whereas in Study 2 they habituated to each texture within a similar number of trials. Thus, vision did not appear to facilitate habituation to the rough texture; infants were as efficient when exploring the rough texture only haptically in Study 1 as they were when they explored the rough texture when it was visible. In addition, when examining the rough texture in Study 1, its relative haptic salience may have led to faster habituation, relative to the smooth texture. This pattern of results supports the "salience" of the rough texture to haptics as discussed in Study 1, and is consistent with past findings that during bimodal exploration infants' examination of objects may be guided by salient haptic information or cues (Bushnell et al., 1989 in Bushnell & Boudreau, 1991; Ruff, 1982a, 1984, 1989).

The results from trials to habituation also suggests that infants were attending to both haptic and visual input. The visibility of the rough texture in Study 2, may not have further accelerated habituation, due to the lack of any additional salient visual information or cues. In the case of the smooth texture, the visibility of the texture did not provide any salient visual information either, but influenced infants' haptic habituation. The lack of salient visual information, combined with the lower salience of smooth, relative to the rough, texture for haptics, may have contributed towards faster habituation during bimodal exploration. It appears then that the influence that vision may have on haptic processing may be qualified by both the nature of the visual and haptic input experienced.

The results from the magnitude of habituation also reflect an influence of the visibility of the textures on infants' habituation responses. In Study 2, infants, with the exception of females habituating to the smooth texture, displayed a similar magnitude of habituation to the rough and smooth textures. In Study 1, infants showed a greater magnitude of habituation to the rough, relative to the smooth texture. It is not clear why the female infants in Study 2 showed a greater magnitude of habituation to the smooth relative to the rough texture. This sex effect did not re-emerge in the cross-study analyses, which indicated that all infants in Study 2 displayed a similar magnitude of habituation to the smooth as to the rough texture. It is possible that the sex difference in Study 2 was not strong enough to emerge in the cross-study analyses. Moreover, the cross-study analyses confirmed that the magnitude of habituation to the rough texture in Study 1 was greater than to the smooth texture in Study 1, and greater than to the rough texture in Study 2. Any interpretations regarding sex differences are also precluded by their infrequency in this data set. Only one other sex difference was found in Study 2; females met the baseline criterion faster than males. The interpretations of the influence of the visibility of the textures on the magnitude of habituation were thus based on the cross-study analyses.

The cross-study analyses indicated a greater magnitude of habituation in Study 1, relative to Study 2, only for the rough texture, implying that vision influenced the response to each texture differently. The similar magnitude of habituation to the smooth texture in Studies 1 and 2, implies that the visibility of the textures did not have any effect. However, the magnitude of habituation depends on the number of trials to habituation, and as discussed earlier, infants habituated to the smooth texture within fewer trials in Study 2, relative to Study 1. In order for infants to display similar magnitudes of habituation while they differed on the number of trials to habituation to the smooth texture in each study, they must have differed on their patterns of haptic manipulation to habituation. According to the mathematical formula for magnitude of habituation, in order for the magnitudes of habituation to be similar across the studies when infants required fewer trials to habituate to the smooth texture in Study 2, there must have been a smaller discrepancy in levels of haptic manipulation between CRIT and baseline trials in Study 2, relative to Study 1. Given that levels of haptic manipulation did not differ on the CRIT trials between the two studies, (as supported by the cross-study analyses on haptic manipulation), the smaller discrepancy must be attributed to lower levels of haptic manipulation during the baseline trials of study 2. This suggests that the visibility of the textures led to lower levels of manipulation of a haptically less salient stimulus, and to habituation within fewer trials. In Study 1, when the smooth texture was not visible, infants appeared to have manipulated more during the baseline trials, relative to Study 2, but continued to manipulate over a greater number of trials, leading to the same magnitude of habituation in each study. The different patterns, between Studies 1 and 2, of haptic exploration and habituation to the smooth texture suggests that vision contributed to more efficient processing of the smooth texture, since it led to less manipulation to baseline and fewer trials to habituation. However, the pattern in Study 1 suggests that in the absence of vision, infants will continue to pursue the acquisition of information through haptic exploration.

The visibility of the textures also led to the observed effect of a greater magnitude of habituation to the rough texture in Study 1 than in Study 2 by influencing infants' pattern of haptic manipulations of the rough texture. Given the similar number of trials to habituation with the rough texture in both studies, the greater magnitude of habituation in Study 1 must be attributed to higher manipulation of the rough texture during the baseline trials of Study 1, relative to the baseline trials of Study 2. Alternatively stated, the visibility of the textures in Study 2 appears to have suppressed haptic manipulation of the rough texture, at least during the baseline trials. This suppression may represent a facilitative effect of visual input with the rough texture, as with the smooth texture, in that infants habituated in Study 2 in a more "cost efficient" manner (i.e., less manipulation).

While vision may have had a facilitative effect with both the smooth and rough textures, the patterns of infants' haptic manipulation support the view that haptics is an organized and functionally adaptive system (Rochat & Senders, 1991) both when operating in isolation from, and in combination with vision. That is, when infants had recourse to only haptic exploration, and were exploring a relatively novel and salient haptic stimulus (i.e., the rough texture), they manipulated more intensely initially, but habituated within a similar number of trials compared to when the stimulus was visible. When the same stimulus was visible, infants manipulated less during baseline trials and habituated within a similar number of trials as when it was not visible. Similarly, when exploring the relatively less haptically salient smooth texture bimodally, infants also manipulated less during baseline trials, and habituated faster than when they explored only haptically. The data also suggest that haptics was responding adaptively to the visual information available. In the present study, the stimuli did not contain any salient visual cues. The lack of salient visual cues may have reduced levels of haptic manipulation during baseline trials in Study 2 relative to Study 1. The lower levels of haptic manipulation on baseline trials, with either the smooth or rough texture, are consistent with Bushnell and Weinberger's (1987) findings of lower levels of manipulation when viewing the smooth cube relative to the furry cube. Haptics appears responsive to, and changes adaptively according to visual information.

The facilitative influence of the visibility of the textures, however, is questioned when the results for the total levels of haptic manipulation over the entire BHAB phase are considered. While bimodal, relative to unimodal, exploration led to lower levels of haptic manipulation of both textures during baseline trials, and to fewer trials to habituation in the case of the smooth texture, the Study 2 analyses of haptic manipulation indicated that infants' total haptic manipulation to habituation (i.e., during the BHAB and CRIT phases) were similar for the smooth and rough textures. The cross-study analyses further suggested that levels of haptic manipulation during the haptic BHAB phase of Study 1 were only slightly higher than those in the bimodal BHAB phase of Study 2 (the difference was only marginally significant). In addition, the slight decrease in haptic manipulation during the BHAB phase in Study 2 may actually have been compensated for by additional haptic manipulation obtained through the bimanual contact during this phase in Study 2. Bimanual contact was significantly higher during the BHAB phase of

Study 2 than in Study 1. Thus, it appears that when the measure of total haptic manipulation during habituation is considered, there does not appear to be any facilitative effect of vision. Fairly similar amounts of haptic experience were necessary in unimodal as in bimodal exploration, and with each texture, before infants could haptically habituate.

Overall, the examination of the habituation phase data suggest that the relations between vision and haptics may be more intricate than simple cooperative or facilitative effects. A similar level of haptic manipulation, contact or familiarity was required for complete processing of each texture despite different patterns (i.e., trials to, and magnitude of habituation) of haptic habituation with each texture. This implies that the effects of vision may be limited to modifying infants' patterns of haptic manipulation during habituation, rather than facilitating the acquisition of haptic information. There may be cooperative relations between haptics and vision that may lead to more adaptive patterns of haptic examination of objects, however, haptics also seems to have simultaneous independent criteria that need to be met even during bimodal exploration of texture stimuli. That is, infants required similar levels of haptic manipulation to habituation under bimodal and unimodal conditions. In turn, this suggests a certain degree of independence for haptics from vision during exploration of objects. The results also highlight the utility of considering multiple indices of habituation and exploring patterns of habituation, rather than basing interpretations regarding the influence of vision on haptic exploration and processing on any one individual index of habituation (Columbo et al., 1987; Columbo, 1993).

The results pertaining to the second objective of Study 2, to assess response to novelty, discrimination, and recognition memory abilities, confirmed the prediction that infants would attend to, and process the haptically available texture information during the bimodal HAB phase. In Study 2 it was predicted that infants would display a response to the novelty in texture and display recognition memory for textures during the NOV and RFAM test phases, respectively, and that these abilities would be reflected on the measure of haptic manipulation. The experimental group infants displayed higher levels of haptic manipulation relative to controls during the NOV phase. This difference is a clear indicator of discrimination between the textures in the habituation and NOV phases. The novelty response suggests that: 1) the visibility of the textures during habituation did not interfere with the haptic processing, or the acquisition of, the relevant stimulus information (i.e., texture) necessary for successful discrimination; and 2) infants must have been attending to the haptic input, as well as perhaps the visual input, during the bimodal HAB phase. These findings are consistent with past research indicating that infants attend to, and process haptic input even when other stimulus properties (e.g., colour, shape) are visible (Bushnell et al., 1985; Casey, 1979; Ruff, 1982a, 1984, 1989).

The cross-study analyses, however, suggest that the visibility of the textures may have lowered, as in the baseline trials, levels of haptic manipulation in response to the novel texture. That is, the experimental group in Study 1 engaged in more haptic manipulation of the novel texture relative to the experimental group in Study 2. It is unlikely that the lower levels of the experimental group in Study 2 were due to a methodological artifact, such as the placement of the opaque cover, or to the unimodal test phase being less engaging or interesting for these infants. If this were true, a corresponding lower response should have been observed among the controls in Study 2, relative to the controls in Study 1. However, the control groups in both studies showed similar levels of haptic manipulation during this phase. Rather, the lower levels of haptic manipulation by the experimental group in Study 2, relative to Study 1, may be more likely attributable to the earlier visual experience of the experimental group in Study 2. While the visibility of the textures in the HAB phase may not have interfered with the processing of the haptic stimulus information required to detect the novelty in texture, it appears to have had some facilitative effect in permitting detection of discrepancies with lower haptic exploration levels in response to novelty. However, the cross-study analyses indicated no difference in the magnitude of the dishabituation response between the two studies; the strength of the response to the texture in the NOV phase was similar whether it followed unimodal or bimodal habituation, despite lower levels of haptic manipulation in Study 2. These findings suggest an impact of vision on levels of haptic manipulation during NOV, but the similar magnitude of the response to novelty in both studies implies again a certain level of independence of haptic responding to novelty from vision. Thus, there is evidence for some facilitative effect of the visibility of the textures, but this effect appears to be operating simultaneously with some independent responding within haptics.

The visibility of the textures during the HAB phase of Study 2 also appeared to have enhanced recognition memory. In Study 2, the experimental and control groups did not differ during the RFAM phase, as they did in Study 1. However, in Study 2, the experimental group's levels of haptic manipulation decreased significantly from the NOV to the RFAM phase to reach the lower levels of the controls during this phase. The control groups displayed similarly low levels of haptic manipulation between the NOV and RFAM phases. Given the support for texture discrimination abilities in the NOV phase, it is likely that the decrease in the experimental group's haptic manipulation in the RFAM phase represents a faster recognition of the original HAB phase texture, rather than a lack of detection of the discrepancy. The faster recognition of the original HAB phase texture, in turn, suggests a facilitative effect of the bimodal HAB input. The novelty response of the control group during the DHAB trials supports this interpretation in ruling out fatigue effects as the source of the decline in the experimental groups' haptic manipulation between the NOV and RFAM phases. Furthermore, when the data from both Studies 1 and 2 were analysed in combination in the cross-study analyses, both discrimination abilities and recognition memory abilities were evident in the NOV and

RFAM phases, respectively. That is, experimental group infants displayed higher levels of haptic manipulation relative to controls in both the NOV and RFAM phases and the studies did not differ in this respect. Thus, cross-study analyses confirm discrimination and recognition memory abilities in both studies, but analyses of Study 2 alone indicate some enhanced discrimination and recognition memory abilities following bimodal habituation.

Facilitated or enhanced haptic discrimination of, and recognition memory for the textures in Study 2 relative to Study 1 may both be the result of a stronger or more complete mental representation or understanding of the stimulus as a result of bimodal exploration (Bushnell & Weinberger, 1987; Hernandez-Reif & Bahrick, 2001; Ruff, 1989). Faster discrimination and recognition in Study 2 were indicated by lower levels of haptic manipulation during the NOV phase among infants in the experimental group in Study 2 relative to Study 1, and similar levels of haptic manipulation between experimental and control groups during RFAM in Study 2, respectively. The visual information about the stimulus in Study 2 did not provide an understanding of its texture properties that was necessary or integral for the haptic discrimination of the textures during the NOV phase; infants were able to make texture discriminations in Study 1, following only haptic habituation. However, the visibility of the stimulus provided a visual representation in addition to the haptic representation formed during unimodal haptic habituation. That is, during bimodal exploration infants saw and felt many additional features of the stimulus (e.g., the colour, shape and size of the stimulus), which may have led to a better understanding of what they were touching than when exploring only haptically. Moreover, some of the additional visual features (e.g., shape and size) were also explored haptically, or at least lent themselves to haptic exploration, enriching perhaps the haptic representation.

The indication that the bimodal exploration in Study 2 facilitated discrimination and recognition memory relative to unimodal exploration in Study 1 is consistent with auditory-visual research indicating that multimodal stimulation has greater perceptual salience than unimodal stimulation in that multimodal stimulation facilitates infants' perception of auditory-visual relationships (Lewkowicz 1988a, 1988b, 1992, 1994, 1996). In the present research, infants who had both visual and haptic representations had more information, or cues in memory, from which to understand the nonvisible test stimuli during the unimodal test phases. In turn, this may have facilitated faster attention to, or detection of, the one existing difference (i.e., texture) between the HAB phase and test phase stimuli. In contrast, visual input was not available during the unimodal HAB phase, and therefore, during the test phases infants may have spent more time attending to, or haptically exploring, features such as shape and size in addition to texture. They therefore displayed higher levels of haptic manipulation during the NOV and RFAM phases relative to infants who had the benefit of bimodal habituation.

This interpretation of the facilitative effects of bimodal, relative to unimodal, habituation to texture, suggests the existence of cooperative relations between haptics and vision, which in turn implies integration of the systems. As Ruff (1989) described, cooperative relations may occur through the detection of amodal properties or detection of modality-specific information. Both processes may have occurred in the present study. That is, during bimodal exploration, visual and haptic exploration may have resulted in the detection of amodal properties or characteristics of objects (e.g., shape and size information), creating a redundancy in the information gathered by the two systems, and leading to a better understanding of the stimuli. As explained above, the redundancies in the haptic and visual mental representations may have in turn facilitated discrimination and recognition memory of texture. These facilitation effects are consistent with Hernandez-Reif and Bahrick's (2001) findings that infants detect amodal information across vision and haptics, and that the experience of amodal information in both modalities during familiarization facilitated the learning of even arbitrary relationships. Similar to the Hernandez-Reif and Bahrick (2001) study, the experience of the textures in both modalities during the HAB phase of Study 2 may have led to the detection of amodal relationships (as discussed above), and possibly also to the detection of arbitrary relations between the visual and haptic input (e.g., the shape and the texture) of the HAB phase stimuli. However, further research specifically manipulating the presence of amodal information would be necessary to assess the detection of arbitrary relations in the present study. The facilitative effects in Study 2 are also consistent with the research indicating that redundant information presented across vision and audition leads to infants' perception of auditory-visual relationships (Lickliter & Bahrick, 2001). Moreover, the facilitative effects suggest that infants attended to both haptic and visual input and therefore can, similar to the auditory-visual perception research, be interpreted as supporting the Gibsonian view that the senses are integrated for the detection of invariants or amodal properties (E. J. Gibson, 1969, 1982; E.J. Gibson & Spelke, 1983; Lickliter & Bahrick, 2001).

In addition, the evidence for texture discrimination and recognition memory in Study 2 suggests that haptics appears to have been simultaneously acquiring modality-specific texture information during bimodal habituation. Texture information was not conveyed by any visible aspect of the stimuli but was rather perceivable through haptic exploration. The simultaneous detection of haptic-specific texture information suggests that haptics is organized during the first half-year of life for the perception of object affordances (E.J. Gibson, 1969, 1982; E.J. Gibson & Spelke, 1983; J.J. Gibson, 1962). In the present study, the stimulus afforded action for the haptic modality. The detection of the modality-specific texture information during bimodal exploration is also consistent with literature demonstrating organized and adaptive haptic (both oral and manual) abilities in very young infants (Rochat & Senders, 1991).

However, it is important to note that the perception and processing of haptic modality-specific information may have been permitted through the use of the haptically based infant-controlled habituation procedure. Fixed trials habituation procedures have precluded detection of texture perception, processing and discrimination abilities in both unimodal haptic and bimodal haptic and visual studies with even older infants (Stack & Tsonis, 1999), and have also led to interpretations of a dominant role for vision, or visual input, during bimodal exploration. The infant-controlled habituation procedure permitted observation of cooperative relations between haptics and vision, suggesting that the systems are integrated for, and perceptual learning of object affordances may be enhanced by, the detection of amodal properties by 3 months of age. The results also suggest that by 3 months of age haptic modality-specific functions may also be operative, and contribute independently to the understanding of unique haptic affordances of objects.

While the bimodal input of Study 2 may have facilitated haptic perceptual abilities (i.e., discrimination and recognition memory), it may have interfered with motor-haptic, or exploratory, procedures. Discrimination and recognition abilities were not reflected in infants' exploratory procedures in Study 2. Levels of exploratory procedures were low in Study 1, but experimental group infants responded with marginally higher levels of exploratory procedures during the NOV phase, relative to controls. A similar pattern of experimental and control group differences was not observed in Study 2, suggesting that perhaps the visibility of the textures dampened infants' tendencies to engage in exploratory procedures in response to the novelties in texture. This may be because the presence of visual information, during bimodal exploration, precluded infants from engaging in specific haptic exploratory procedures, especially since the visible textures did not contain any salient visual cues that could direct specific haptic exploratory procedures. This is consistent with Bushnell and Weinberger's (1987) conclusion that visually salient cues guide haptic exploration, as well as with their findings that the lack of salient visual cues (e.g., as in the smooth box relative to the fur box) may interfere with the detection of visual-haptic discrepancies, and lead to lower durations of various forms of haptic manipulations relative to when salient visual cues are available. Infants in Study 2 also displayed significantly higher levels of exploratory procedures overall in the NOV relative to the CRIT phase. This effect was not qualified by Group, experimental or control, assignment, and occurred in the phase where the visibility of the textures was occluded suggesting that all infants engaged in higher levels of exploratory procedures when the textures were no longer visible. This phase difference also suggests that a general effect of the visibility of stimuli is the suppression of haptic exploratory procedures, and is consistent with past findings that exploratory procedures are more pronounced in the dark or when stimuli are not visible (Bushnell et al., 1992; Stack & Tsonis, 1999).

However, the results for exploratory procedures suggest that the interference effects of vision may be limited to motor-haptic responses, (i.e., exploratory procedures) rather than perceptual-haptic functions. While the lack of salient visual cues may have interfered with the observation of discrimination and recognition memory on infants' exploratory procedures, the lack of salient visual cues did not interfere with the observation of these abilities on the measure of haptic manipulation. This is likely due to the use of the infant-controlled, haptic, habituation procedure which permitted infants to process texture information adequately and with whatever form of haptic manipulation they were capable of. The lack of corresponding discrimination and recognition memory findings on the measures of exploratory procedures and haptic manipulation suggests that while the visual input may have dampened some finer forms of haptic manipulation (i.e., exploratory procedures), it did not affect infants' haptic perception of texture.

In addition, the interference of the visibility of the textures on exploratory procedures may by less pronounced among the older, 6-month-old, infants. As in

Study 1, the older, 6-month-old infants in Study 2, engaged in more exploratory procedures in response to the rough texture. Six-month-olds engaged in nearly twice the level of exploratory procedures when exposed, over all phases, more frequently to the rough texture (i.e. in the order of RSR or RRR, for experimental and control groups, respectively) relative to those exposed to the smooth texture more frequently (i.e., in the order of SRS or SSS, for experimental and control groups, respectively). It is likely that the greater amount of exposure to the rough stimulus in the RSR/RRR order elicited higher levels of scrumbling and stroking. However, 3-month-olds in Study 2 displayed similar levels of exploratory procedures in both orders. The visibility of the textures may have suppressed differences in exploratory procedures among 3-month-olds both as a function of novelty in texture (i.e., group) and salience of haptic cues (i.e., order). These results suggest that by 6 months of age, visual input may not override or interfere with infants' exploratory procedures in response to salient haptic cues, as much as it does at 3 months. This is consistent with literature documenting an increase during the second half-year of life in attention to and in responding according to haptic, rather than visual input, during bimodal exploration (Bushnell et al., 1985; Bushnell et al., 1989, cf., Bushnell & Boudreau, 1991; Ruff, 1989).

In contrast, the visibility of the textures appears to have had the opposite effect on levels of bimanual contact. In Study 2, infants displayed significantly higher levels of bimanual contact during the BHAB phase relative to the other phases. The cross-study analyses indicated that infants also displayed substantially higher levels of bimanual contact during the BHAB phase of Study 2 relative to Study 1. The higher levels of bimanual contact in Study 2 may have contributed additional haptic experience and familiarity with the visible textures, and thus, as proposed earlier resulted in a stronger mental representation and memory trace of the textured stimulus. However, similar to Study 1, the visibility of the textures did not result in the display of discrimination and recognition abilities during the NOV and RFAM phases of Study 2 on the measure of bimanual contact. This was most likely due to the return to unimodal haptic exploration during the test phases.

However, the cross-study analyses also suggested a tendency for infants to respond with higher levels of bimanual exploration in response to detection of novelties in texture. That is, when the studies were combined for analysis, the experimental group infants displayed higher levels of bimanual contact relative to control groups in the NOV phase. The cross-study results assisted in understanding infants' bimanual manipulation; they suggest that the low levels of bimanual manipulation may have precluded detection of a novelty response on this measure when each study was analyzed separately. More importantly, they suggest that haptic novelty may elicit higher levels of bimanual manipulation even during unimodal haptic test phases, and regardless of whether these test phases followed unimodal or bimodal habituation. While the data are consistent with a role for vision in facilitating bimanual exploration (Bushnell et al., 1992; Stack & Tsonis, 1999), they also highlight that haptic novelty, in both studies, may have incited bimanual exploration even among 3-month-olds with yet to be developed visually guided reaching abilities. This interpretation however is a cautious one given that levels of bimanual manipulation were low, and bimanual responding to haptic novelty was not observed in the analysis of each study independently. Further replication is required before conclusions can be drawn regarding perceptual-haptic, in addition to motor-haptic, abilities in the development of bimanual reaching behaviour.

It was hypothesized, as for Study 1, that infants' texture discrimination abilities would also be reflected in their visual attention responses, even though the infant-controlled procedure was based on haptic habituation to the textures. This hypothesis was supported only on the measure of total attention, but not direct attention or fixation. In Study 2, the experimental group displayed higher levels of total attention, relative to the control group, during the NOV phase, but not during the RFAM phase. The experimental group then displayed a significant decrease in total attention in the RFAM phase, relative to the NOV phase. Levels of total attention were similar for controls during these two phases. The novelty response in visual attention is consistent with past research indicating that haptic novelty directs visual attention and elicits longer looking even when there is no visual novelty to be detected (Stack & Tsonis, 1999; Bushnell et al., 1985; Bushnell et al., 1989 cf Bushnell & Boudreau, 1991). Moreover, these findings parallel the results of total haptic manipulation in Study 2, suggesting that infants' facilitated haptic recognition may also be reflected in their visual attention. However, since novelty and recognition effects were reflected only on the more global measure of visual attention, and not on specific measures of direct attention and fixation, haptic processing may elicit only a general visual orienting response (Rubenstein, 1974; Ruff, 1976).

Infants' direct attention (i.e., looking towards the experimenter and fixation towards the stimuli) varied as a function of order, phase, and age. The order effect indicated that infants displayed higher levels of direct attention when experiencing the textures in the order of RSR/RRR, relative to the order of SRS/SSS. These results parallel the findings for exploratory procedures in Study 2, and similarly suggest that the haptic salience of the rough texture also directed infants' visual attention. Since this order effect on direct attention was not observed in Study 1, it is possible that the bimodal exploration during HAB may have helped direct infants' visual attention. It is important to emphasize, however, that it is unlikely that the higher levels of direct attention among infants in the RSR/RRR order (who were habituated to the rough texture) were due to the visual features of the rough texture; neither the smooth and rough textures contained any salient visual cues, or any visual cues that would guide perception of texture. If higher levels of direct attention were due to a greater salience of the visual input of the rough texture, then higher levels of direct attention to the rough, relative to the smooth texture, during the HAB phase (when each of the textures were visible) should have also been observed. This was not the case; the phase effect indicates that infants showed higher levels of direct attention during the BHAB phase, irrespective of order. Thus, the higher levels of direct looking in the RSR/RRR order appear, like the higher levels of exploratory procedures among older infants in this order, to have been elicited by the sensory input available to haptics about each stimulus. This interpretation is substantiated by the findings in Study 1 documenting the salience of the rough texture even in the absence of any visual input.

In contrast to Study 1 and to the results for total attention, the visibility of the textures appeared to have interfered with infants' abilities to fixate more in response to texture novelties during the unimodal test phases. Infants displayed higher levels of fixation during the bimodal BHAB phase of Study 2, relative to the unimodal test phases. However, experimental and control group differences in the NOV and RFAM phases were not observed following bimodal habituation. Hence, fixation responses were not coordinated with discrimination and recognition abilities as reflected in infants' haptic manipulation in Study 2. However, following unimodal haptic manipulation in Study 1, experimental group infants were able to visually fixate towards the novel texture more than control infants during the NOV phase. It appears that, in Study 2, the visual input did not interfere with infants' haptic texture discrimination and recognition, but it may have interfered with coordination of the two sensory systems.

This interference, however, may actually reflect an adaptive relationship between haptics and vision given infants' experience during the HAB phase. In Study 2, the response to the texture novelty with renewed haptic manipulation but not visual fixation suggests that infants may have been attending to both visual and haptic input during HAB, and that each modality contributed to determining infants' behavioural responses during the NOV phase. Haptic manipulation provided texture information during HAB. Visual fixation may have provided a more complete understanding of the stimulus, in terms of its shape, size and colour, but it did not provide an understanding of the texture; there were no cues salient for vision nor any visual cues that afforded information about the stimuli's texture. Thus, in Study 2, the visual input did not contain any salient or informative features, nor any cues that may have fostered or sustained fixation, or even haptic manipulation. As discussed earlier, the lack of salient visual input may have also led to lower levels of haptic manipulation during baseline trials, and lower levels of exploratory procedures. The visibility of the stimulus in Study 2 may have suppressed orientation of the eyes to the texture novelty possibly because fixation towards the stimulus during the HAB phase did not yield any salient information for vision, or for haptics. Hence, during the unimodal NOV phase of Study 2, infants responded only in the modality that afforded information about texture (i.e., haptic manipulation) and showed only a corresponding general attention response (i.e., total attention), rather than fixation, in response to the haptic detection of the novelty in texture. Infants appear to have responded, during the test phases, according to what the object afforded for action in each modality (E.J. Gibson, 1969; E.J. Gibson & Spelke, 1983; J.J. Gibson, 1966). This interpretation supports both a cooperative relationship between the senses, in that each modality contributed to the understanding of an object and its features or properties, as well as an adaptive hierarchical response system in that infants responded to the features detected with exploration in the modality most efficient at perceiving and processing the detected properties (Ruff, 1989).

The third and final objective of Study 2 was to assess whether bimodal exploration would affect 3- and 6-month-olds' haptic behaviour and visual attention differently. The predictions that 6-month-olds would display faster habituation, and higher levels of bimanual manipulation, total attention, and fixation during the bimodal

HAB phase were not supported. The only hypothesis that was supported, and the only developmental difference as a result of bimodal exploration in Study 2, was higher levels of direct attention among 6- relative to 3-month-olds. Levels of direct attention in Study 1 were comparable between 6- and 3-month-olds during the HAB phase. However, the impact or meaning of more directed gaze among 6-month-olds is questionable, since it did not appear to assist older infants in habituating faster, in making haptic texture discriminations, nor did it lead to novelty or recognition responses among 6-month-olds on the measure of direct attention.

Overall, the visibility of the textures appears not to have affected 3- and 6-month-olds' visual attention or haptic behaviour differently. The lack of more fixation among 6- relative to 3-month-olds may be due to the fact that the visible stimulus did not contain any salient visual cues. This suggests that vision does not have very specific visual orienting effects when the visual stimulus does not provide salient visual cues. In addition, both 3- and 6-month-olds displayed more direct attention in response to the haptic salience of the rough texture, suggesting that haptic information can direct the attention of both 3- and 6-month-old infants. Finally, both 3- and 6-month-old infants in the experimental group responded to the novelty in texture with higher levels of total attention, suggesting that haptic novelty can orient, prime, or at least modify, the attention of infants as young as 3-months of age.

The one other, albeit, unexpected age difference observed in Study 2 also questions the contributions of vision during the texture task. As in Study 1, a more specific pattern of exploratory procedures was observed among the 6- relative to the 3-month-olds. That is, 6-month-olds in the orders of RSR and RRR, relative to 6-month-olds in the order of SRS and SSS. Three-month-olds responded similarly in each order of stimulus presentation. However, it is difficult to attribute this effect to the visibility of the textures for two reasons. First, the effect among 6-month-olds was not specific to the

BHAB phase during which the textures were visible. Second, greater specificity in exploratory procedures was also observed among 6-month-olds relative to 3-month-olds in Study 1 (i.e., 6-month-olds engaged in more exploratory procedures when the rough texture served as the novel, whereas 3-month-olds responded with more exploratory procedures either to the smooth or rough novelty).

Rather, the difference between 6- and 3-month-olds in Study 2 may actually reflect an interference of vision on the exploratory procedures of both age groups. Comparisons between Study 1 and Study 2 suggest that the visibility of the textures suppressed the execution of exploratory procedures in response to changes in textures. The 6-month-olds in Study 1 responded with more exploratory procedures to changes in texture, but only when the rough texture was the novel. In Study 2, the 6-month-olds responded with more exploratory procedures not to changes in texture, but only when they were in the order that contained greater exposure to the rough texture (i.e., RSR and RRR). It appears then that the visibility of the textures may have suppressed the expression of exploratory procedures in response to texture discriminations, but nonetheless it did not affect responding to the salience of the rough texture. Similarly, the visibility of the textures appears to have suppressed the higher exploratory procedures observed in response to the changes in texture among 3-month-olds in Study 1. Three-month-olds in Study 2 did not respond differently as a function of Group (i.e., experimental or control) as they did in Study 1. The comparisons of the results for exploratory procedures between the studies are consistent with past findings suggesting that vision dampens exploratory procedures (Bushnell et al., 1992; Stack & Tsonis, 1999). However, the present findings suggest that the dampening effect may be more moderate among older infants.

The very little support for a different impact of vision, during bimodal exploration, on 3- and 6-month-olds highlights the efficiency of the haptic system at 3-

months of age and prior to the development of visual-prehension. It also questions the view of visual dominance following the development of visual-prehension. In the context of the present texture task, the visibility of the textures did not result in more efficient haptic processing among 6-month-olds, relative to younger infants without visual-prehensile coordination. The results of Study 2 are consistent with Study 1 in supporting an independent and unique role for haptics during the processing of texture information, even during bimodal exploration, at both 3- and 6-months of age. They do not support the idea that vision assists haptics during texture perception tasks by influencing infants' haptic manipulations, either before or after the development of visual control of the hands. In fact, 6-month-olds displayed higher levels of direct attention in Study 2, but they did not display more efficient habituation, or higher levels of exploratory procedures relative to 3-month-olds. Moreover, while there was some evidence that the visibility of the textures may have facilitated discrimination and recognition memory for the textures, it exerted a similar effect on both 3- and 6-month-olds.

Taken together, the results from Study 2, and the cross-study comparisons contribute to the understanding of the contributions of haptic processing and perceptual discrimination abilities to the acquisition of information during bimodal exploration. Overall, the findings indicate that: 1) the visibility of the textures may dampen levels of haptic manipulations during baseline trials but does not assist in faster processing of texture information among either 3- or 6-month-old infants; 2) infants at both 3- and 6-months of age attend to, and process haptic texture information even during bimodal exploration; 3) infants attend to both haptic and visual input and bimodal input may lead to a more complete mental representation of an object which in turn may facilitate haptic discriminations of, and recognition memory for texture; 4) bimodal exploration does not affect 3- and 6-month-olds' haptic perception and processing of texture differently, despite differences in visual-prehension abilities, and despite directing the visual gaze of

6-month-olds; 5) bimodal exploration dampens both 3- and 6-month-olds' exploratory procedures in response to haptic novelty; and 6) infants attend to both visual and haptic input and respond adaptively according to salient haptic information or novelties; the lack of visually salient cues suppressed infants' visual fixation in response to novelty, but not their overall visual attention or haptic manipulation. The findings suggest that during bimodal exploration of texture, perceptual learning results from both the unique and independent contributions from haptics, but also from simultaneous cooperative and adaptive relationships with vision.

Chapter 4: General Discussion

The present studies have enriched and extended the existing knowledge on the importance of haptics for infant development. The primacy of touch and haptics has been acknowledged in the writing of many pioneer thinkers in the area of infant cognitive development, such as Piaget (1952, 1954), E.J. Gibson (1969, 1982) and J.J. Gibson (1966). A substantial amount of animal and human research has documented the contributions of haptics to adaptive development in many domains (biological, social, and cognitive growth; Barnard & Brazelton, 1990; Denenberg & Karas, 1959, 1960, 1961; Harlow, 1959; Levine, 1956, 1958, 1960; Montagu, 1978; Rose, 1990a; Scafidi et al., 1986, 1990; Spitz, 1946; Spitz & Wolfe, 1946). Moreover, research has also documented infants' haptic abilities, and has substantiated that haptics is an important contributing source of perceptual learning (Barnard & Brazelton, 1990; Bushnell & Boudreau, 1991, 1993, 1998; Ruff, 1989; Rochat & Senders, 1991; Streri, 1993). However, most of this research has concentrated on infants' oral-haptic abilities shortly after birth, or on infants' haptic abilities during the second half-year of life, following gains in visual prehension and fine-motor abilities. This has left a dearth of research directly focused on haptic perception during the first half-year of life, and the research that is available is often plagued by methodological limitations. In turn, many theoretical issues regarding how this modality develops and functions also remain unresolved.

The present studies, designed with four global objectives in mind, have contributed to addressing some of these theoretical and empirical issues by examining infants' haptic perception and processing abilities during the first half-year of life. The present set of studies was successful in addressing four primary objectives. These were to: 1) to assess infants' haptic processing, discrimination and recognition memory abilities during unimodal haptic exploration; 2) to document whether these haptic abilities are influenced by vision during bimodal exploration; 3) to examine developmental changes between 3 and 6 months of age in haptic abilities during unimodal and bimodal exploration of texture; and 4) to address, and correct for some of, the limitations imposed by methodology in accessing and understanding infants' haptic perception abilities. The findings are reviewed and discussed in the context of each objective and with regards to their implications for theory and research. The applied implications of the present findings are discussed and directions for future research are proposed.

Haptic Perception of Texture

The first objective of documenting that texture information can be processed independently through haptic exploration was accomplished through Study 1. Infants as young as 3-months of age processed, discriminated, and even recognized textures on the basis of haptic manipulation alone. They displayed novelty responses not only in levels of haptic manipulation, but also with more refined haptic exploratory procedures, and visual attention and fixation. In addition, Study 1 indicated that at both 3 and 6 months, haptic habituation patterns vary in response to the nature, or salience, of the texture being explored, and that at 6 months exploratory procedures are more specific to the novelty of the rough texture. Collectively these findings indicate that: 1) haptics can independently serve as a source of perceptual learning about texture information in infants as young as 3-months of age and with limited fine-motor abilities; and 2) that specific haptic stimulation can activate, or instigate, a purposive search for information by guiding further haptic manipulation, exploratory procedures and visual attention.

The findings provide a number of contributions to the study of haptic perception. The findings are the first to document that infants at 3 and 6 months of age can process, discriminate and recognize texture solely on the basis of haptic exploration. The findings fill a large gap in the empirical research available on haptic perception during the first half-year of life which has been, to date, limited largely to the study of shape perception. In addition, the findings of Study 1 represent an empirical challenge to the view that haptic perception before 6 months of age is precluded by: 1) infants' limited fine motor abilities, specifically the exploratory procedures deemed necessary for the perception of texture (Bushnell & Boudreau, 1991, 1993, 1998; Hatwell, 1987, 1993) and 2) immature visual-prehension since vision's guiding role on infants' exploratory procedures is necessary for the perception of texture (Heller, 1982; Ruff, 1989). Instead, the present findings highlight the perceptual abilities of the haptic system even at a developmental stage of immature manual/motor haptic abilities and in the absence of vision. These findings are consistent with the literature documenting very early oral-haptic perceptual abilities (Rochat & Senders, 1991). They also provide empirical support for Bushnell and Boudreau's (1991) proposal that infants may process aesthetically pleasing properties, such as texture, earlier than functional properties. Overall, the findings document a role for haptics in perceptual learning about texture that is independent from vision and fine-motor abilities.

The findings also suggest a role for haptics in promoting intersensory coordination. Study 1 indicated that vision is not necessary for haptic exploration and perception of texture, and that haptically perceived novelties in texture may actually guide visual attention and fixation. These findings are consistent with research documenting, during the second half-year of life, that haptic experience may modify visual preferences, and incite and guide both haptic and visual exploration (Bushnell et al., 1985; Rubenstein, 1974; Ruff, 1976; Ruff, 1984, 1989; Steele & Pederson, 1977). Moreover, the findings suggest that such a guiding role for haptics may be functional during the first half-year of life, even before vision comes to guide reaching behaviour. This parallels the findings of earlier transfer of information from haptics to vision relative to transfer in the opposite direction (Streri, 1987; Streri & Pêcheux, 1986a,b). An earlier developing role for haptics in intersensory coordination and integration are consistent with the view and research findings that earlier developing sensory modalities, in the invariant maturational sequence, serve important functions in intersensory perceptual organization (Lewkowicz, 1988a,b, 1991; Lickliter, 1990, 1993; Lickliter & Virkar, 1989; Turkewitz & Kenny, 1982, 1985). The present findings support a role for haptics, as the earliest developing system, in the organization of haptic and visual exploration.

The findings also provide support for Gibson's (1962) view that the haptic system engages in a purposive search for stimulation even during the first half-year of life. In Study 1, infants appeared to learn about texture information through purposeful, active haptic exploration. Not only were infants engaged in haptic exploration of the textures to the point of habituation, they habituated to each texture differently reflecting an active haptic response to the nature of the external stimulation. Subsequently, detection of texture novelties led to renewed levels of haptic manipulation, and possibly also to higher levels of exploratory procedures. It can therefore be argued that infants' haptic behaviours in Study 1 reflected active, purposeful exploration of external stimulation that permitted an understanding of external reality, rather than passive, reflexive or mechanistic responses as suggested by Piaget (1952, 1954). Moreover, the texture discrimination and recognition memory abilities observed solely on the basis of haptic exploration in Study 1 challenge Piaget's view that an understanding of external reality emerges out of pairings of haptic and visual schemata.

Finally, the results from Study 1 are also consistent with the Gibsonian view that infant action is functionally tied to the environment and its resources or affordances (E.J. Gibson, 1969, 1982; E.J. Gibson & Spelke, 1983; J.J. Gibson, 1966, 1979; Rochat & Reed; 1987). J.J. Gibson (1962) proposed that the purpose of haptic exploratory movements is to isolate and enhance the component of stimulation which specifies the characteristics of the object being touched. The results suggest that haptics may be an early contributor to the understanding of object affordances. For instance, the different habituation patterns observed in response to the rough and smooth textures suggest that infants' haptic manipulation patterns may be functionally tied to the affordances of external texture stimuli. In addition, the higher levels of haptic manipulation and exploratory procedures displayed by experimental infants during the NOV phase also suggests that the novel textures, relative to familiar textures, afforded more haptic manipulation and perhaps even purposive scrumbling and stroking for both 3- and 6-month-olds. Moreover, the higher levels of exploratory procedures in response to the rough, relative to the smooth, texture displayed by 6-month-olds, but not by 3-month-olds is also consistent with the view that the discovery of environmental affordances is tied to the individual's action capabilities and developmental stage (E.J. Gibson, 1982). Given the more developed fine-motor abilities of 6-month-olds, they may have engaged in more scrumbling and stroking of the rough texture because these procedures afforded greater understanding of a texture that is unfamiliar, and uncommon, in the daily life of an infant. This greater specificity may not have been observed among 3-month-olds because of limited fine-motor abilities, and less sensory experience.

While the findings suggest that haptics contributes independently to the processing of, and perceptual learning about texture even during the first half-year of life, they do not resolve the issue of whether development consists of a process of sensory differentiation or integration. The findings of renewed visual attention and fixation in response to haptic novelty suggest integration of vision and haptics, by 3 months of age which is inconsistent with Piaget's (1952, 1954) view that sensory experiences are stored as distinct and separate schema prior to the integration of visual and haptic space. Integration emerges only with the development of visual prehension near the end of the second half-year of life (Bushnell, 1981). Integration at 3 months of age is, however, more consistent with the differentiation view that infants' touching and looking may be inherently coordinated for the perception of a unitary world through the detection of invariants, rather than yielding separate sensory impressions, or modality-specific schemata (E.J. Gibson, 1969, 1982; E.J. Gibson & Spelke, 1983). According to information processing theory, novelty responses and recognition memory abilities on haptic and visual attention measures in Study 1 suggest the formation of mental representations of texture information, and the occurrence of mental comparisons. However, the products of haptic perception and the nature of the mental representations are still unspecified. Moreover, one can only speculate that the renewed visual attention and fixation in response to haptic novelty may reflect a search for invariant relationships by attempting to also see the novelties available and detected in Study 1 only haptically.

Haptic Perception and Haptic-Visual Relations During Bimodal Exploration

Study 2 fulfilled the second general objective of examining the influence of vision on haptic perception and processing of texture. Moreover, comparisons between Studies 1 and 2 permitted a clearer understanding of the relative contributions of haptics during bimodal exploration; that is, whether vision and visual input influences haptic perception of texture and if so, how. Overall, the results indicated that while haptics may serve unique functions in perceptual learning during bimodal exploration, there may simultaneously exist a cooperative relationship between the two senses that permits integration of separate sensory information and ultimately a more adaptive exploration and understanding of external reality.

The independent contributions of haptics to perceptual learning about texture information were observed in Study 2 as in Study 1. First, the Study 2 and the cross-study analyses supported novelty responses and recognition memory on the measures of haptic manipulation and total attention. Novelty and recognition memory in Study 2 imply that: 1) even when the textures were visible during the bimodal habituation phase, infants attended to and processed the haptically available texture information as they did when the textures were not visible in Study 1; and 2) that haptic novelty could still elicit renewed total attention even following a habituation phase during which the stimuli contained no salient visual cues. In Study 2 as in Study 1, infants processed, and acted according to haptic information. Thus the visibility of the textures did not interfere with the perception and processing of the texture information, nor with the ability of the haptic system to guide visual attention in response to haptic novelty. Moreover, the visibility of the textures did not appear to facilitate the speed of haptic information processing; infants accumulated the same amount of haptic manipulation to habituation in Study 2 as in Study 1. Thus, the criteria for haptic perception and processing of texture remain independent from vision. The findings from both Studies 1 and 2 also support the contention that haptics may be tailored for the perception of texture information and also challenge the view that vision is necessary, dominates, or guides haptic perception of texture (Hatwell, 1987, 1993; Heller, 1982). Overall these results indicate that haptics contributes in a manner that is unique and independent from vision both during unimodal and bimodal exploration.

However, there was substantial evidence that, in addition to the unique role haptics serves during bimodal exploration, haptics and vision are simultaneously engaged in cooperative relations. That is, a number of findings suggest that infants attended to, processed, integrated, and responded adaptively according to both the haptic and visual input available. First, facilitated haptic discrimination and recognition of the textures, as reflected in lower levels of haptic manipulation during NOV and RFAM in Study 2 relative to Study 1, can be attributed to the integration of the visual input, available during HAB, with the haptic input. The visible stimuli did not contain any visual features (e.g., fur, bristles, etc...) that facilitated understanding, or processing, of texture, or any other visually salient cues; infants accumulated the same amount of haptic manipulation to habituation in Study 2 as in Study 1. Nonetheless, the visual input appears to have been attended to, integrated, and to have contributed to an enhanced understanding of the stimulus, and in turn facilitated discrimination and recognition.

Facilitated discrimination and recognition memory suggest integration of, and cooperative relations between haptics and vision. Facilitation effects, as a result of visual input that was not informative regarding texture, suggest that perception may indeed consist of the extraction of redundant information, amodal properties or higher order relationships in the flow of stimulation (Bushnell, 1986; E.J. Gibson, 1982; E.J. Gibson & Spelke, 1983; J.J. Gibson, 1966, 1979; Hernandez-Reif & Bahrick, 2001; Lickliter & Bahrick, 2001; Ruff, 1989; Walker-Andrews, 1994), rather than simply of the sum of separate sensory impressions. The bimodal exploration in Study 2 may have permitted extraction of redundant, or amodal, information such as size and shape of the stimulus since it was available in two modalities. In turn, extraction of this information may have resulted in a more complete, unitary understanding of the stimulus, and facilitated discrimination and recognition. An alternative mechanism of cooperative relations, as Ruff proposed, may be the integration of information salient to, and detected and processed by each modality (e.g., texture by haptics and shape by vision). Modality-specific information may then be integrated into a more complete understanding of the stimulus, or a more complete mental representation. A final alternative proposed by Ruff (1989) is that both the integration of haptic and visual modality-specific information and/or detection of amodal properties may have occurred. Thus, during the unimodal test phases, infants with an understanding of visual and haptic parameters of the stimuli, as well as perhaps of amodal properties, may not have had to spend as much time haptically exploring all aspects of the stimulus before detecting novelties in texture and recognizing familiar textures.

Additional findings support the possibility that infants attended to, integrated, and acted according to both the visual and haptic input of the texture that was presented during the HAB phase. First, while infants displayed lower levels of haptic manipulation during the baseline trials of Study 2, relative to Study 1, they displayed the same amount of haptic manipulation during habituation in both studies. Both textures were designed so that regardless which of the two the infants saw during HAB, the visual input or features were not salient to vision (e.g., they did not contain any protrusions or interesting colour patterns, but rather were white, and flat surfaces). They resembled the smooth, visually non-salient, cube in Bushnell and Weinberger's (1987) study which did not activate haptic manipulation of the felt stimulus and precluded the detection of the visual-haptic discrepancy. Similarly, in Study 2, infants' initially lower levels of haptic manipulation may reflect an adaptive response to the lack of features salient to vision. However, the repeated presentations of the stimulus entailed by the haptic habituation procedure may have overridden the influence of the lack of salient visual features. In turn, infants may have resumed haptic exploration since this modality afforded further understanding of the stimulus, especially of the one property salient to haptics (i.e., texture) and not apparent to vision. This interpretation is consistent with the view that infants were attending to, perceiving and processing both visual and haptic features, however, it is also consistent with the view that infants' are oriented towards discovery of affordances or possibilities for action that are offered by objects (E.J. Gibson, 1982, 1983; E.J. Gibson & Spelke, 1983; J.J. Gibson, 1979).

Integration of visual and haptic input of the smooth texture also accounts for the finding of fewer trials to habituation for the smooth, relative to the rough texture in Study 2. The haptic input of the rough texture was more salient than the haptic input of the smooth texture (as observed in various effects in both Studies 1 and 2). However, in Study 2, the integration of the nonsalient visual input of the smooth texture with the less salient haptic input of this texture may have led to habituation within fewer trials with the smooth texture in Study 2, relative to Study 1. In contrast, the more salient haptic input of the rough texture may have led infants to continue to haptically manipulate the rough texture over a similar number of trials in Study 2 as when they could not see it in Study 1, despite the fact that the rough texture also did not provide any salient features for vision. In the case of the rough texture, infants acted on the salience of the haptic input, even in the presence of non-salient visual input. Comparisons of infants' trials to habituation to each texture suggests that the observation, or emergence of, either cooperative mechanisms or independent (unique) haptic functions during bimodal exploration depends on the integration of information from both sources of input.

Finally, the lack of a novelty response on the measures of exploratory procedures and visual fixation suggests that exploration following integration of sensory information is dependent on developmental stage. The discovery of affordances is thought to be limited by infants' capabilities for action, or the physical properties of an actor in addition to those of the environment (Adolf et al, 1990). The findings discussed above suggest that infants integrated both the visual and the haptic input, however, the lack of salient, or guiding visual information did not reduce infants' haptic manipulation during habituation, nor did it interfere with novelty responses on the measures of haptic manipulation and total attention. In contrast, responses to novelty were not observed in Study 2 on the finer measures of exploratory procedures and visual fixation. It can be argued that this also represents an integration of both the visual and haptic input; consistent with Bushnell and Weinberger's (1987) findings that salient visual cues guide haptic exploration, the lack of any salient or guiding visual cues in the present study may have suppressed exploratory procedures and fixation in response to the novel textures. However, novelty responses on the more global measures of haptic manipulation and visual attention suggest that infants' limited fine-motor exploratory abilities and visual-motor coordination also interfered with the display of novelty responses on the measures of exploratory procedures and fixation. Thus, interference effects of vision on exploratory procedures as documented and interpreted in past research (Bushnell et al., 1992; Stack & Tsonis, 1999) may actually represent an integration of a lack of visual information in conjunction with limited exploratory procedures.

The developmental progression in infants' capacities for action as held by differentiation theory is further supported in Study 2. While neither 3- nor 6-month-olds in Study 2 displayed a response to novelty on the measure of exploratory procedures, the 6-month-olds nonetheless displayed higher levels of exploratory procedures, relative to 3-month-olds, when they had more exposure to the rough, and haptically more salient, texture. The 6-month-olds appeared to be more resistant to the effect of the visual input on exploratory procedures, and responded according to the haptic input as indicated by more exploratory procedures overall in response to the rough texture. Six-month-olds were able to display exploratory procedures with the stimulus that afforded further haptic exploration, despite the lack of salient or guiding visual features, perhaps because of their more developed fine-motor abilities.

Overall, the research findings pertaining to the second objective highlight that during bimodal exploration infants attend to and process both haptic and visual information. Moreover, the findings suggest that in a bimodal context where the stimulus property is salient to haptics, and the visual input is relatively noninformative, infants will pursue exploration in the haptic modality since this modality is the one that affords greater understanding of the properties of the stimulus. The findings highlight however, that this will depend on sufficient capacity for haptic and visual exploration and on sufficient exposure to the stimulus as provided by the infant-controlled habituation procedure. The findings are consistent with the views that an understanding of external reality emerges from the integration of haptic and visual input, that haptics and vision are engaged in adaptive and cooperative relations, and that infants' haptic behaviour is purposeful and motivated by an object's affordances for action even during bimodal exploration. However, the findings also indicate that understanding of external reality is also dependent on infants' capabilities for action or exploration. Finally, the findings challenge the view that visual input dominates haptic exploration.

Developmental Changes in Haptic Perception and Haptic-Visual Relations

The third objective was to examine developmental changes between 3- and 6-months of age, given gains in fine-motor abilities and visual prehension, in both unimodal and bimodal haptic perception of texture. There was a lack of age differences, in both Studies 1 and 2, on habituation measures reflecting speed of processing, and in haptic discrimination and recognition memory abilities. The lack of age differences in Studies 1 and 2 on measures of speed of haptic processing (i.e., trials to baseline and to habituation, and levels of haptic manipulation to habituation) suggest that there may not be an increase in speed of haptic processing of texture between 3 and 6 months of age, despite gains in fine-motor abilities. This is consistent with infant-controlled habituation studies on haptic perception of shape which have found no increase in speed of haptic processing between infants 2- to 3-months of age and infants 4- to 5-months of age (Streri, 1987; Streri et al., 1984; Steri & Milhet, 1988; Steri & Pêcheux, 1986a,b). Moreover, the cross-study analyses indicated that speed of haptic processing of texture information does not increase when stimuli are visible, not even among 6-month-olds with the ability for visually guided reaching. Thus, haptic speed of processing may also be independent from vision at least during bimodal contexts in which the visual input is not salient.

Similarly, the lack of age differences on the haptic measures (haptic manipulation and exploratory procedures) of discrimination and recognition abilities also suggests that haptic perceptual functions may be independent of fine-motor development and visual guidance. The lack of age differences in Study 1 on haptic discrimination and recognition of textures suggests that haptic sensitivity or acuity to differences in texture, as well as the speed with which mental comparisons are conducted and/or the quality of mental comparisons, may be similar between 3 and 6 months of age. Moreover, in

Study 2, vision did not enhance discrimination or recognition abilities among 6-month-olds relative to 3-month-olds. This suggests that vision may not enhance haptic perception abilities as widely thought (Hatwell, 1987; Heller, 1982) through a guiding role among infants with more mature visual-motor coordination and visual-prehension abilities. Moreover, the lack of age differences in Study 2 are inconsistent with the view that visual dominance precludes independent haptic perception following the development of visually guided reaching (Hatwell, 1987; Heller, 1982). The above findings imply that haptic perception may contribute independently to perceptual learning about texture, and that haptic perceptual functions may be independent from visual-motor coordination or any guiding role vision may have on haptic manipulations.

The lack of age differences in Study 1 on the measure of exploratory procedures implies an important and early role for haptics in perceptual learning. While it is not clear whether the novelty response exhibited in levels of exploratory procedures was solely due to the detection of the novel texture or to the potentially longer trials of haptic manipulation, it was not qualified by age. The findings suggest that 3-and 6-month-olds behaved similarly with regards to their exploratory procedures, either in response to detection of texture novelty or in response to longer opportunities for haptic manipulation. This in turn, implies that infants as young as 3-months-old may, as Streri (1987) suggested and documented in studies of shape perception, be capable of exploratory procedures that are sufficient for the perception of texture. The implication is that perception of texture may not be precluded during the first half-year of life, as previously thought, by limited motor abilities required for the execution of exploratory procedures deemed necessary for the perception of texture (Bushnell & Boudreau, 1991, 1993, 1998). Furthermore, the lack of an age difference in exploratory procedures during the NOV phase of Study 1 suggests that exploratory procedures required for texture perception may not be dependent on visual-motor coordination or visual guidance

(Heller, 1982). Given that infants had recourse only to haptic exploration in Study 1, the evidence for higher levels of exploratory procedures during the NOV phase among experimental groups of both ages is consistent with the differentiation view that infants from very early in life act, or explore, in the modality that holds promise for the perception of an object's properties. The lack of age differences during the NOV phase in Study 1 is consistent with past research supporting an early, active, role for haptics in perception as held by differentiation theory. The lack of age differences also challenges the Piagetian and the integrationist view that infant haptic activity at very young ages is mechanistic and that external reality is understood only when visual and haptic schemas are integrated. Finally, novelty responses in exploratory procedures among 3-month-olds challenge and extend past research by documenting haptic abilities much earlier than previously presumed or identified.

However, the age differences that were observed in exploratory procedures in both studies suggest developmental trends in the capacity to explore according to what objects afford for action and that action is influenced by prior perceptual learning or experiences. In Study 1, the 6-month-olds displayed a greater specificity in exploratory procedures by scrumbling and stroking more when the rough texture served as the novel. In contrast, 3-month-olds displayed higher levels of exploratory procedures to the novelty of both the rough and the smooth texture. The greater specificity of exploratory procedures among 6-month-olds may be due to their greater experience with smooth textures, and because the rough texture also afforded more exploration due to its more haptically salient features. In contrast, the smooth texture, when novel, may have held as much interest and afforded as much exploration as the rough texture to 3-month-olds with less experience. Thus, perception of object affordances appears not only to depend on capacities for action, but actions may also be dependent on prior experience and learning of object affordances. In Study 2, the visibility of the textures suppressed exploratory procedures in response to texture novelties for both age groups. However, the 6-month-olds still displayed more exploratory procedures overall in response to the rough texture. As explained in the previous section of the discussion, 6-month-olds, given their greater capacity for exploratory procedures were perhaps able to respond according to the more salient haptic input, and not the visual input. Overall, the age differences in both studies suggest that 6-month-olds' exploration may correspond more to the haptic salience of stimuli being explored regardless of whether stimuli are visible or not. This may be due, in part, to their greater capacity for exploratory procedures and a longer history of perceptual learning. Such an interpretation is consistent with E.J. Gibson's (1982) thinking that with experience comes a specialization of modes of exploration in picking up information for which they are specifically adapted. It is also consistent with Ruff's (1989) extension of Gibson's thinking that as infants' actions or activities become more refined and fall under more voluntary control, they may be more likely to use specific activities to obtain specific kinds of information.

Finally, there was evidence that vision may not influence haptic perception of 3- and 6-month-olds differently due to their differences in visual-motor coordination and visually guided reaching. In Study 2, 6-month-olds exceeded 3-month-olds only on levels of direct attention, but not total attention or fixation. This suggests that bimodal input may have had a greater impact on directing attention towards the experimental situation among 6-month-olds. However, this effect did not appear to lead to any enhanced discrimination or recognition abilities among 6-month-olds relative to 3-month-olds, either on any haptic measure (i.e., haptic manipulation, exploratory procedures, or bimanual manipulation) or visual attention measure (i.e., total attention, direct attention, or fixation). It may therefore simply reflect older infants' greater attentional capacities.

<u>Methodological Considerations and Contributions</u>

The original contributions of the present studies were in part possible due to improvements that were implemented in the methodology that has typically been employed in the study of infant haptic perception. Assessing haptic perception presents a unique challenge, particularly in infancy, due to the difficulty in isolating haptic-motor from haptic-perceptual functions and in isolating vision from haptics. However, a number of methodological factors were considered and decisions made in order to maximize access to the haptic modality, to isolate the unique contributions of haptics to the perception of texture both when functioning independently and in conjunction with vision, and to clarify the impact of confounds often present in past studies.

First, the use of an infant-controlled procedure which was based on, and driven by, infants' haptic manipulation is likely to have contributed greatly to the display of haptic discrimination and recognition of textures in the NOV and RFAM phases respectively, since it permitted 3- and 6-month-old infants to habituate at their own pace and to process texture adequately even during bimodal exploration. This procedure also provided a window to infants' haptic processing abilities (i.e., speed of haptic information processing, and patterns of habituation). Moreover, the haptically driven infant-controlled habituation procedure may have also facilitated access to the exploratory procedures and visual attention and fixation responses in infants as young as 3 months. The present studies support the contention by Streri and Pêcheux (Streri, 1987; Streri & Pêcheux 1986a,b), who used an infant controlled habituation procedure in the study of haptic perception of shape, that the haptic modality lends itself as well as other modalities to infant-controlled procedures.

Second, the systematic control over vision and the visual features of the textures facilitated attributions of texture perception to haptics. The visibility of stimuli and their visual features during studies of haptic perception have confounded past interpretations regarding infants' haptic perception abilities. In Study 1, eliminating the visibility of the textures permitted attribution of novelty and recognition memory responses to infants' haptic perception and processing of texture information. In order to subsequently assess the relative contributions of haptics during bimodal exploration in Study 2, the visual features of the stimuli were controlled in order to clarify whether salient visual features guide haptic manipulation and perception (Bushnell & Weinberger, 1987) or whether merely the ability to see stimuli would influence infants' haptic manipulations (Hatwell, 1987; Heller, 1982). These controls permitted clearer interpretations regarding the unique contributions of haptics to perceptual learning during bimodal exploration, and a clearer understanding of how vision affects haptic perception, and of haptic-visual relations in general.

Finally, selecting texture as the property for study may have been the final element necessary to access the haptic modality and its functioning. Studies of haptic texture perception, and of haptic perceptual abilities in general, during the first half-year of life are sparse due to a focus on the motor abilities deemed necessary for haptic perception, and immature visual-motor control. Differentiation theory, however, holds an early role for haptics in perceptual learning and conceptualizes development as a process of differentiation or specialization of sensory systems; with age, sensory systems become better able to pick up the information for which they are specifically adapted (E.J. Gibson, 1982). In addition, the salience of texture to haptics has been documented in the adult literature. Thus, there exists a strong basis from which to argue that, despite haptic-motor limitations, haptic perception of texture may be possible during the first half-year of life. Apart from the use of an optimal stimulus for the study of haptic perception, controls were also implemented to isolate this property (texture) from others. Habituation and test phase texture stimuli were created with all other features (e.g., shape, size, temperature, weight, etc...) held constant; that is, habituation and test phase stimuli differed only on texture. Holding all other stimulus features constant permitted attribution of discrimination and recognition abilities during the unimodal haptic test phases of both studies to haptic perception of texture information. Finally, the use of texture may have also facilitated the expression of exploratory procedures either in response to haptic novelty or in response to the salience of the rough texture. In the present studies, the textures may have afforded scrumbling and stroking. This is consistent with the view that infants explore the affordances of objects (E.J. Gibson, 1969, 1982; E.J. Gibson & Spelke, 1983; J.J. Gibson, 1966). It is also consistent with the adult literature indicating that texture prompts exploratory procedures, which like scrumbling and stroking, consist of lateral motion over texture surfaces (Lederman, 1982; Lederman & Klatzky, 1987).

While additional controls were employed in the design of each study, the methodological controls reviewed above merit consideration in all studies of haptic perception. The present studies highlight the tremendous role of methodology in studying haptics and the weight it carries in conclusions and interpretations. Negative findings in past studies of haptics may not have necessarily been due to infants' motor or perceptual limitations but rather to methodological limitations and constraints placed on infants. The methodology in perception research provides the means for communication with infants who cannot speak; the onus is therefore on researchers to design studies in a manner that will facilitate understanding, or minimize misinterpretations, of infant behaviour.

Limitations and Future Research Directions

While the contributions of the present studies are many, there remain many interesting and unresolved empirical and theoretical issues. First, as Ruff (1989) highlighted, the nature of the objects presented in unimodal research greatly influences the understanding of a sensory system's capabilities, and in bimodal research, the understanding of relationships between the systems. Basing the selection of the texture stimuli on a strong empirical rationale and constructing them to correct for stimulus confounds in past research, permitted clearer results and the attribution of effects to specific variables. Nonetheless, the present findings remain limited to the present stimuli. Replications of the studies with different variations of the present stimuli are warranted in order to substantiate interpretations.

The conclusions that can be drawn from Studies 1 and 2 regarding the acuity and scope of the haptic system are also limited to the present textures. Replication with different stimuli would be necessary to extend the understanding of the acuity and scope of the haptic system. For instance, investigating the acuity of the haptic system may involve a replication of Study 1 but with a more difficult texture discrimination task (e.g., use textures that are rated as more similar on the dimension of roughness). Replication with progressively more difficult texture discrimination tasks would document the acuity of the haptic system. Success on more difficult texture tasks may depend more on capacity for exploratory procedures. Similarly, replication of Study 2 with more difficult texture tasks would be necessary to substantiate the findings with regards to visual-haptic relations. Such replications with different age groups may identify developmental differences in haptic sensitivity. In addition, the understanding of the scope of haptic perception and processing could be extended by replication of Study 1 with stimuli chosen on dimensions, other than roughness, that apply to texture (e.g., slippery, grainy), as well as with stimuli that differ on dimensions other than texture (e.g., shape, hardness, temperature, and weight). Moreover, replication of Study 2 with these different stimuli would indicate whether and how haptic-visual relations vary as a function of the object being explored. Replication of findings would support generalization and the validity of the present conclusions, while inconsistencies would shed further light on the contributions of haptics to perceptual learning.

The present studies are also limited, like much perceptual infancy research, in deciphering the nature of products of haptic perception. Further research in deciphering the nature of the cognitive representations of haptic information, and of integrated haptic and visual input, is merited given the early contributions for haptics in development. One option consists of building a data base of infants' haptic and bimodal perception of various stimuli, whose features are systematically manipulated. The goal would be to categorize stimuli processed either haptically or bimodally according to factors such as speed of processing, age and properties. The long term ultimate objective of such a categorization or classification system would be to clarify the nature of the cognitive representations of haptically processed objects, as well as of those processed bimodally (Bushnell & Weinberger, 1987; Hernandez-Reif & Bahrick, 2001; Rose, 1990b, 1994b; Rose & Ruff, 1987; Ruff, 1989).

A second option stemming directly from the present studies would be to systematically manipulate the visual features of the texture stimuli employed in Study 2, and to assess how these changes influence infants' responding relative to when the visual features are minimized as in Study 2. This would further elucidate the relative contributions of haptics during bimodal exploration, expand the understanding of how infants use each modality in understanding the objects they are exploring, and ultimately shed light on the nature of cognitive representations of various objects. For example, the visual features in Study 2 could be made increasingly more salient in a systematic way and the effects of salient visual information on haptic perception and subsequent unimodal haptic discriminations could be examined. Interesting questions to be addressed would include: 1) whether infants still perceived and processed texture information; 2) whether salient visual features would interfere with the perception and processing of the texture of the stimulus (and in turn impede texture discriminations during the unimodal test phase); 3) what types of changes in infants' responding might be effected as a result of salient visual features relative to when visual features are not salient. Systematically assessing how varying visual features in the same texture task as in Study 2 influence infants' haptic perception, discrimination, and recognition memory may shed light on how visual and haptic input influence infants' cognitive or mental representations of external reality. Finally, pursuing this line of research with different age groups would also establish whether there are developmental trends in the quality of mental representations.

The present findings are also limited to the age groups studied. Replication with additional age groups during the first half-year of life may be valuable in establishing a more comprehensive understanding the contributions of haptics to early development. While the present studies are consistent with research supporting very early, organized oral-haptic perceptual functioning (Rochat & Senders, 1991) and with the differentiation view of innate integration of sensory input, replication with much younger infants would provide more conclusive evidence of very early contributions of haptic perceptual functions. In addition, testing infants between 3- and 6-months of age would directly assess haptic perceptual abilities during the development of visual-prehension. Haptic perceptual functioning may be different during the emergence of this important ability. Finally, testing infants during the second half year of life would permit evaluation of the role for haptics during unimodal and bimodal exploration at a time when visual information processing exceeds haptic information processing (Streri & Pêcheux, 1986a,b), and following substantial gains in visual-prehension and fine-motor exploration. It is possible that these changes during the second half-year of life may lead to complementary or different results and conclusions.

A final, more applied, domain of future research that merits consideration is whether the data obtained in infant-controlled habituation studies of haptic perception such as in the present studies can be predictive of future cognitive status. The information processing procedures in the visual and auditory domains have been fruitful in this respect (Bornstein et al., 1997; Rose & Tamis-LeMonda, 1999). Since haptics lends itself to study in the same fashion, and since information processing procedures are valuable in understanding information processing in the haptic modality, perhaps there is a role for haptics in predictive research. For example, haptic speed of information processing and responses to novelty may, like the visual and auditory indices, be related to later cognitive ability.

Applied Implications

The findings from the present two studies have implications for both the assessment and fostering of cognitive development in infancy. Studies 1 and 2 suggest that haptics may contribute to cognitive growth both by providing unique information and through the integration of haptic and visual information. These conclusions were in part possible through the use of an infant-controlled habituation procedure, and through the adaptation of information processing procedures and measures of information processing typically employed in studies of visual and auditory perception. The visual and auditory information processing measures are thought to tap central processing ability (Zelazo, 1988; Zelazo & Kearsley, 1984, Zelazo et al., 1995). They have been shown to have greater predictive validity, or continuity with performance in childhood, relative to standard infant measures such as the Bayley Scales of Infant Development for both full-term and pre-term infants (Bornstein et al., 1997; McCall, 1994; McCall & Carringer, 1993; Rose & Tamis-LeMonda, 1999). In addition, they have been shown to distinguish between various risk groups from low-risk controls (Rose & Tamis-LeMonda, 1999; Zelazo et al., 1989) and to also distinguish among delayed children with intact versus impaired mental ability (Zelazo, 1988; Zelazo & Kearsley, 1984; Zelazo et al., 1995). The assessment of cognitive functioning in infancy can be complemented through the development of haptic analogues to the visual and auditory information processing tools (Stack & Bennett, 1990; Stack et al., 1992; Zelazo et al., 1995). A haptic branch to the information processing tools of infant assessment, while still a distant possibility, would permit evaluation through an additional important modality. Haptic information processing tools may be particularly valuable with specific high risk populations. For instance, since the somasthetic system is the earliest developing and functional system (Gottlieb, 1971), haptic information processing procedures may be particularly useful in monitoring cognitive functioning among premature infants whose visual and auditory systems are immature at birth, impaired, or vulnerable to sensory impairment. In addition, haptic information processing procedures may present an important means by which to assess cognitive status among infants and toddlers with sensory impairments or disabilities, either visual or aural (Stack & Bennett, 1990; Stack et al., 1992; Zelazo et al., 1995).

The present findings, by indicating that haptics is an important source of perceptual experiences that contribute to learning about texture, imply a role for haptics in fostering development, cognitive and otherwise, and learning among both high- and no-risk samples. The findings suggest that haptic stimulation may foster cognitive development through opportunities for perceptual learning, and through the organization of intersensory coordination, intersensory integration and knowledge. The perceptual learning opportunities and the organizational functions of haptics may account for the beneficial physiological, attachment, and behavioural outcomes of haptic stimulation regimens (e.g., Kangaroo care, body massage, and passive movement of the limbs) administered to high risk preterm neonates (Adamson-Macedo & Atree, 1994; Browne, 2000; Field, 1998; Scafidi et al., 1986, 1990; Kisilevsky et al., 1991; de Roiste & Bushnell, 1996). Moreover, the findings suggest stimulation with properties such as texture that are salient to, and therefore may be processed through, haptics at an early age may be an important addition to these regimens, particularly following discharge since preterm infants remain at risk for developmental delays following discharge. Similarly, haptic stimulation with appropriately salient stimuli may foster development in other risk populations such as the visually and aurally impaired.

Appropriate haptic stimulation of preterm, sensorially impaired, as well as no-risk, term infants may foster both cognitive and social development since infants' exploration and perception of objects takes place in a social context (Lockman & McHale, 1989). Infant play experiences initially consist of dyadic play between caregiver and infant without the inclusion of objects or toys. Shifts to triadic play (e.g., mother-infant-toy), occurring around 5 months of age, have been attributed to infants' increased interest in their nonsocial surroundings (Bakeman, Adamson, Konner, & Barr, 1990; Cohen & Beckwith, 1976; Papousek & Bornstein, 1992; Trevarthen, 1977). Triadic play has been shown to foster language, attention and exploratory competence (Baldwin, 1991, Lawson, Parrinello & Ruff, 1992; Pêcheux, Findji & Ruel, 1992). This age also represents new developments in visually guided reaching towards nonsocial objects. However, for very young immobile infants, parents and other adults are their primary source for exposure to nonsocial objects such as toys (Ruff, 1989). The present findings suggest that haptic stimulation in the form of textured toys, and novelties in texture, may foster learning even among infants with limited manipulation skills.

In addition, the findings suggest that haptic stimulation and novel experiences may promote learning by enhancing independent exploration of the environment. Adult intervention (such as demonstrations, talking and degree of physical proximity) during the social context of play has been found to promote infant independent examining defined as simultaneous visual inspection and manipulation (Parrinello & Ruff, 1988). While moderate levels of intervention were most likely to promote independent examining, intervention had its largest effects on infants who examined relatively little on their own. Gandour (1988) also found that more intense stimulation from the mother facilitated exploratory competence in children with a low activity level. Exposure to toys and exposure to novelty have also been found to stimulate infants' exploration and learning about objects (Collard, 1971; Ruff, 1989). Furthermore, a developmental progression in infants' exploration of toys has been documented (Belsky & Most, 1981; Doehring, Benaroya, Klaimain, Steinbach & Wayland, 1997; Zelazo & Kearsley, 1980). Initially, contact consists of indiscriminate mouthing which later becomes tailored to the specific features, properties and functions, of the toys. During toy or object play, caregivers function as facilitators of exploration (Uzgiris & Raeff, 1995). Haptic exploration is a prominent component over this course of toy exploration. The findings of the present studies suggest that intervention with stimuli salient to haptics during adult-infant play may contribute to the promotion of exploratory abilities.

Summary and Conclusions

Overall, the present studies have extended understanding of infants' haptic abilities and the influence of vision on haptic functioning. Both studies are the first to empirically examine and support haptic texture perception and discrimination abilities among infants as young as 3 months of age. Prior research has suggested that infants' limited fine-motor exploratory abilities and lack of visual-prehension precluded the perception of texture prior to 6 months of age (Bushnell & Boudreau, 1991). Study 1 indicated that texture information is processed by haptics alone, and Study 2 indicated that infants attend to and process texture information even during bimodal exploration. These studies are the first to document that haptic perception and processing of texture information may be as efficient at 3 as at 6 months of age, both during unimodal and bimodal exploration. Furthermore, comparison of the two studies indicated that vision does not facilitate speed of haptic information processing either among 3- or 6-month-olds. However, it did facilitate haptic perception of novelties in texture and recognition of familiar textures both among 3-and 6-month-olds, suggesting that infants attended to the visual, as well as the haptic, input during habituation. Finally, Study 1 indicated that haptic novelty alone can elicit exploratory procedures and direct visual fixation towards the novelty in infants as young as 3 months of age, who have limited fine-motor and eye-hand coordination. In contrast, the visual input in Study 2 appears to have suppressed novelty responses in these more specific exploratory strategies within each modality (i.e., exploratory procedures and fixation). However, in both studies the rough texture elicited more exploratory procedures than the smooth texture among 6-month-olds, indicating that active, purposive and finer exploratory strategies are elicited by salient haptic stimulation when infants have greater capacity for their execution. Nonetheless, the salience of the rough texture was also apparent in the habituation patterns of both 3- and 6-month-olds, in both studies, suggesting that the more global haptic manipulation patterns of even 3-month-olds correspond to haptic features or salience of objects.

The present findings hold a number of implications for theories of perceptual development, and have challenged many predominating notions regarding visual-haptic relationships. The findings suggest that: 1) the perceptual functions of haptics contribute uniquely, and early in development, to the learning about texture both during unimodal and bimodal exploration; 2) haptic perceptual functions may be independent from haptic-motor exploratory abilities and from visual guidance of haptic manipulations and visual-prehension; 3) haptic novelty alone may promote exploratory procedures and direct visual attention; 4) during either unimodal or bimodal exploration, infants' haptic exploration appears to represent an active and purposeful search that is responsive to salient haptic features; 5) during bimodal exploration, haptic input is integrated with visual input to enhance cognitive representations of objects, either by their specification in more than one modality or by the detection of amodal properties or relationships.

The findings challenge the views that haptic activity is simply mechanistic, and that perception of external reality is precluded before the integration of visual and haptic space as reflected in visual prehension. The findings also challenge the more pervasive developmental view of the dominance of vision over haptics, and instead support the view of cooperative relationships that depend on integration of the available visual and haptic input. The findings suggest that haptics is an early, active source of perceptual learning, even before visual-prehension and fine-motor exploratory abilities emerge. Haptics appears to contribute to perceptual learning both during unimodal and bimodal exploration, and haptic and visual information may be integrated early in development for the adaptive exploration and perception of external reality.

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Appendix A

Mean Rank Value, Anova Summary and Post-Hoc Comparison Tables for Ranking of Textures on the Dimension of Roughness

Table A1

Mean Ranks for Textures Across Participants on the Dimension of Roughness

Texture	Square Surface		Cylindrical Surface	
	M	SE	M	SE
1	5.85	0.28	6.10	0.30
2	7.40	0.26	7.00	0.37
3	7.55	0.45	7.95	0.39
4	1.00	0.00	1.15	0.08
5	8.55	0.37	8.30	0.44
6	6.40	0.28	5.95	0.32
7	3.10	0.12	3.10	0.25
8	8.95	0.26	8.95	0.20
9	2.10	0.07	2.15	0.11
10	4.10	0.19	4.35	0.29

Note. Rank range is from 1 to 10, 1 = most rough to 10 = least rough.

Table A2

Analysis of Variance for Mean Rank Values on Dimension of Roughness on Square Surface

Source	df	F
	Between subjects	
Grand mean	1	0.00
S within-group error	19	(0.00)
	Within Subjects	
Texture (T)	9	101.39*
T x S within-group error	171	(1.523)

Note. Values in parentheses represent mean square errors.
S = subjects.

*$p<.001$

Table A3

Tukey HSD Mean Rank Absolute Difference Values on the Dimension of Roughness on Square Surface

Texture	4	9	7	10	1	6	2	3	5	8
M	1.00	2.10	3.10	4.10	5.85	6.40	7.40	7.55	8.55	8.95
	Absolute Rank Difference Values									
4	---	1.10	2.10	3.10	4.85	5.40	6.40	6.55	7.55	7.95*
9		---	1.00	2.00	3.75	4.30	5.30	5.45	6.45	6.85
7			---	1.00	2.75	3.30	4.30	4.45	5.45	5.85
10				---	1.75	2.30	3.30	3.45	4.45	4.85
1					---	0.55	1.55	1.70	2.70	3.10
6						---	1.00	1.15	2.15	2.55
2							---	0.15	1.15	1.55
3								---	1.00	1.40
5									---	0.40
8										---

Note. Tukey HSD $_{(p=.01, df=120, k=10)}$ = 1.46

*Largest significant absolute difference

Appendix B

Consent Form for Study 1

Consent Form

Infants' understanding and exploration of texture

This study is designed to look at how infants explore objects through touch; more specifically, how infants explore tactile stimuli such as textured surfaces and the fine discriminations they can make using tactile information in the absence of visual information.

I understand that my baby will participate in one session lasting about 60 minutes. My baby will be seated on my lap directly facing an experimenter. An opaque plastic non-toxic cover will be placed at approximately upper chest level to prevent my baby from seeing the objects he/she will be touching. The procedure will consist of one period lasting about 5 to 10 minutes, where objects that may differ in texture will be presented to my baby. No manipulation will be obtrusive or harmful to my baby. 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 questions about this study, I may express these to Dr. Dale Stack (848-7565) or Mary Tsonis (848-7547) of the Psychology Department and Centre for Research in Human Development at Concordia University. In addition, the patient representative at the Jewish General Hospital is Lianne Brown (340-8222). Thank you for your cooperation.

I, ________________________________, do hereby give my consent for my baby
(your name)
________________________ to participate in a study conducted by Dr. Dale Stack
(your baby's name)

and Mary Tsonis at Concordia University, and with the cooperation of the Jewish General Hospital. A copy of this consent form has been given to me.

Parent's signature on behalf of infant:______________ Date: ________________

Parent's signature: ____________________________ Date: ________________

Witness: ____________________________________ Date: ________________

Appendix C

Demographic Questionnaire

Demographic Information

Infant no. ____________ Test Date: ___________________

Group: ______________ Study no.: ___________________

Order: ______________

Infant's name: _______________DOB: ___________ EDOB: _____________

Age: __________ Sex:______ Birth weight: ______ Length of Labour: _____

Mother's name: _____________________________ Age: _________________

Occupation: ____

Languages spoken: ____

Recent work history: (full/part-time/home): ____________________________

Father's name: _____________________________ Age: _________________

Occupation: ____

Languages spoken: ____

Recent work history: (full/part-time/home): ____________________________

Phone number: _____________________________

Address: ____

____

Pregnancy Complications and Delivery Status:___________________________

____

Medical History: ____

____

Breast fed: __________ Bottle fed: __________

Siblings:	Age	Sex
	___	___
	___	___

Hours spent with infant each day:

Mother:	all day 3/4	1/2	1/4	<1/4
Father:	all day 3/4	1/2	1/4	<1/4

Interested in participating in future studies at the Centre for Research in Human Development (CRDH)? YES NO

Appendix D

Operational Definitions for Haptic and Visual Attention Measures

Haptic Measures

Haptic Manipulation. This measure was coded live during testing via the computer mouse held by the experimenter. It consisted of all forms of tactile contact with, and manipulation of, the stimulus including patting, stroking, grasping, as well as static tactile contact maintained during movement of the texture by infants (e.g., waving of the texture). When infants manipulated the texture with both hands simultaneously, haptic manipulation was coded as the duration of the simultaneous contact, and not for each hand separately. For example, if an infant touched the stimulus with both hands simultaneously for 10 seconds, then the total duration of haptic manipulation coded was 10 seconds, and not 20 seconds.

Exploratory Procedures. The two exploratory procedures coded consisted of scrumbling and stroking, the sum of which comprised the total duration of exploratory procedures. Scrumbling was coded when infants were alternatively flexing and 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 (Bushnell, Boudreau, Weinberger & Roder, 1992). Stroking was defined as running one or more fingers and/or the hand in a lateral motion over the surface of the stimulus. When infants touched the stimulus with both hands simultaneously, each hand was coded separately for stroking and scrumbling. The durations of the exploratory procedure exhibited by each hand were summed to yield a total. For example, if infants stroked for 5 seconds with one hand, and for 3 seconds simultaneously with the other hand, the total duration of stroking was 8 seconds.

Bimanual Manipulation. The duration of bimanual manipulation consisted of the length of time infants had both hands simultaneously on the stimulus.

Attention Measures

Total Attention. This measure consisted of the sum of attention to the cover, attention to the experimenter, and fixation toward the stimulus.

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

Attention to Cover. This measure was coded when infants were looking at the cover, either opaque or transparent, but not in the direction of the stimulus.

Fixation towards the stimulus. This measure was coded when infants were looking directly at the stimulus that they were touching. Fixation was coded slightly differently for each study since the cover was opaque in Study 1 and transparent during the HAB phase of Study 2. Fixation in Study 1: Since the textures were not visible in Study 1, fixation towards the stimulus was coded when the infants were looking at the cover, but only when in the direction of the stimulus that they were in contact with. That is, fixation was coded when the infants would have been looking directly at the stimulus they were in contact with should the cover have been transparent, or not there at all. When infants lost contact with the stimulus while they were fixating toward it, but continued to look in the same direction, then fixation was coded until the stimulus was again in contact with the infants' hands. Fixation in Study 2: During the habituation phase of Study 2, the textures were visible through the transparent cover. Therefore, fixation was coded when the infants were looking directly toward the stimulus, including the handle held by the experimenter. During the remaining phases, when the opaque cover was reinserted and the textures were blocked from view, fixation was coded as in Study 1 above.

Appendix E

ANOVA, Follow-up Analyses and Means Summary Tables for

Habituation Indices, Study 1

Table E1

Analysis of Variance for Trials to Baseline, Study 1

Source	df	F
	Between subjects	
Sex (S)	1	4.23*
S within-group error	46	(0.0164)

Note. Values in parentheses represent mean square errors. S = subjects.

*p = .05.

Table E2

Analysis of Variance for Trials to Habituation, Study 1

Source	df	F
	Between subjects	
Age (A)	1	0.13
Order (O)	1	13.65***
Sex (S)	1	6.43*
A x O	1	2.31
A x S	1	2.78
O x S	1	1.89
A x O x S	1	7.98**
S within-group error	40	(3.971)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .05$.
**$p = .01$.
***$p = .001$.

Table E3

Simple Two-Way Age x Order Interactions at each level of Sex on Trials to Habituation, Study 1

Source	df	F
	Between subjects	
Age at Male	1	0.85
Order at Male	1	12.85*
Age x Order at Male	1	0.85
Age at Female	1	2.06
Order at Female	1	2.69
Age x Order at Female	1	9.44*
S within-group error	40	(3.971)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.

Table E4

Simple Effects Analyses on Age x Order at each level of Sex on Trials to Habituation, Study 1

Source	df	F
	Between subjects	
Age at SRS/SSS, male	1	1.70
Age at SRS/SSS, female	1	10.16*
Age at RSR/RRR, male	1	0.00
Age at RSR/RRR, female	1	1.34
S within-group error	40	(3.971)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .01$.

Table E5

Analysis of Variance for Magnitude of Habituation, Study 1

Source	df	F
	Between subjects	
Order (O)	1	11.38*
S within-group error	46	(0.283)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.

Table E6

Mean Number of Trials to Baseline as a function of Age, Group, Order and Sex, Study 1

			Age	
Group	Order	Sex	3 Months	6 Months
Experimental	SRS	Male	2.00 (0.00)	5.00 (1.53)
		Female	3.00 (1.00)	2.00 (0.00)
	RSR	Male	3.00 (1.00)	3.00 (1.00)
		Female	2.33 (0.33)	2.00 (0.00)
Control	SSS	Male	4.67 (1.33)	3.67 (1.20)
		Female	3.00 (1.00)	2.00 (0.00)
	RRR	Male	3.00 (1.00)	2.33 (0.33)
		Female	2.33 (0.33)	2.33 (0.33)

Note. Values in parentheses represent standard errors.

Table E7

Mean Number of Trials to Habituation as a Function of Age, Group, Order and Sex, Study 1

			Age	
Group	Order	Sex	3 Months	6 Months
Experimental	SRS	Male	6.67 (0.67)	11.67 (0.67)
		Female	8.00 (0.58)	4.67 (0.33)
	RSR	Male	5.67 (0.88)	6.67 (1.76)
		Female	5.00 (1.00)	6.33 (0.88)
Control	SSS	Male	10.00 (1.00)	8.00 (2.31)
		Female	9.33 (1.76)	5.33 (0.33)
	RRR	Male	6.67 (0.88)	5.67 (0.33)
		Female	4.67 (0.67)	6.00 (1.15)

Note. Values in parentheses represent standard errors.

Table E8

Mean Magnitude of Habituation as a Function of Age, Group, and Order, Study 1

		Age	
Group	Order	3 Months	6 Months
Experimental	SRS	1.37 (0.22)	2.34 (0.80)
	RSR	4.74 (1.49)	3.38 (1.04)
Control	SSS	1.02 (0.77)	2.28 (0.59)
	RRR	2.58 (0.38)	3.34 (0.86)

Note. Values in parentheses represent standard errors.

Appendix F

ANOVA, Follow-up Analyses and Means Summary Tables for

Haptic Measures, Study 1

Table F1

Analysis of Variance for Haptic Manipulation, Study 1

Source	df	F
	Between subjects	
Group (G)	1	17.14*
S within-group error	46	(231.88)
	Within subjects	
Phase (P)	3	174.16*
P x G	3	6.67*
P x S within-group error	138	(165.63)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.

Table F2

Simple Effects for Haptic Manipulation, Study 1

Source	df	F
Group (G) at BHAB	1	0.39
S within-cell error	46	(421.159)
G at CRIT	1	0.77
S within-cell error	46	(18.41)
G at NOV	1	34.76*
S within-cell error	46	(176.70)
G at RFAM	1	8.60**
S within-cell error	46	(112.49)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.
**$p = .01$.

Table F3

Within Subjects Simple Comparisons of NOV and RFAM for each level of Group for Total Haptic Manipulation, Study 1

Source	df	F
NOV vs. RFAM at Experimental	1	11.41*
S within-cell error	138	(165.63)
NOV vs. RFAM at Control	1	0.083
S within-cell error	138	(165.63)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .01$.

Table F4

Analysis of Variance for Novelty Dishabituation Index, Study 1

Source	df	F
	Between subjects	
Group (G)	1	14.60*
S within-group error	46	(0.020)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.

Table F5

Analysis of Variance for Exploratory Procedures, Study 1

Source	df	F
	Between subjects	
Age (A)	1	0.10
Group (G)	1	5.11**
Order (O)	1	0.33
A x G x O	1	6.23**
S within-group error	40	(0.843)
	Within subjects	
Phase (P)	3	19.05***
P x A	3	0.18
P x G	3	2.76*
P x O	3	0.73
P x A x G	3	0.24
P x A x O	3	3.94**
P x G x O	3	1.07
P x A x G x O	3	1.13
P x S within-group error	120	(0.385)

Note. Values in parentheses represent mean square errors. S = subjects.

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

Table F6

Simple Two-Way Age x Group Interactions at each level of Order for Exploratory Procedures, Study 1

Source	df	F
	Between subjects	
Age at SRS/SSS	1	0.07
Group at SRS/SSS	1	7.80*
Age x Group at SRS/SSS	1	1.33
Age at RSR/RRR	1	0.03
Group at RSR/RRR	1	0.18
Age x Group at RSR/RRR	1	5.65*
S within-group error	40	(0.843)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .05$.

Table F7

Simple Effects Analyses on Age x Group at each level of Order for Exploratory Procedures, Study 1

Source	df	F
	Between subjects	
Age at Control, SRS/SSS	1	0.39
Age at Control, RSR/RRR	1	3.27
Age at Experimental, SRS/SSS	1	1.00
Age at Experimental, RSR/RRR	1	2.41
S within-group error	40	(0.843)

Note. Values in parentheses represent mean square errors. S = subjects.

Table F8

Simple Effects Analyses of Order at Group for Exploratory Procedures, Study 1

Source	df	F
	Between subjects	
Order at Experimental	1	2.54
Order at Control	1	0.60
S within-group error	40	(0.843)

Note. Values in parentheses represent mean square errors. S = subjects.

Table F9

Simple Two-Way Group x Order Interactions at each level of Age for Exploratory Procedures, Study 1

Source	df	F
	Between subjects	
Group at Three	1	4.93*
Order at Three	1	0.13
Group x Order at Three	1	0.34
Group at Six	1	0.99
Order at Six	1	0.20
Group x Order at Six	1	8.69**
S within-group error	40	(0.843)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .05$.
**$p = .01$.

Table F10

Simple Effects Analyses on Group x Order at each level of Age for Exploratory Procedures, Study 1

Source	df	F
	Between subjects	
Group at Three, SRS/SSS	1	1.34
Group at Three, RSR/RRR	1	3.93*
Group at Six, SRS/SSS	1	7.78**
Group at Six, RSR/RRR	1	1.90
Order at Three, Control	1	0.45
Order at Three, Experimental	1	0.02
Order at Six, Control	1	3.12
Order at Six, Experimental	1	5.78*
S within-group error	40	(0.843)

Note. Values in parentheses represent mean square errors. S = subjects.

*p = .05.
**p = .01.

Table F11

Simple Effects Analyses of Age at Group for Exploratory Procedures, Study 1

Source	df	F
	Between subjects	
Age at Experimental	1	0.15
Age at Control	1	0.70
S within-group error	40	(0.843)

Note. Values in parentheses represent mean square errors. S = subjects.

Table F12

Simple Effects for Exploratory Procedures, Phase x Group interaction, Study 1

Source	df	F
Group (G) at BHAB	1	0.00
S within-cell error	46	(0.575)
G at CRIT	1	0.58
S within-cell error	46	(0.367)
G at NOV	1	9.03*
S within-cell error	46	(0.596)
G at RFAM	1	3.42
S within-cell error	46	(0.571)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.

Table F13

Within Subjects Simple Comparisons of NOV and RFAM for each level of Group for Exploratory Procedures, Study 1

Source	df	F
NOV vs. RFAM at Experimental	1	7.545*
S within-cell error	120	(0.385)
NOV vs. RFAM at Control	1	1.589
S within-cell error	120	(0.385)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .01$.

Table F14

Simple Two-Way Age x Order Interactions at each level of Phase, for Exploratory Procedures, Study 1

Source	df	F
Age (A) x Order (O) at BHAB	144	2.58
S within-cell error		(0.56)
A x O at CRIT	144	1.78
S within-cell error		(0.36)
A x O at NOV	144	2.90
S within-cell error		(0.69)
A x O at RFAM	144	0.75
S within-cell error		(0.63)

Note. Values in parentheses represent mean square errors. S = subjects.

Table F15

Analysis of Variance for Mean Duration of Bimanual Exploration, Study 1

Source	df	F
	Within Subjects	
Phase (P)	3	4.31*
P x S within-group error	141	(0.29)

Note. Values enclosed in parentheses represent mean square errors. S = subjects.

*$p = .01$

Table F16

Tukey HSD Multiple Comparisons on the Phase Main Effect for Bimanual Exploration

Comparison	Mean Absolute Difference	Critical Difference
BHAB vs. CRIT	0.39	0.35*
BHAB vs. NOV	0.12	0.35
BHAB vs. RFAM	0.38	0.35*
CRIT vs. NOV	0.27	0.35
CRIT vs. RFAM	0.01	0.35
NOV vs. RFAM	0.26	0.35

*$p < .01$

Table F17

Mean Duration of Haptic Manipulation (in sec) as a Function of Age, Group, Order and Phase, Study 1

Age	Group	Order	Phase: BHAB	CRIT	NOV	RFAM
3 Months	Experimental	SRS	60.92	8.48	36.58	18.73
			(5.19)	(1.11)	(3.28)	(3.00)
		RSR	62.91	10.67	41.65	33.13
			(9.69)	(2.34)	(7.88)	(5.12)
	Control	SSS	67.47	5.87	9.33	11.95
			(9.56)	(0.96)	(1.92)	(3.96)
		RRR	57.87	9.28	17.87	16.75
			(7.74)	(2.04)	(3.25)	(2.10)
6 Months	Experimental	SRS	73.14	11.10	43.60	21.25
			(11.20)	(2.27)	(6.86)	(5.93)
		RSR	71.82	8.25	26.67	25.13
			(8.26)	(1.33)	(9.02)	(5.21)
	Control	SSS	64.17	9.50	17.40	15.78
			(11.73)	(2.21)	(3.12)	(4.83)
		RRR	64.47	9.50	13.40	17.85
			(3.12)	(1.22)	(1.31)	(1.92)

Note. Values in parentheses represent standard errors.

Table F18

Mean Index of Novelty Dishabituation as a Function of Age, Group, and Order, Study 1

		Age	
Group	Order	3 Months	6 Months
Experimental	SRS	0.74 (0.03)	0.71 (0.05)
	RSR	0.69 (0.06)	0.61 (0.09)
Control	SSS	0.50 (0.04)	0.57 (0.08)
	RRR	0.56 (0.05)	0.49 (0.02)

Note. Values in parentheses represent standard errors.

Table F19

Mean Duration of Exploratory Procedures (in sec) as a Function of Age, Group, Order and Phase, Study 1

			Phase			
Age	Group	Order	BHAB	CRIT	NOV	RFAM
3 Months	Experimental	SRS	2.86	1.09	1.79	1.64
			(0.84)	(0.69)	(0.65)	(0.55)
		RSR	2.27	0.20	5.01	2.05
			(0.55)	(0.10)	(1.39)	(1.13)
	Control	SSS	3.72	0.35	0.53	0.26
			(0.53)	(0.09)	(0.17)	(0.15)
		RRR	1.09	0.17	1.02	0.68
			(0.42)	(0.12)	(0.45)	(0.26)
6 Months	Experimental	SRS	2.88	1.15	4.50	2.47
			(0.87)	(0.34)	(1.57)	(1.14)
		RSR	2.58	0.45	1.18	0.94
			(1.45)	(0.26)	(0.58)	(0.75)
	Control	SSS	2.01	0.27	0.78	0.84
			(0.92)	(0.23)	(0.35)	(0.45)
		RRR	3.94	1.74	2.04	1.39
			(1.38)	(1.04)	(0.98)	(0.88)

Note. Values in parentheses represent standard errors.

Table F20

Mean Duration of Bimanual Manipulation (in sec) as a Function of Age, Group, Order and Phase, Study 1

Age	Group	Order	Phase: BHAB	CRIT	NOV	RFAM
3 Months	Experimental	SRS	1.27	0.00	0.00	0.00
			(1.27)	(0.00)	(0.00)	(0.00)
		RSR	0.60	0.50	2.55	0.00
			(0.60)	(0.50)	(1.62)	(0.00)
	Control	SSS	1.18	0.00	0.00	0.02
			(0.92)	(0.00)	(0.00)	(0.02)
		RRR	1.44	0.80	0.76	0.18
			(1.44)	(0.80)	(0.76)	(0.18)
6 Months	Experimental	SRS	1.35	0.67	2.78	0.00
			(1.08)	(0.62)	(1.78)	(0.00)
		RSR	0.43	0.34	0.00	0.00
			(0.43)	(0.34)	(0.00)	(0.00)
	Control	SSS	0.00	0.00	0.04	0.00
			(0.00)	(0.00)	(0.04)	(0.00)
		RRR	0.95	0.96	0.00	0.00
			(0.75)	(0.96)	(0.00)	(0.00)

Note. Values in parentheses represent standard errors.

Appendix G

ANOVA, Follow-up Analyses and Means Summary Tables for

Visual Attention Measures, Study 1

Table G1

Analysis of Variance for Total Attention, Study 1

Source	df	F
	Between subjects	
Group (G)	1	13.40**
S within-group error	46	(250.69)
	Within subjects	
Phase (P)	3	161.47**
P x G	3	5.15*
P x S within-group error	138	(117.61)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p = .01$
**$p < .001$

Table G2

Simple Effects for Total Attention, Phase x Group Interaction, Study 1

Source	df	F
Group (G) at BHAB	1	1.42
S within-cell error	46	(329.22)
G at CRIT	1	1.00
S within-cell error	46	(18.68)
G at NOV	1	21.53*
S within-cell error	46	(183.44)
G at RFAM	1	9.40*
S within-cell error	46	(72.17)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.

Table G3

Within Subjects Simple Comparisons of NOV and RFAM for each level of Group for Total Attention, Study 1

Source	df	F
NOV vs. RFAM at Experimental	1	15.87*
S within-cell error	138	(117.61)
NOV vs. RFAM at Control	1	0.349
S within-cell error	138	(117.61)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .01$.

Table G4

Analysis of Variance for Direct Attention. Study 1

Source	df	F
	Within Subjects	
Phase (P)	3	73.65*
P x S within-group error	141	(110.69)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$

Table G5

<u>Tukey HSD Multiple Comparisons on the Phase Main Effect for Direct Attention</u>

Comparison	Mean Absolute Difference	Critical Difference
BHAB vs. CRIT	29.38	6.83*
BHAB vs. NOV	21.64	6.83*
BHAB vs. RFAM	24.82	6.83*
CRIT vs. NOV	7.74	6.83*
CRIT vs. RFAM	4.56	6.83
NOV vs. RFAM	3.18	6.83

*$p < .01$

Table G6

Analysis of Variance for Fixation, Study 1

Source	df	F
	Between subjects	
Group (G)	1	6.20*
S within-group error	46	(1.46)
	Within subjects	
Phase (P)	3	4.14**
P x G	3	3.87*
P x S within-group error	138	(0.464)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .05$
**$p = .01$

Table G7

Simple Effects for Fixation, Phase x Group Interaction, Study 1

Source	df	F
Group (G) at Baseline	146	1.37
S within-cell error		(1.14)
G at CRIT	146	0.00
S within-cell error		(0.56)
G at NOV	146	28.09*
S within-cell error		(0.38)
G at RFAM	146	2.80
S within-cell error		(0.77)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.

Table G8

Within Subjects Simple Comparisons of NOV and RFAM for each level of Group for Fixation, Study 1

Source	df	F
NOV vs. RFAM at Experimental	1138	0.094
S within-cell error		(0.464)
NOV vs. RFAM at Control	1138	2.83
S within-cell error		(0.464)

Note. Values in parentheses represent mean square errors. S = subjects.

Table G9

Mean Duration of Total Attention (in sec) as a Function of Age, Group, Order and Phase, Study 1

			Phase			
Age	Group	Order	BHAB	CRIT	NOV	RFAM
3 Months	Experimental	SRS	53.17	8.53	30.69	18.03
			(8.81)	(1.56)	(3.40)	(3.66)
		RSR	56.80	9.53	37.26	23.61
			(8.64)	(2.10)	(7.18)	(4.43)
	Control	SSS	56.22	4.59	9.22	6.23
			(9.04)	(0.70)	(2.01)	(0.94)
		RRR	47.36	7.27	17.49	13.84
			(5.12)	(2.30)	(4.72)	(1.96)
6 Months	Experimental	SRS	56.70	7.79	32.88	14.30
			(10.67)	(2.73)	(6.38)	(4.32)
		RSR	55.53	5.14	22.46	17.46
			(7.30)	(1.54)	(10.46)	(5.51)
	Control	SSS	43.69	6.70	12.91	9.55
			(6.77)	(1.14)	(2.40)	(2.35)
		RRR	49.99	7.41	11.11	13.70
			(3.64)	(1.33)	(2.27)	(1.17)

Note. Values in parentheses represent standard errors.

Table G10

Mean Duration of Direct Attention (in sec) as a Function of Age, Group, Order and Phase, Study 1

Age	Group	Order	Phase: BHAB	CRIT	NOV	RFAM
3 Months	Experimental	SRS	27.55	5.04	11.49	7.97
			(8.37)	(1.88)	(3.38)	(3.69)
		RSR	23.13	2.18	17.81	12.65
			(4.55)	(1.19)	(5.80)	(3.48)
	Control	SSS	25.63	2.58	6.31	3.10
			(10.23)	(1.04)	(2.28)	(0.93)
		RRR	39.08	4.93	13.69	10.05
			(8.40)	(1.47)	(3.39)	(2.56)
6 Months	Experimental	SRS	44.67	6.35	23.63	10.61
			(10.87)	(2.23)	(5.20)	(4.30)
		RSR	42.59	3.90	11.89	15.85
			(6.28)	(1.11)	(4.76)	(5.38)
	Control	SSS	32.66	4.89	9.17	6.23
			(5.66)	(1.03)	(1.95)	(2.40)
		RRR	35.07	5.48	6.40	7.27
			(7.98)	(1.52)	(1.72)	(2.00)

Note. Values in parentheses represent standard errors.

Table G11

Mean Duration of Fixation (in sec) as a Function of Age, Group, Order and Phase, Study 1

Age	Group	Order	Phase BSLN	CRIT	NOV	RFAM
3 Months	Experimental	SRS	1.70	0.47	0.95	0.90
			(0.63)	(0.40)	(0.83)	(0.59)
		RSR	3.68	0.34	2.95	3.09
			(2.04)	(0.34)	(1.19)	(1.42)
	Control	SSS	0.39	0.14	0.04	0.52
			(0.19)	(0.14)	(0.04)	(0.44)
		RRR	1.09	0.00	0.06	0.08
			(1.02)	(0.00)	(0.06)	(0.08)
6 Months	Experimental	SRS	2.90	1.79	2.35	1.24
			(1.39)	(0.87)	(0.44)	(0.66)
		RSR	1.79	0.23	0.81	1.86
			(0.97)	(0.16)	(0.38)	(1.21)
	Control	SSS	2.26	1.94	0.07	0.95
			(1.69)	(0.99)	(0.07)	(0.91)
		RRR	2.16	1.16	0.04	0.86
			(1.06)	(0.61)	(0.04)	(0.35)

Note. Values in parentheses represent standard errors. BSLN = Baseline.

Appendix H

Consent Form for Study 2

Consent Form

Infants' understanding and exploration of texture

This study is designed to look at how infants explore objects through touch; more specifically, how infants explore tactile stimuli such as textured surfaces and the fine discriminations they can make using tactile information in the absence of visual information.

I understand that this study consists of one session, lasting approximately 10 minutes, during which objects that may differ in texture will be presented to my baby. My baby will be seated on my lap directly facing an experimenter. A transparent plastic non-toxic cover will be placed at approximately upper chest level during the first segment of the procedure. An opaque plastic cover will be placed over the transparent cover during the second segment to prevent my baby from seeing the objects he/she will be touching. No manipulation will be obtrusive or harmful to my baby. 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 outside of the research context 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 questions about this study, I may express these to Dr. Dale Stack (848-7565) or Mary Tsonis (848-7547) of the Psychology Department at Concordia University. In addition, the patient representative at the Jewish General Hospital is Lianne Brown (340-8222). She can be contacted should you have any questions regarding your rights as a research volunteer. Thank you for your cooperation.

I, ______________________________, do hereby give my consent for my baby
(your name)

______________________ to participate in a study conducted by Dr. Dale Stack and
(your baby's name)

Mary Tsonis at Concordia University, and with the cooperation of the Jewish General Hospital. A copy of this consent form has been given to me.

Parent's signature on behalf of infant: _______________ Date: _________________

Parent's signature: ______________________________ Date: _________________

Witness: _______________________________________ Date: _________________

Appendix I

ANOVA, Follow-up Analyses and Means Summary Tables for

Habituation Indices, Study 2

Table 11

Analysis of Variance for Trials to Baseline, Study 2

Source	df	F
	Between subjects	
Sex (S)	1	6.49*
S within-group error	46	(0.014)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .05$.

Table I2

Analysis of Variance for Trials to Habituation, Study 2

Source	df	F
	Between subjects	
Age (A)	1	0.17
Group (G)	1	1.56
Order (O)	1	2.36
Sex (S)	1	2.55
A x G	1	0.40
A x O	1	0.84
A x S	1	0.14
G x O	1	0.48
G x S	1	0.41
O x S	1	1.60
A x G x O	1	0.00
A x G x S	1	0.24
A x O x S	1	0.06
G x O x S	1	0.34
A x G x O x S	1	0.73
S within-group error	32	(0.014)

Note. Values in parentheses represent mean square errors. S = subjects.

Table 13

Analysis of Variance for Magnitude of Habituation, Study 2

Source	df	F
	Between subjects	
Order (O)	1	2.59
Sex (S)	1	3.43
O x S	1	5.58*
S within-group error	44	(1.378)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .05$.

Table I4

Simple Effects Analyses on Magnitude of Habituation, Study 2

Source	df	F
	Between subjects	
Order at male	1	0.28
Order at female	1	7.90*
Sex at SRS/SSS	1	8.88**
Sex at RSR/RRR	1	0.13
S within-group error	44	(1.378)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p \leq .01$.
**$p < .001$.

Table I5

Mean Number of Trials to Baseline as a function of Age, Group, Order and Sex, Study 2

			Age	
Group	Order	Sex	3 Months	6 Months
Experimental	SRS	Male	3.00 (1.00)	3.20 (0.58)
		Female	2.00 (0.00)	2.00 (0.00)
	RSR	Male	3.00 (1.00)	3.67 (1.20)
		Female	3.33 (0.67)	2.33 (0.33)
Control	SSS	Male	3.67 (1.20)	2.00 (0.00)
		Female	3.00 (1.00)	2.00 (0.00)
	RRR	Male	4.00 (0.58)	3.33 (1.33)
		Female	2.00 (0.00)	2.00 (0.00)

Note. Values in parentheses represent standard errors.

Table 16

Mean Number of Trials to Habituation as a Function of Age, Group, and Order, Study 2

		Age	
Group	Order	3 Months	6 Months
Experimental	SRS	5.33 (0.50)	4.67 (0.33)
	RSR	6.17 (0.77)	6.83 (2.09)
Control	SSS	6.33 (1.61)	6.33 (1.33)
	RRR	6.67 (1.22)	7.50 (1.33)

Note. Values in parentheses represent standard errors.

Table I7

Mean Magnitude of Habituation as a function of Age, Group, Order and Sex, Study 2

			Age	
Group	Order	Sex	3 Months	6 Months
Experimental	SRS	Male	1.44 (0.23)	2.08 (0.33)
		Female	3.91 (0.93)	3.87 (1.05)
	RSR	Male	2.46 (0.75)	2.42 (0.97)
		Female	1.49 (0.21)	2.01 (0.78)
Control	SSS	Male	2.28 (0.97)	1.51 (0.12)
		Female	2.05 (0.17)	3.19 (0.88)
	RRR	Male	1.23 (0.30)	2.22 (0.71)
		Female	3.13 (0.56)	1.00 (0.12)

Note. Values in parentheses represent standard errors.

Appendix J

ANOVA, Follow-up Analyses and Means Summary Tables for

Haptic Measures, Study 2

Table J1

Analysis of Variance for Haptic Manipulation, Study 2

Source	df	F
Between subjects		
Group (G)	1	0.28
S within-group error	46	(171.78)
Within subjects		
Phase (P)	3	146.70**
P x G	3	5.38*
P x S within-group error	138	(138.74)

Note. Values in parentheses represent mean square errors. S = subjects.

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

Table J2

Simple Effects for Haptic Manipulation, Study 2

Source	df	F
Group (G) at BHAB	1	2.46
S within-cell error	46	(469.66)
G at CRIT	1	3.40
S within-cell error	1	(12.78)
G at NOV	1	13.79*
S within-cell error	46	(71.99)
G at RFAM	1	2.85
S within-cell error	46	(33.55)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.

Table J3

Within Subjects Simple Comparisons of NOV and RFAM for each level of Group for Haptic Manipulation, Study 2

Source	df	F
NOV vs. RFAM at Experimental	1	6.38*
S within-cell error	138	(138.74)
NOV vs. RFAM at Control	1	0.46
S within-cell error	138	(138.74)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .05$.

Table J4

Analysis of Variance for Novelty Dishabituation Index, Study 2

Source	df	F
	Between subjects	
Group (G)	1	6.30*
S within-group error	46	(0.017)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .05$.

Table J5

Analysis of Variance for Exploratory Procedures, Study 2

Source	df	F
Between subjects		
Age (A)	1	0.23
Order (O)	1	2.35
A x O	1	5.42*
S within-group error	44	(0.659)
Within subjects		
Phase (P)	3	38.19**
P x A	3	0.21
P x O	3	1.14
P x A x O	3	1.29
P x S within-group error	132	(0.432)

Note. Values in parentheses represent mean square errors. S = subjects.

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

Table J6

Simple Effects Analyses on Age x Order Interaction for Exploratory Procedures, Study 2

Source	df	F
	Between subjects	
Age at SRS/SSS	1	3.93*
Age at RSR/RRR	1	1.71
Order at Three Months	1	0.32
Order at Six Months	1	7.45**
S within-group error	44	(0.659)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p = .05$.
**$p \leq .01$.

Table J7

<u>Tukey HSD Multiple Comparisons on the Phase Main Effect for Exploratory Procedures, Study 2</u>

Comparison	Mean Absolute Difference	Critical Difference
BHAB vs. CRIT	1.32	0.28**
BHAB vs. NOV	0.97	0.28**
BHAB vs. RFAM	1.12	0.28**
CRIT vs. NOV	0.35	0.28*
CRIT vs. RFAM	0.2	0.28
NOV vs. RFAM	0.15	0.28

*p < .05
**p < .01

Table J8

Analysis of Variance for Total Duration of Bimanual Exploration, Study 2

Source	df	F
	Within Subjects	
Phase (P)	3	22.82*
P x S within-group error	141	(1.04)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$

Table J9

Tukey HSD Multiple Comparisons on the Phase Main Effect for Bimanual Exploration, Study 2

Comparison	Mean Absolute Difference	Critical Difference
BHAB vs. CRIT	1.332	0.65*
BHAB vs. NOV	1.149	0.65*
BHAB vs. RFAM	1.451	0.65*
CRIT vs. NOV	0.087	0.65
CRIT vs. RFAM	0.119	0.65
NOV vs. RFAM	0.032	0.65

*p < .01

Table J10

Mean Duration of Haptic Manipulation (in sec) as a Function of Age, Group, Order and Phase, Study 2

Age	Group	Order	Phase: BHAB	CRIT	NOV	RFAM
3 Months	Experimental	SRS	44.80	8.33	25.50	11.53
			(5.45)	(0.87)	(4.80)	(1.53)
		RSR	47.07	7.07	18.65	12.30
			(7.52)	(1.18)	(2.56)	(2.04)
	Control	SSS	46.35	5.18	14.40	9.17
			(7.36)	(0.39)	(2.54)	(1.28)
		RRR	58.87	7.62	10.45	14.50
			(12.26)	(1.50)	(2.94)	(2.56)
6 Months	Experimental	SRS	41.30	10.63	25.18	14.60
			(5.86)	(2.51)	(4.12)	(3.37)
		RSR	59.90	9.80	20.55	17.10
			(8.97)	(1.58)	(5.09)	(3.21)
	Control	SSS	62.28	8.05	15.42	9.75
			(11.85)	(1.44)	(2.72)	(1.87)
		RRR	64.85	7.37	13.23	10.83
			(9.72)	(1.30)	(2.39)	(2.09)

Note. Values in parentheses represent standard errors.

Table J11

Mean Index of Novelty Dishabituation as a Function of Age, Group, and Order, Study 2

		Age	
Group	Order	3 Months	6 Months
Experimental	SRS	0.65 (0.06)	0.64 (0.05)
	RSR	0.64 (0.05)	0.57 (0.05)
Control	SSS	0.63 (0.05)	0.52 (0.07)
	RRR	0.44 (0.05)	0.52 (0.03)

Note. Values in parentheses represent standard errors.

Table J12

Mean Duration of Exploratory Procedures (in sec) as a Function of Age, Group, Order and Phase, Study 2

			Phase			
Age	Group	Order	BHAB	CRIT	NOV	RFAM
3 Months	Experimental	SRS	4.03	1.06	2.71	1.62
			(1.05)	(0.43)	(0.77)	(1.26)
		RSR	4.97	0.69	1.32	1.29
			(2.20)	(0.56)	(0.61)	(0.55)
	Control	SSS	5.01	0.72	1.83	0.73
			(0.96)	(0.35)	(0.55)	(0.29)
		RRR	4.69	0.99	0.92	1.94
			(2.66)	(0.49)	(0.70)	(0.71)
6 Months	Experimental	SRS	1.82	1.01	1.18	1.41
			(0.98)	(0.62)	(0.69)	(0.64)
		RSR	7.69	0.67	1.64	1.95
			(4.24)	(0.59)	(0.68)	(1.18)
	Control	SSS	6.41	0.49	0.66	0.23
			(4.35)	(0.41)	(0.32)	(0.23)
		RRR	6.45	1.34	2.46	1.63
			(1.17)	(0.82)	(1.44)	(0.73)

Note. Values in parentheses represent standard errors.

Table J13

Mean Duration of Bimanual Manipulation (in sec) as a Function of Age, Group, Order and Phase, Study 2

			Phase			
Age	Group	Order	BHAB	CRIT	NOV	RFAM
3 Months	Experimental	SRS	8.93	1.58	1.24	0.78
			(5.68)	(1.01)	(0.75)	(0.61)
		RSR	0.20	0.00	0.08	0.46
			(0.20)	(0.00)	(0.05)	(0.46)
	Control	SSS	3.43	0.13	0.00	0.03
			(1.27)	(0.13)	(0.00)	(0.03)
		RRR	7.20	0.02	0.25	0.26
			(4.81)	(0.02)	(0.25)	(0.26)
6 Months	Experimental	SRS	2.48	0.40	0.97	0.40
			(1.89)	(0.30)	(0.63)	(0.30)
		RSR	10.10	0.55	0.00	0.00
			(4.63)	(0.45)	(0.00)	(0.00)
	Control	SSS	12.55	1.26	0.07	0.21
			(6.04)	(0.81)	(0.07)	(0.21)
		RRR	8.04	0.44	0.09	0.00
			(4.03)	(0.44)	(0.09)	(0.00)

Note. Values in parentheses represent standard errors.

Appendix K

ANOVA, Follow-up Analyses and Means Summary Tables for

Visual Attention Measures, Study 2

Table K1

Analysis of Variance for Total Attention, Study 2

Source	df	F
Between subjects		
Group (G)	1	0.06
S within-group error	46	(173.86)
Within subjects		
Phase (P)	3	137.90**
P x G	3	3.57*
P x S within-group error	138	(150.17)

Note. Values in parentheses represent mean square errors. S = subjects.

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

Table K2

Simple Effects for Total Attention, Phase x Group Interaction, Study 2

Source	df	F
Group (G) at BHAB	1	2.32
S within-cell error	46	(494.18)
G at CRIT	1	0.39
S within-cell error	46	(19.98)
G at NOV	1	6.76*
S within-cell error	46	(67.31)
G at RFAM	1	0.24
S within-cell error	46	(42.88)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p \leq .01$.

Table K3

Within Subjects Simple Comparisons of NOV and RFAM for each level of Group for Total Attention, Study 2

Source	df	F
NOV vs. RFAM at Experimental	1	4.07*
S within-cell error	138	(150.17)
NOV vs. RFAM at Control	1	0.29
S within-cell error	138	(150.17)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .05$.

Table K4

Analysis of Variance for Direct Attention, Study 2

Source	df	F
	Between subjects	
Age (A)	1	6.12*
Order (O)	1	6.81**
A x O	1	1.44
S within-group error	44	(187.47)
	Within subjects	
Phase (P)	3	88.06***
P x A	3	1.42
P x O	3	2.43
P x A x O	3	0.33
P x S within-group error	132	(167.84)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .05$.
**$p = .01$.
***$p < .001$.

Table K5

Tukey HSD Multiple Comparisons on the Phase Main Effect for Direct Attention

Comparison	Mean Absolute Difference	Critical Difference
BHAB vs. CRIT	35.07	8.23*
BHAB vs. NOV	33.76	8.23*
BHAB vs. RFAM	36.22	8.23*
CRIT vs. NOV	1.38	8.23
CRIT vs. RFAM	1.09	8.23
NOV vs. RFAM	2.46	8.23

*$p < .01$.

Table K6

Analysis of Variance for Fixation, Study 2

Source	df	F
	Within Subjects	
Phase (P)	3	73.55*
P x S within-group error	141	(0.938)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.

Table K7

Tukey HSD Multiple Comparisons on the Phase Main Effect for Fixation, Study 2

Comparison	Mean Absolute Difference	Critical Difference
BHAB vs. CRIT	1.45	0.63*
BHAB vs. NOV	2.41	0.63*
BHAB vs. RFAM	2.77	0.63*
CRIT vs. NOV	0.97	0.63*
CRIT vs. RFAM	1.32	0.63*
NOV vs. RFAM	0.35	0.63

*$p < .01$.

Table K8

Mean Duration of Total Attention (in sec) as a Function of Age, Group, Order and Phase, Study 2

			Phase			
Age	Group	Order	BHAB	CRIT	NOV	RFAM
3 Months	Experimental	SRS	42.25	7.31	19.41	9.06
			(6.24)	(1.08)	(4.45)	(1.89)
		RSR	47.98	7.09	17.06	9.57
			(7.32)	(1.35)	(3.52)	(1.46)
	Control	SSS	43.51	4.72	12.17	8.34
			(7.21)	(0.72)	(2.95)	(2.72)
		RRR	58.53	7.36	8.64	12.66
			(12.75)	(1.60)	(3.64)	(3.30)
6 Months	Experimental	SRS	39.67	9.35	18.88	9.37
			(4.87)	(2.61)	(3.81)	(3.13)
		RSR	57.39	8.95	13.52	12.33
			(9.79)	(1.58)	(3.21)	(4.37)
	Control	SSS	62.85	8.54	11.98	6.65
			(12.61)	(2.62)	(3.25)	(1.61)
		RRR	61.46	8.85	11.46	8.96
			(9.35)	(2.34)	(2.78)	(2.24)

Note. Values in parentheses represent standard errors.

Table K9

Mean Duration of Direct Attention (in sec) as a Function of Age, Group, Order and Phase, Study 2

			Phase			
Age	Group	Order	BHAB	CRIT	NOV	RFAM
3 Months	Experimental	SRS	27.35	4.73	5.19	1.70
			(7.55)	(1.42)	(2.65)	(0.70)
		RSR	34.26	4.05	10.62	5.93
			(10.62)	(1.26)	(3.37)	(1.99)
	Control	SSS	24.03	2.41	2.25	0.95
			(7.13)	(1.00)	(1.47)	(0.86)
		RRR	55.50	6.67	5.55	6.27
			(13.11)	(1.65)	(1.42)	(2.51)
6 Months	Experimental	SRS	29.10	7.23	10.42	6.57
			(5.64)	(2.24)	(3.37)	(2.55)
		RSR	49.55	7.42	8.41	7.18
			(8.42)	(1.43)	(3.20)	(3.39)
	Control	SSS	56.24	7.02	7.13	2.98
			(13.61)	(2.60)	(3.08)	(1.15)
		RRR	52.49	7.89	8.89	7.17
			(9.34)	(2.17)	(1.73)	(2.20)

Note. Values in parentheses represent standard errors.

Table K10

Mean Duration of Fixation (in sec) as a Function of Age, Group, Order and Phase, Study 2

Age	Group	Order	Phase: BSLN	CRIT	NOV	RFAM
3 Months	Experimental	SRS	10.05	3.62	1.13	0.72
			(3.48)	(1.60)	(0.86)	(0.67)
		RSR	7.16	1.76	2.05	0.04
			(3.59)	(0.72)	(1.01)	(0.04)
	Control	SSS	12.14	2.41	0.00	0.84
			(4.51)	(1.00)	(0.00)	(0.84)
		RRR	12.94	5.27	1.24	0.34
			(5.92)	(2.10)	(1.23)	(0.34)
6 Months	Experimental	SRS	12.63	5.35	2.25	0.70
			(4.42)	(2.20)	(1.35)	(0.50)
		RSR	13.77	3.09	1.01	0.87
			(4.67)	(1.54)	(0.59)	(0.65)
	Control	SSS	19.00	5.62	1.41	0.19
			(4.35)	(2.63)	(0.76)	(0.11)
		RRR	12.69	5.62	0.98	0.00
			(5.31)	(2.56)	(0.88)	(0.00)

Note. Values in parentheses represent standard errors. BSLN = Baseline.

Appendix L

ANOVA and Follow-up Summary Tables for Cross-Study Analyses

Table L1

Analysis of Variance for Trials to Habituation, Cross-Study

Source	df	F
	Between subjects	
Study (S)	1	2.05
Order (O)	1	1.16
S x O	1	12.21*
S within-group error	92	(5.19)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.

Table L2

Simple Effects Analyses on Trials to Habituation, Cross-Study

Source	df	F
	Between subjects	
Study at SRS/SSS	1	12.14*
Study at RSR/RRR	1	2.12
Order at Study 1	1	10.44*
Order at Study 2	1	2.93
S within-group error	92	(5.19)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.

Table L3

Analysis of Variance for Magnitude of Habituation, Cross-Study

Source	df	F
	Between subjects	
Study (S)	1	1.10
Order (O)	1	3.37
Sex (Sx)	1	7.09*
S x O	1	12.85**
S x Sx	1	0.42
O x Sx	1	1.11
S x O x Sx	1	2.29
S within-group error	88	(2.34)

Note. Values in parentheses represent mean square errors. S = subjects.

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

Table L4

Simple Effects Analyses on Magnitude of Habituation, Cross-Study

Source	df	F
	Between subjects	
Study at SRS/SSS	1	2.99
Study at RSR/RRR	1	9.99*
Order at Study 1	1	13.66*
Order at Study 2	1	1.42
S within-group error	92	(2.511)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.

Table L5

Analysis of Variance for Haptic Manipulation, Cross-Study

Source	df	F
	Between subjects	
Study (S)	1	24.54***
Group (G)	1	12.13***
S x G	1	7.80**
S within-group error	92	(201.83)
	Within subjects	
Phase (P)	3	319.98***
P x S	3	3.30*
P x G	3	10.30***
P x S x G	3	1.87
P x S within-group error	276	(152.18)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p = .05$
**$p = .01$
***$p < .001$.

Table L6

Simple Effects for Haptic Manipulation, Cross-Study

	Source	df	F
BHAB	Study (S)	1	7.98*
	Group (G)	1	0.50
	S x G	1	2.46
	S within-cell error	92	(445.41)
CRIT	S	1	1.78
	G	1	3.44
	S x G	1	0.26
	S within-cell error	92	(15.60)
NOV	S	1	12.01**
	G	1	48.55**
	S x G	1	8.83**
	S within-cell error	92	(124.35)
RFAM	S	1	18.98**
	G	1	11.44**
	S x G	1	3.12
	S within-cell error	92	(73.02)

Note. Values in parentheses represent mean square errors. S = subjects.
*p = .01
**p < .001

Table L7

Mean Duration of Haptic Manipulation as a function of Study and Phase, Cross Study

	Phase			
Study	BHAB	CRIT	NOV	RET
Study 1 (Haptics)	65.34 (4.19)	9.08 (0.88)	25.81 (2.48)	20.07 (2.12)
Study 2 (Haptics & Vision)	53.18 (4.36)	8.00 (0.72)	17.92 (1.69)	12.47 (1.17)

Note. Values in parentheses represent standard errors.

Table L8

Simple Pairwise Comparisons on Study x Group interaction at NOV, Haptic Manipulation, Cross-Study

Source	df	F
	Between subjects	
Study 1 vs. Study 2 at Control	1	0.12
Study 1 vs. Study 2 at Experimental	1	20.72**
S within-group error	92	(124.35)

Note. Values in parentheses represent mean square errors. S = subjects.

*p < .001

Table L9

Analysis of Variance for Novelty Dishabituation Index, Cross-Study

Source	df	F
	Between subjects	
Group (G)	1	20.17*
S within-group error	94	(0.02)

Note. Values in parentheses represent mean square errors. S = subjects.

*$p < .001$.

Table L10

Analysis of Variance for Bimanual Manipulation, Cross-Study

Source	df	F
	Between subjects	
Study (S)	1	9.24**
Group (G)	1	0.01
S x G	1	0.44
S within-group error	92	(1.42)
	Within subjects	
Phase (P)	3	25.80**
P x S	3	13.12**
P x G	3	3.25*
P x S x G	3	1.98
P x S within-group error	276	(0.64)

Note. Values in parentheses represent mean square errors. S = subjects.

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

Table L11

Simple Effects for Bimanual Manipulation, Cross-Study

	Source	df	F
BHAB	Study (S)	1	16.04**
	Group (G)	1	1.61
	S x G	1	1.73
	S within-cell error	92	(2.32)
CRIT	S	1	0.70
	G	1	0.25
	S x G	1	0.03
	S within-cell error	92	(0.42)
NOV	S	1	0.14
	G	1	4.85*
	S x G	1	0.13
	S within-cell error	92	(0.48)
RFAM	S	1	5.97*
	G	1	0.68
	S x G	1	2.60
	S within-cell error	92	(0.13)

Note. Values in parentheses represent mean square errors. S = subjects.
*$p < .05$
**$p < .001$

Table L12

Mean Duration of Bimanual Manipulation as a function of Phase and Group, Cross Study

	Phase			
Group	BHAB	CRIT	NOV	RFAM
Experimental	3.17 (1.05)	0.51 (0.18)	0.95 (0.34)	0.20 (0.10)
Control	4.35 (1.20)	0.45 (0.19)	0.15 (0.10)	0.09 (0.05)

Note. Values in parentheses represent standard errors.